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IMF Working Paper

Autonomous Factor Forecast Quality: The Case of the Eurosystem

By Romain Veyrune and Shaoyu Guo

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Monetary and Capital Market Department

Autonomous Factor Forecast Quality: The Case of the Eurosystem

Prepared by Romain Veyrune and Shaoyu Guo¹

Authorized for distribution by Jihad Alwazir

December 2019

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Abstract

The publication of liquidity forecasts can be understood as part of central banks' push toward greater transparency regarding monetary policy implementation. However, the advantages of transparency can only be realized if the information provided is accurate and reliable. This paper (1) provides an overview of the international practice of publishing the forecasts; (2) proposes and implements a framework to evaluate the accuracy and reliability of forecasts using the long history of Eurosystem forecasts as a case study; and (3) analyzes the Eurosystem forecast errors to determine the factors influencing forecast quality. A supporting factor for a high-quality forecast is the contemporaneousness of the information used, whereas money market segmentation can weigh on forecast quality.

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GLOSSARY

AFF	Autonomous Factor Forecasts
AFR	Realized Autonomous Factors
CBPP	Covered Bond Purchase Program
ECB	European Central Bank
EU	European Union
MRO	Main Refinancing Operation
NCBs	National Central Banks
NADIE	Net Assets Denominated in Euro
OAF	Other Autonomous Factors
OMO	Open Market Operations
RMSE	Root Mean Square Error
SMP	Securities Markets Program

I. INTRODUCTION

Central banks have become more independent and transparent in the past three decades (Dincer and Eichengreen 2014). In part, this push toward transparency is for the sake of greater accountability. There is also a growing perception that transparency reinforces smooth policy implementation by fostering a better understanding of the objectives and actions of central banks and by building a reputation for credibility (Ötoker-Robe and others 2007; Laurens and others 2015).

This trend toward monetary policy transparency is evident, particularly in economies implementing inflation targeting and which publish macroeconomic forecasts. However, transparency has not increased in the implementation of monetary policy (Bindseil 2016). In particular, only a limited number of central banks publish autonomous factor forecasts (AFF), as well as readily accessible data on realized autonomous factors (AFR).¹

This lack of transparency is surprising considering the potential benefits of publishing AFF. Current and future autonomous factors are pivotal data for money market participants to anticipate current and future liquidity conditions. At the same time, market participants' beliefs about liquidity conditions guide their decision to participate in central bank monetary policy operations (Carpenter and Demiralp 2006; Vogel 2016). Consequently, information about AFF feeds into the calibration and outcome of open market operations (OMOs), and, thus, facilitates the interaction between market participants and central banks.

Central banks have access to information about the dynamics of autonomous factors that is not available to market participants. Furthermore, information that is available in the market might not be equally distributed among market participants. With the publication of realized and forecasted autonomous factors, central banks can create a level playing field, disclosing information on the expected liquidity developments for the market as a whole. With information from central banks, counterparties can make better informed decisions when bidding at central bank refinancing operations, contributes to stabilize of short-term rates close to the targeted policy rate.

Given these potential advantages, there are no reservations *per se* to publishing AFF. Central banks have nothing to gain from keeping private the information in their balance sheets that comprise the autonomous factors. Reluctance in publishing AFF in many central banks arises from concerns over the quality of their forecasts and the impact on their credibility when producing forecasts that present noticeable errors.

First, to gain an understanding of current motivations to publish (or not to publish) AFF, we analyze the approaches of 36 economies. Second, we propose a framework for the evaluation of AFF and develop a forecast quality control paradigm that aims to mitigate possible reservations related to forecast quality. We use the Eurosystem as a case study to implement

¹ The term “autonomous factors” refers to central bank balance sheet items that influence banks’ reserves at the central bank, but that are not under the control of the central bank.

this framework. Third, analyzing the variations in forecast errors of the Eurosystem publications over time, we identify factors that influence forecasts quality.

In our international comparisons, about half of the central banks publish AFF on a regular basis. Only a fraction publishes detailed information on autonomous factors compared to those providing significant transparency in other areas of monetary policy design. The frequency, forecast horizon, and level of detail vary significantly across central banks. One factor that seems to motivate their publication is a monetary policy framework with an interest rate target. More specifically, many economies that publish a forecast maintain an interest rate corridor system under neutral liquidity allotment (i.e., where the central bank calibrates its OMOs to provide the amount of reserve that banks require).

However, the added value of the autonomous factor publication depends on the quality of the forecast. Good practice predicates that central bank liquidity managers analyze forecast errors as frequently as every maintenance period. This evaluation could be seen as part of the accountability obligation that comes with transparency. The practitioner's evaluation is currently focused on accuracy, that is, the size of the forecast errors. We put forward an evaluation exercise that draws on two dimensions of forecast quality: accuracy and reliability. Not meeting quality standards for these two criteria significantly decreases benefits for market participants.

1. **Accuracy:** false forecasts can lead to unwarranted actions by market participants who rely on this information, especially if they consist of one-sided errors (i.e., the forecasts are biased).
2. **Reliability:** even unbiased forecasts could inflict a liquidity premium in money markets if the likelihood of large forecast errors is high (i.e. the forecasts are not reliable).

We operationalize these two dimensions by introducing three sets of tests. First, we test forecast accuracy using the root mean square error (RMSE), which is currently often used by liquidity managers for forecast evaluations. Second, we supplement the forecast accuracy check adding a test for conditional and unconditional forecasting bias. Third, we test reliability by looking at the volatility of forecast errors over time.

We employ these three sets of tests using the Eurosystem as a case study. The Eurosystem has published granular data on AFF and AFR since 2000. The Eurosystem provides a time series long enough to include shifts in liquidity conditions (neutral liquidity versus excess liquidity), operational frameworks (from fixed-allotment variable rates to fixed-rate full allotments), and general money market conditions.

By analyzing data set variations over time, this case study also contributes to understanding the building blocks necessary for a high quality of AFF. The structural changes over the observation period allow us to draw some inferences from the correlates of forecast errors. We find that a using the most contemporaneous information supports high-quality forecasts, whereas money market segmentation reduces forecast quality.

The paper is structured as follows. Section II describes the policy of autonomous factors publication in the Eurosystem and other central banks. It explains the rationale for publishing

autonomous factors, presents international best practices, and describes the history of autonomous factor publication in the Eurosystem. Section III evaluates the autonomous factor publication of the Eurosystem as to accuracy and reliability. It includes an analysis of the forecast errors and identifies supporting factors for and impediments to achieving high forecast quality. Finally, Section IV concludes.

II. PUBLICATION OF AUTONOMOUS FACTOR FORECASTS

A. Rationales for Central Banks to Publish Autonomous Factor Forecasts

Banks' demand for reserves is motivated by three factors: (1) the reserve requirement; (2) autonomous factors (which changes have an exogenous impact on banks' reserves); and (3) a possible demand for excess reserves. Central banks need to forecast these three factors to calibrate their OMOs until the end of the maintenance period and keep excess reserves low at the end of the maintenance period (Kraenzlin and Schlegel 2012). In so doing, central banks can anchor short-term rates close to the policy rate and prevent them from drifting lower if reserves are in excess of the assessed needs, or higher if the supplied reserves are insufficient to meet market liquidity needs (Hilton and Hrung 2010).

Looking at the details of banks' refinancing needs, some items are highly predictable. The reserve requirement is set by the central bank. The target is set before the beginning of the maintenance period. Thus, there is no uncertainty over the reserves to be maintained on average by the end of the maintenance period.

The demand for excess reserves is expected to be small, stable, and, thus, predictable in well-functioning money markets. In tranquil times, banks are unlikely to keep excess reserves remunerated at a rate lower than their funding cost—so long as they are confident of their access to the market. However, the demand for excess reserves could become large, volatile, and, thus, impossible to predict if risk perception increases and the money market functioning deteriorates, causing liquidity to dry up, market segmentation to emerge, rates and volume volatility to increase, and uneven market access across counterparties to develop.

The forecast exercise concentrates on autonomous factors that show some level of volatility over maintenance periods and that the central bank can forecast with some level of accuracy. To illustrate, Box 1 describes the challenges of forecasting autonomous factors in the Eurosystem. Besides currency in circulation, holdings at central banks by non-financial institutional clients (e.g., governments) are a main driver of autonomous factors in the Eurosystem.

Box 1. Autonomous Factors and the Eurosystem Information Advantage

In the Eurosystem balance sheet, six items qualify as autonomous factors: (1) government deposits; (2) net foreign assets; (3) items in course of settlement; (4) net assets denominated in euro (NADIE); (5) banknotes in circulation; and (6) other autonomous factors (OAF), which is a sundry item that used to be a small residual but has grown over the years. The largest and therefore most important items are grouped in the categories of *banknotes in circulation*, *government deposits*, and *NADIE and OAF*.

Net Foreign Assets do not play a role in the euro area because the free-floating exchange rate arrangement reduces the need for official intervention in the foreign exchange market, and, thus, stabilizes the stock of these assets in the Eurosystem balance sheet.

Banknotes in Circulation fluctuate with the public demand for means of payment. In the long term, this demand is driven by macroeconomic variables, for example, GDP growth and financial innovation in payment systems. In the short term, banknotes fluctuate with the seasons, including a higher use of banknotes during holiday periods and often at year's end (Cabrero and others 2002). Monthly and weekly banknote patterns could be identified, based on time series analysis. In addition, central banks could liaise with the major sources of cash demanders (usually commercial banks and other cash handling firms) to get a feel for the demand for banknotes in the near future. Thus, this balance sheet item can be predicted with limited forecasting errors in normal times with the help of statistical models that replicate their long-term trends and seasonal tendencies.

Government Deposits represent the balance of euro area government accounts with their respective national central banks (NCBs). This balance is influenced by tax collection, government payments (such as pensions or civil servant salaries), government debt management (that is, debt issuance and redemption), as well as sovereign treasury cash management. Active cash flow management allows government deposits at the central bank to be reinvested in the market and helps stabilize government deposits. Critically, however, this depends on the cash management arrangements in place.¹ Traditionally, government deposits are the main source of errors in the AFF. Therefore, the size of the errors depends on how actively the treasury manages its cash flows. On the central bank side, monthly and seasonal patterns, especially for tax collections, can be derived from historical data. Moreover, central banks have usually developed information-sharing mechanisms with national treasuries. This helps inform central banks about provisional cash flows of treasuries, and thereby the impact of government transactions on liquidity. Counterparties usually do not have access to the same depth and breadth of information.

NADIE and OAF play an important role in Eurosystem because of reserve management services² provided by several NCBs and by some clients that are neither Eurosystem banks or governments. They include foreign institutions, such as non-Eurosystem central banks, as well as supra-national, European, and international institutions. In some cases, NCBs act as a financial agent for institutional clients, such as foreign central banks, and manage their accounts. As such, they could reinvest in the market the balance on these accounts, and thus neutralize the liquidity impact of customer transactions. In other cases, special customers manage their accounts themselves more or less actively. Agreements to provide information about changes above a certain size help NCBs anticipate large changes in these balance sheet items.

Forecasting government deposits, NADIE, and OAF has become more difficult since 2012 due to market circumstances. National Treasuries, NCBs, and NCB clients have found it more difficult to invest their excess balance with creditworthy counterparties since the global financial crisis and in an environment of low interest rates and high excess reserves, in which the demand for refinancing is scarce.

¹ A description of the institutional setup for treasury cash flow management can be found on the ECB website: <http://www.ecb.europa.eu/mopo/liq/html/treas.en.html>

² See <https://www.ecb.europa.eu/ecb/legal/107663/eurosystemreserves/html/index.en.html>.

Note: For an overview of the Eurosystem monetary policy operations, see Alvarez and others (2017).

From the market point of view, the publication of AFF is important (Bindseil 2001). Banks wish to maintain reserves at the central bank to make daily payments and to fulfill the reserve requirement obligations at the end of the maintenance period. Therefore, bank treasurers will assess their refinancing needs over the maturity of the central bank OMOs based on reserve targets. The assessment will determine their participation in the central bank's operations. However, they do not know the positions of all other banks, and thus cannot assess market conditions over the maturity of the upcoming refinancing operation.

Central banks usually have good information on the expected changes in their balance sheet items that correspond to autonomous factors. If a bank's treasurer happens to be short, but knows (via the autonomous factors publication) that the rest of the market is long, he or she will likely try to find market funding to meet liquidity needs instead of turning to the central bank's refinancing operations. The opposite is true if the forecast reveals tighter liquidity conditions in the market due to a change in the autonomous factors; the treasurer is likely to secure refinancing at the central bank operation rather than tapping the market and taking the risk of paying more than the central bank refinancing rate.

In an environment of fixed rate and full allotment, it becomes even more important that banks make informed decisions on whether to satisfy their refinancing needs either at the central bank or in the market. We assume that there are two types of counterparties: (1) banks with significant excess reserves and no refinancing needs (*L1*); and (2) banks with refinancing needs (*L2*). Under this allotment method, banks in group *L2* could obtain unlimited refinancing for seven days at the central bank (as long as collateral is available) for a predetermined rate R_c , or borrow in the overnight market for seven consecutive days at rate R , which is not determined ex ante. The challenge for banks in *L2* is to minimize their overall cost of refinancing by getting the right mix of central bank and market funding.

If counterparties in *L2* were certain about the supply of reserves over the main refinancing operation (MRO)¹ week (S), they could request at the central bank refinancing operation the exact difference between their refinancing needs ($BL2$) and the autonomous factor-dictated supply of reserves (S). Consequently, counterparties in *L2* can collectively bid at the refinancing operation, which will produce in sum enough excess reserves in cash-rich banks in *L1* to drive short-term rates in the market to the deposit facility rate. The AFF are supposed to provide the information on the expected supply of reserves (S). However, if banks in *L2* fail to collectively bid for a sufficient amount based on the information available, short-term rates could become volatile ("coordination failure").

Market segmentation complicates bidding coordination of *L2* banks at the MRO. Market segmentation is the result of restrictive credit line (*CCL*), due to the lack of confidence between counterparties, in particular, between banks with refinancing needs of the group *L2* and cash-rich banks of the group *L1*. Therefore, only part of the autonomous reserve supply S will be available in the market, depending on the credit policy of cash-rich banks.

¹ The Main Refinancing Operation is the principal regular operation of the Eurosystem. Since 2004, it has had a maturity of seven days, which has been extended sometimes in case of holidays.

Alternatively, market segmentation encourages counterparties to hold precautionary excess reserves. Therefore, counterparties in *L2* have a demand for excess reserves, which increases their refinancing need *BL2* independently from developments in autonomous factors. In such cases, the demand for excess reserves becomes more difficult to predict.

Since the introduction of fixed rate and full allotment in October 2008, the Eurosystem has experienced different levels of excess reserves. There have been periods in which the existing stock of excess liquidity has not been high enough to absorb all liquidity needs of all banks with structural or contingency liquidity needs. In the context of stricter bilateral credit lines, country risk limits, and collateral concentration limits from Counterparty Clearing Houses (CCP), these episodes led to money market strains as the market found it difficult to accommodate smoothly such concentrated spikes of liquidity need. Misjudging upcoming changes in liquidity needs could therefore lead to high short-term rates (above the Eurosystem refinancing cost), such as what happened in 2009–2011 and again in 2014.

The informational advantage of central banks is even more important in monetary unions where counterparties may face challenges in collecting information from beyond their national borders. Furthermore, the ability counterparties to collect and process the available information could vary substantially, depending on their size and degree of sophistication. Moreover, forecasting challenges are heavily influenced by economy-specific factors. As the forecasting exercise is decentralized, local liquidity managers should be in a position to collect the best information available. In the Eurosystem, for example, each NCB of the euro area forecasts the autonomous factors in their balance sheet and the European Central Bank (ECB) aggregates the NCB's forecasts to publish the Eurosystem's autonomous factor forecast.

B. International Practices in Autonomous Factor Forecast Publication

The cross-economy analysis of the publication of autonomous factors allows a descriptive overview of international practices, providing some insights into underlying motivations. To gain these insights, we compare the publication practices of a sample of 36 other European Union (EU) and non-euro economies, both advanced (17) and emerging markets (19).

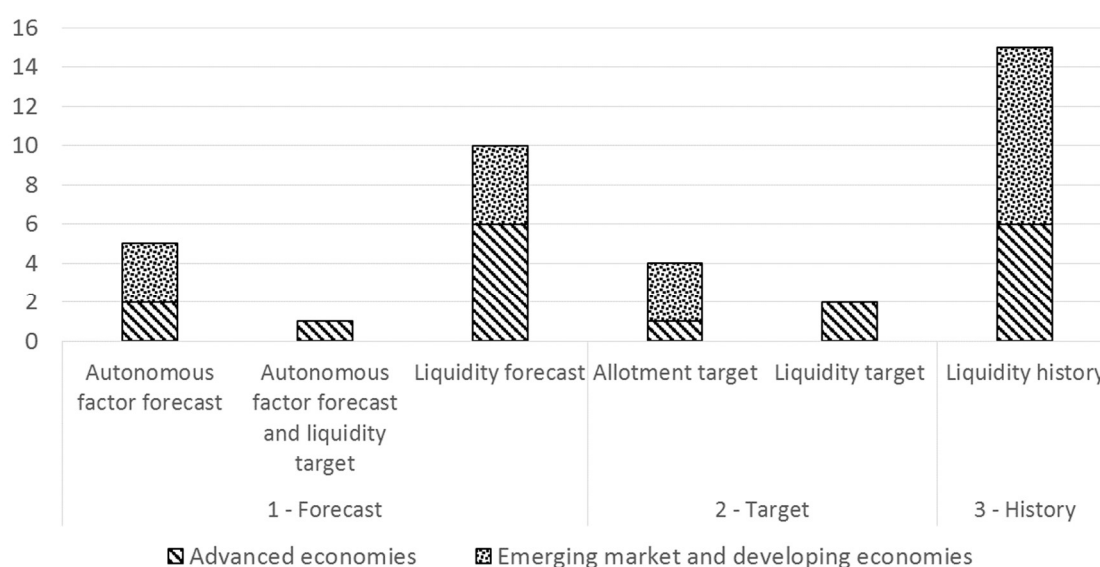
For our sample, we add nine EU non-euro countries (Bulgaria, Croatia, Czech Republic, Denmark, Hungary, Poland, Romania, Sweden, and United Kingdom) as well as five EU candidates (Albania, Montenegro, North Macedonia, Serbia, and Turkey) to the UE, which provide the European comparison against the Eurosystem framework. Furthermore, we complement the international comparison by adding the remaining 12 economies of the IMF grouping of Advanced Economies (Australia, Canada, Hong Kong SAR, Iceland, Israel, Japan, Korea, New Zealand, Norway, Singapore, Switzerland, and United States) as well as the remaining 2 OECD members (Chile and Mexico) and 8 OECD accession and partner countries (Brazil, China, Colombia, Costa Rica, India, Indonesia, Russia, and South Africa).

Of the 36 economies in our sample, 16 publish some sort of forecast, which can be either a forecast of autonomous factors or banks' accounts at the central bank ("liquidity" forecast) based on a projection of autonomous factors (Figure 1). Most central banks publish the sum of AFF without details, but a few (Denmark and Russia) provide forecasts for individual

autonomous factors. Six economies provide a public target either for the allotment of their OMOs (allotment target) or for the balance of banks' accounts at the central bank (liquidity forecast). The remaining 14 monetary authorities do not publish a forecast, but rather some liquidity history which includes an explicit figure, just their balance sheets, or only broad monetary aggregates. Finally, the Federal Reserve publishes the results of a survey that asks banks the minimum level of reserves they would be comfortable holding, which is, to our knowledge, the only initiative to publish an estimate of counterparties' demand for reserves.

In terms of distribution across advanced and emerging economies, the publication practice is notably similar with only a slightly greater tendency in emerging economies to not publish.

Figure 1. International Publication Practices of Autonomous Factor Forecasts

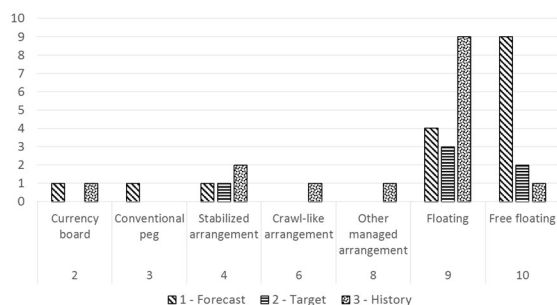


Source: Central banks.

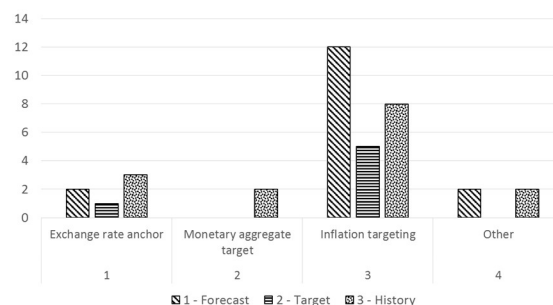
In the following, we scrutinize the incidence of publication practices and distinguish six dimensions: (1) exchange rate arrangement; (2) monetary policy framework; (3) monetary policy implementation framework; (4) OMO allotment method; (5) matching the OMO tenor; and (6) publication frequency. The results are tabulated in the respective panel of Figure 2.

Figure 2: International Comparisons of Publishing Practices of Autonomous Factor Forecasts (Number of Central Banks)

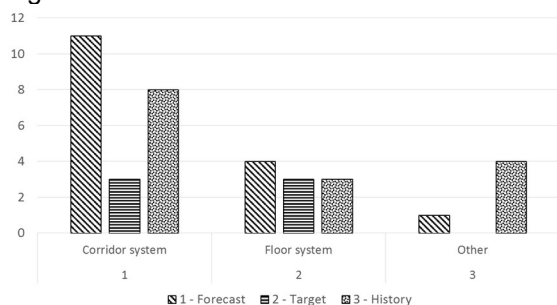
Panel 1: Publication practices and exchange rate regime



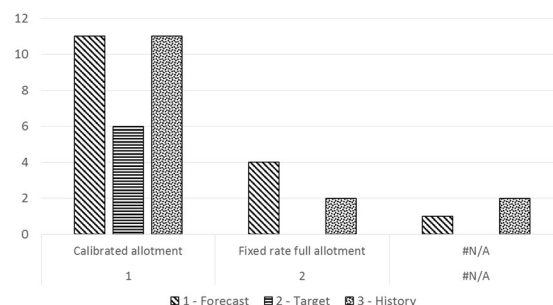
Panel 2: Publication practices and monetary policy framework



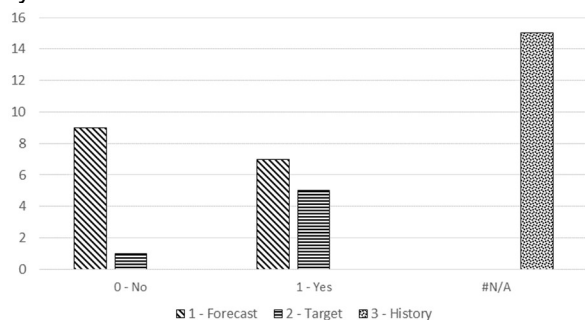
Panel 3: Publication practices and interest rate regime



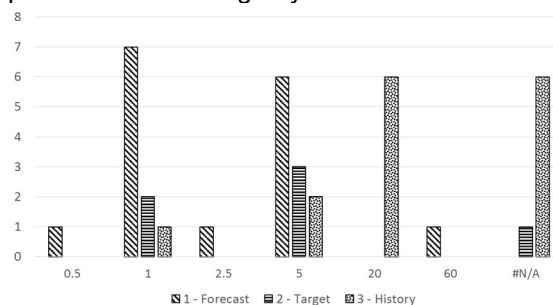
Panel 4: Publication practices and allotment mechanism



Panel 5: Publication practices and synchronization with OMOs



Panel 6: Publication practices and frequency of publication in trading days



Source: Central banks, Annual Report on Exchange Rate Arrangements and Exchange 2018.

Note: The economies that publish a forecast, target, or history are clustered by the exchange rate regime.

Exchange rate arrangement. Using the IMF Annual Report on Exchange Arrangements and Exchange Restrictions (2018 AREAER), we compare the evidence of publishing autonomous factors across exchange rate regimes. Our sample covers seven exchange rate

regimes, including systems ranging from currency board to free floating. We observe relatively more central banks that publish AFF with flexible exchange rate regimes than fixed exchange rate arrangements. This finding reflects the preference of these economies to use exchange rates as their operational target, rather than interest rates or liquidity conditions. Furthermore, monetary authorities that are active in foreign exchange markets often have unforeseen changes in autonomous factors, owing to changes in net foreign assets. Specifically, the changes in net foreign assets due to FX interventions in fixed exchange rate arrangements are difficult to predict beyond the settlement horizon of FX transactions, which is spot ($t+2$) in most cases. Only changes in liquidity shorter than the settlement date of FX interventions are known with certainty.

Monetary policy regime. Our sample covers all monetary policy regimes of the IMF AREAER: from exchange rate anchors to monetary aggregate targets, inflation targeting, and other regimes. The density of economies with both an inflation target and providing some target forecast for autonomous factors is large. This finding supports earlier evidence that economies with exchange rate targets do not publish a forecast. In addition, monetary authorities with monetary aggregate targets also do not publish forecasts, although they could provide some guidance on their operational target by publishing medium-term projections of currency in circulation and short-term forecasts of banks' accounts at the central bank. Consequently, it is necessary to focus on the details of inflation targeting regimes.

Interest rate framework. We distinguish three main interest rate frameworks: (1) corridor systems (in which the central bank strives to provide the exact amount of refinancing that banks need over a short-term horizon); and (2) floor systems (in which the central bank aims at keeping more reserves in the system than what banks need over a short-term horizon); as well as (3) others. Most economies in our sample operate in a corridor system (22), but there is still a sizable number of them operating a floor system (10), and a few with other systems (4). The first category requires an accurate autonomous factor forecast to reach the neutral allotment (which is the allotment for which the supply of reserves equals the demand for reserves of central bank counterparties). In contrast, the second category, floor system, tolerates a larger quantity of excess reserves and relies more on short-term fine tuning operations. Our findings support this reasoning: corridor systems more often publish a forecast than floor systems (or other systems). Yet, a notable number of monetary authorities publish forecasts or targets within a floor system, implying that short-horizon forecasts and their publication remain relevant for calibrating and fine-tuning operations under a floor system, particularly as the policy signal can be more blurred (Beirne 2012).

Allotment mechanism. Allotment methods of OMOs can be broken down into: (1) variable rate tender and calibrated allotment; (2) fixed rate and full allotment; and (3) others. We find that most economies in our sample use some form of calibrated allotment for their OMOs (28). Some stand out, allotting full amounts at a fixed rate (6). For three monetary authorities, we either do not have information about their allotment mechanisms or it is not applicable for them (e.g., they are currently not conducting OMOs).

AFF are necessary to calibrate OMOs, but their publication is less necessary as the central bank keeps control over the allotment. Under the fixed rate and full allotment method, the

bidding of banks determines the allotment. This is consistent with a neutral allotment, under the assumption that banks will not keep excess reserves voluntarily. Forecasts are, thus, not necessary for the central bank to calibrate the allotment of its OMOs. However, the publication of forecast is useful for better-informed bidding by the central bank's counterparties.

Our findings suggest that targets are only published in an environment of calibrated allotments, which is the main reason for publishing any targets. For those that do not calibrate the allotment of their OMOs, the sample is divided between (1) publishing forecasts and (2) publishing history, underlining the trade-off explained above. Fixed rate full allotment is a slight majority for publishing forecast.

Publishing synchronized with OMOs, and publication frequency. The publication usually covers the maturity of the main OMOs (Figure 2, Panel 5). However, there is a notable number of economies publishing a forecast or target independently from OMOs. Publication is surprisingly frequent, with nine economies providing a forecast or target every day and one even publishing intra-daily updates (Figure 2, Panel 6). Large known transactions within the OMO period seem worth disclosing (Gray 2008) as the central bank can provide the banking sector much greater reassurance, with the major benefit of better anchoring of short-term rates. Therefore, it is a common international practice to provide additional updates outside of the OMO cycle. In contrast, the publication of liquidity history approximates the IMF Statistical Data Dissemination Standard of the monthly publication rhythm.

In terms of format, the Eurosystem is one of the few central banks in our review that publishes AFF in stock but not in flow. The publication in stocks provides two advantages. First, stocks are easier to reconcile with central bank balance sheet developments; and, second, the comparison of AFR and AFF at two points in time is easier to comprehend. In contrast, the change in perspective might better facilitate bidding behavior in OMOs, as it is related to the change in liquidity conditions. Over time, the publication format seems to be a matter of habit, convenience, and internal procedures, which is not easy to grasp and quantify in a cross-economy study.

C. History of Autonomous Factor Forecast Publication in the Eurosystem

The Eurosystem decided to publish regularly its average AFF in June 2000 in the context of its MRO announcement (normally occurring on Monday afternoon, for a tender executed on Tuesday morning and operations settled on Wednesday).² In March 2004, the Eurosystem amended the timing of the reserve maintenance period to align the start of the maintenance period with the settlement of any MRO, thereby preventing rate changes within a given maintenance period, and reducing the MRO maturity from two weeks to one. At the same time, it decided to publish a benchmark allotment amount for the MRO in addition to the autonomous factor forecast. This benchmark allotment amount is the ECB estimate of the liquidity needed to be injected to fulfill banks' liquidity needs. The ECB is not bound by the

² A general description of the ECB implementational framework is provided by Ejerskov and others (2008).

benchmark allotment amount and could decide to inject more liquidity than the benchmark (loose allotment), or less than the benchmark (tight allotment).

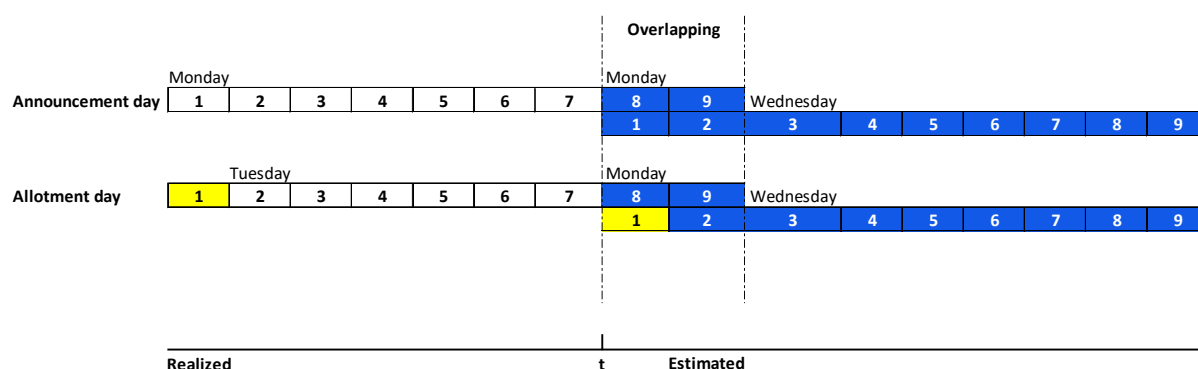
The benchmark calculation includes an excess liquidity objective: null or low under neutral liquidity allotment (2000–08) or a stable (but not enforced) level of excess reserves under the fixed rate and full allotment (2008–14). As such, counterparties could infer the reserve objective of the Eurosystem based on the benchmark and the autonomous factor forecast if the two cover the same period.

The Eurosystem publishes different forecast horizons for the autonomous factor forecast (nine days) and the benchmark (seven days). The nine-day forecast is published at the time of the MRO announcement. The seven-day forecast is published after the MRO allotment. Based on the seven-day forecast, counterparties can replicate the benchmark calculation with published data. This practice still prevails under the fixed rate and full allotment, although bidding by counterparties determines the MRO allotted amount (not the published benchmark).

At the beginning of each maintenance period, the NCBs and the ECB jointly prepare AFF for all days of the full maintenance period. Consecutively, this forecast is updated for the rest of the period up to a minimum of 11 days. Then, the Eurosystem produces a forecast for the next 11 days until the beginning of the next maintenance period. These forecasts are not published.

For the published AFF, the Eurosystem amended its liquidity publication in March 2004 with a time horizon covering normally nine days. Unless Monday is non-settlement day in the euro area payment system, liquidity publication runs from Monday to the Tuesday of the next week, as the MRO is normally announced on Monday and allotted on Tuesday (Figure 3). The period includes the seven-day maturity of the MRO (Wednesday to Tuesday) and two extra days (the first Monday and Tuesday).

Figure 3. Schedule of a Standard Autonomous Factor Publication



Source: European Central Bank.

For the first week of the maintenance period, however, the number of days in the estimate is reduced to seven (Wednesday to Tuesday) because the data from the expired maintenance period do not provide useful information for the smooth fulfilment of the current maintenance period. Hence, they are not incorporated into the calculation of the benchmark. Thus, about 70 percent of the estimates commenced on a Monday, and 22 percent on a Wednesday. The rest reflects changes in the starting day of the estimates due to holidays. In terms of the forecast horizon, 62 percent of the estimates were provided a nine-day horizon and 20 percent a seven-day horizon (the first week of the maintenance period). The rest is generally longer estimates (12–13 days) due to longer MRO periods, such as over holidays.

In March 2004, the Eurosystem also decided to publish an update of the autonomous factor estimate on the allotment day of the MRO (that is, on the Tuesday in a standard MRO week). The update covers the same period as the Monday announcement's estimate, but substitutes the forecast of the first Monday with the AFR on that day. Therefore, an eight-day estimate can be derived from the Tuesday update by removing the Monday realized value and calculating the average of the remaining forecast horizon. The update is published with the allotment of the MRO; therefore, this forecast cannot be used to bid at this operation. Such an update, however, helps the market to disentangle allotment decisions that deviate from the initially announced benchmark.

III. EVALUATING FORECAST QUALITY

This section evaluates the Eurosystem's autonomous factor forecast. The evaluation exercise is split into two quality dimensions: accuracy and reliability. We operationalize the two dimensions of forecast quality by three sets of statistical tests, supplementing the evaluation exercise with the presence of a bias in the forecast (that is, the tendency to systematically under- or over-predict autonomous factors). The presence of a bias is usually considered of particular concern for the forecast accuracy. Additionally, we introduce measures for the reliability of the autonomous factor forecast that is tested by the volatility of forecast errors.

Accuracy: the universal criterion for any high-quality forecast. We implement standard test metrics contained in the literature on macroeconomic forecast evaluation (Bank of England 2015; Diebold and Mariano 1995). Accuracy or the lack thereof measures the size and frequency of the errors committed by the forecasters. It is usually tested using RMSE, a quadratic loss function that is commonly used in forecast evaluations, including those used by central banks, to evaluate AFF. Additionally, we use unbiasedness tests (Frankel and Froot 1989; Froot 1989; Rinaldo and Rupprecht 2019) to see whether errors are biased toward a particular side. In the absence of a bias, the forecast would accurately predict autonomous factors on average through time, although individual forecast errors may be large. One-sided errors are of particular interest in the case of AFF because these might induce a persistent level of excess reserves or a liquidity deficit. Central banks operating in a neutral and balance liquidity environment might be particularly interested in this criterion.

Reliability: any autonomous factor forecast must be reliable if they are to be used by banks to calibrate their liquidity and cash flow management. We test reliability as the consistency of forecast performance; that is, low volatility of forecast errors over time. An unreliable forecast is one where errors are not steady over time. If sudden jumps in forecast errors

occur, a structural liquidity premium may result if bank demand for excess reserves unexpectedly rises. Even when forecast errors are low, sudden and large deviations in autonomous factors (in either side) might lead to a structural demand for excess reserves and a premium in money market rates. Conversely, the size of forecast errors is persistently low in a system where the autonomous factor forecast is reliable.

Using the estimated forecast errors, we analyze the structural correlates of forecast errors, which provide two insights. First, we can identify supporting factors of and impediments to high-quality forecasts. Second, the analysis sheds light on the “usefulness” of the forecast. Usefulness, or the lack thereof, measures whether the forecaster has incorporated all the information available. Conversely, a forecast that is not fully useful could be supplemented by further information. We evaluate the usefulness of the forecast by its efficiency (Frankel and Froot 1987). A forecast is efficient if its forecast error is not correlated to information that was known when the forecast was made. In this paper, we will test whether the forecast errors can be explained by data that were publicly available at the time of the forecast. To our knowledge, central banks have not tested for bias or for the efficiency of their AFF.

A. Forecast Accuracy

The ECB publishes its forecasts of autonomous factor balances on a weekly basis. A forecast is published when an MRO is announced (first forecast), and an updated forecast (second forecast) is published when the MRO allotment is announced the next day. This paper covers all the published AFF from June 26, 2000, to August 19, 2019.

The realized autonomous liquidity factors are published daily, together with data on OMOs, recourse to the lending facility, use of the deposit facility, current account holdings, and reserve requirements. This detailed information has been available since January 1, 1999.³

The ECB has adjusted its publication schemes several times over the years, which creates a challenge for computing the AFR. From 1999 to 2009, the liquidity effect from AFR was published as one series. From 2010 to 2013, the same liquidity effect was reported, but also included reserves injected through an asset purchase program called the Securities Markets Program (SMP). However, for this period, the amount injected under SMP was not published, so it must be deducted from ECB’s tender operations history.⁴ These records contain information about the fine-tuning operations designed to absorb liquidity effects from the SMP operations during this period.

Since 2014, the time series was further modified to include the liquidity effect from all other asset purchase programs. The AFR, then, became the reported series plus the operations through all of ECB’s asset purchase programs. These include the Covered Bond Purchase Program (CBPP), CBPP2, CBPP3, SMP, Asset-Backed Securities Purchase Program, Public Sector Purchase Program, and Corporate Sector Purchase Program.

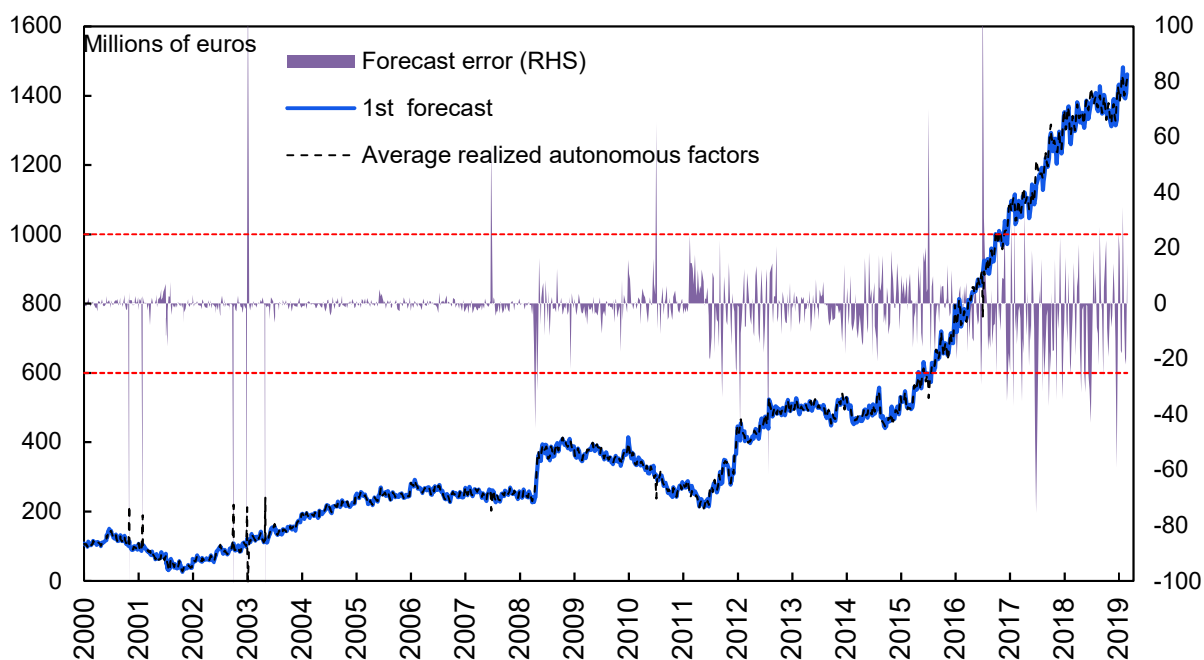
³ See https://www.ecb.europa.eu/stats/policy_and_exchange_rates/minimum_reserves/html/index.en.html.

⁴ See https://www.ecb.europa.eu/mopo/implement/omo/html/top_history.en.html.

A second challenge for this computation is to remove realized data from the second forecast. The first forecast and the second forecast cover the same period, except that one day has passed between them. Therefore, the second forecast includes one day (the first day) of realized data. Based on data published by the ECB, we removed the first day realized data from the forecast to obtain eight-day forecast-only data (instead of the nine-day publication).

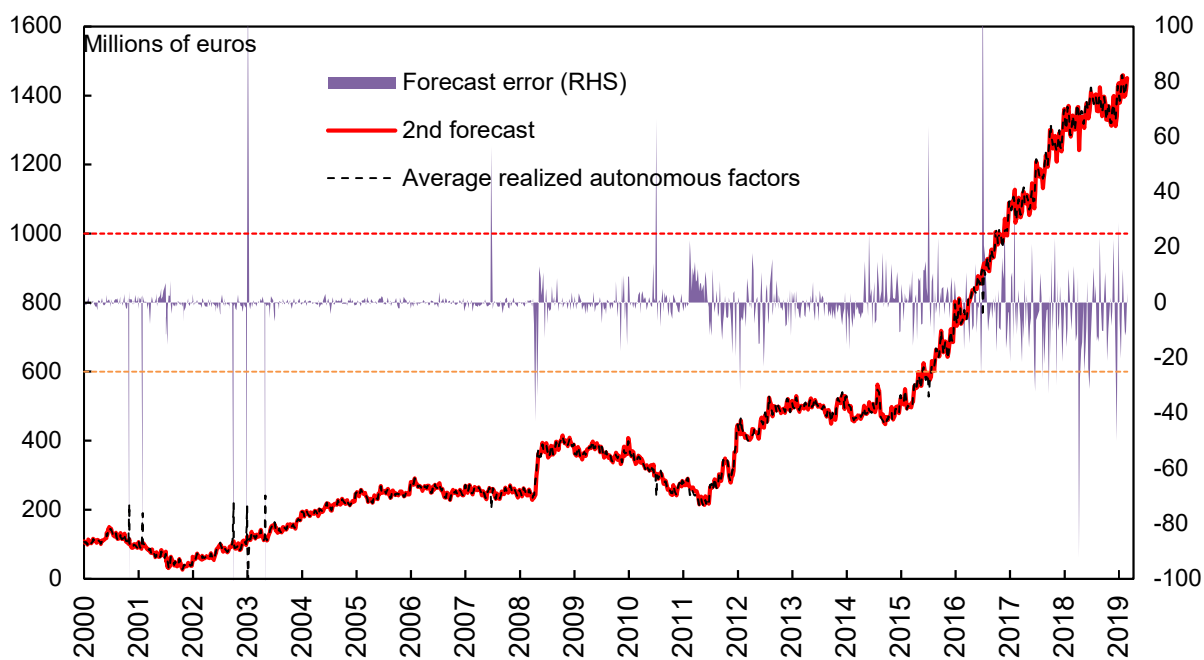
The resulting liquidity forecasts and AFR are plotted in Figure 4 for the first forecast and Figure 5 for the second forecast. The forecast errors are the difference between the AFF and the AFR. At first glance, the difference between realized and forecast autonomous factors did not show large or persistent discrepancies relative to the size of the autonomous factors. However, there were small and short-lasting differences reflecting forecast errors. The average error, in absolute term, is EUR 2.2 billion for the first forecast and EUR 1.7 billion for the second forecast. Twice the standard error of the first forecast error amounted to EUR 25 billion. The first forecast errors exceeded EUR 25 billion in 4 percent of the periods; the same amount was exceeded only 2.4 percent of the time for the second forecast. This points to a notable improvement of the forecasts between the first and the second.

Figure 4. Autonomous Factors: Realized Versus First Forecast



Source: European Central Bank, authors' calculations.

Figure 5. Autonomous Factors: Realized Versus Second Forecast



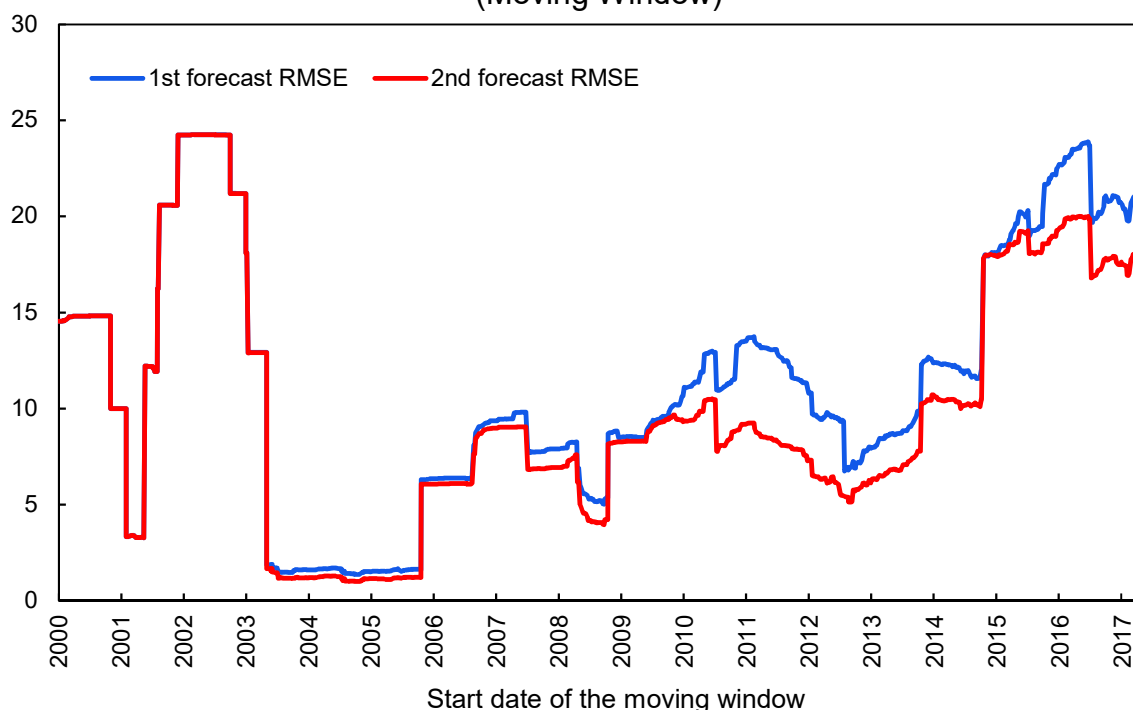
Source: European Central Bank, authors' calculations.

In the following, the accuracy of Eurosystem liquidity forecasts, which indicates how closely the forecast traces reality, is measured as the RMSE:

$$RMSE = \sqrt{\frac{\sum_{t=1}^n e_t^2}{n}} \quad (1)$$

where e is the forecast error defined as the difference between the forecast and the AFR. A smaller RMSE indicates lower degree of forecast error, hence higher accuracy. A 90-forecast-period moving window is used to compute the RMSE for the whole series (Figure 6) to show the changes in accuracy over time. Because the RMSE is not linear, a larger error has more impact than a smaller one, which seems reasonable as large autonomous factor forecast errors are presumed to have the largest market impact.

Figure 6. Autonomous Factor Forecast Root Mean Square Error (Moving Window)



Source: European Central Bank, authors' calculations.

The RMSE was close to one from October 2003 to December 2007, indicating a high degree of forecast accuracy during this period. It broadly corresponds to the period between the March 2004 revision of the Eurosystem's liquidity management framework and the introduction of the fixed rate and full allotment in October 2008 (hereafter, the "new system"). In March 2004, the Eurosystem reduced the maturity of its operations from two weeks to one week and stated that its policy rate would not change during a maintenance period. Step increases in the RMSE, such as in December 2007 and December 2016, reflect disproportionately large forecast errors. Despite a drop in 2009, the RMSE remained above its best performances after 2008 as relatively larger forecast errors became more frequent.

The revised forecasts (“2nd forecasts”) tend to have a higher accuracy than the initial forecasts (“1st forecasts”). This reflects the improvement in the forecasts due to the incorporation of the most up-to-date information, as well as the inclusion of one day of AFR in the forecast average.

Besides the two-sided error metric, we evaluate the biasedness of the forecasts. The forecasting bias is assessed using an ordinary least squares regression of the first difference in Eurosystem forecasts to the first difference in AFR based on the equation:

$$\Delta \log(AFR_t) = c + \beta * \Delta \log(AFF_t) + e_t \quad (2)$$

Where,

- ΔAFR_t is the log-difference of the realized autonomous factor for the MRO week (t),
- ΔAFF_t is the log-difference of the autonomous factor forecast for the MRO week (t), and
- e_t is the residual, representing the estimated forecast errors. They reflect deviations from the relationship between realized and estimated values of autonomous factors, including the presence of any possible forecasting bias.

It is important to use differentiated variables for two reasons. First, from an economic point of view, what matters for the change in liquidity conditions and bidding in OMOs is the change in autonomous factors. The current level of autonomous factors is usually known to market participants, at least with the publication of the central bank balance sheet. Second, from an econometric point of view, using the level of autonomous factors might induce non-stationarity issues.

Under the assumption that forecasts are unbiased, realized autonomous factors should move proportionally to their estimated value without a drift (that is, a constant). As such, the estimated coefficients should have the following values:

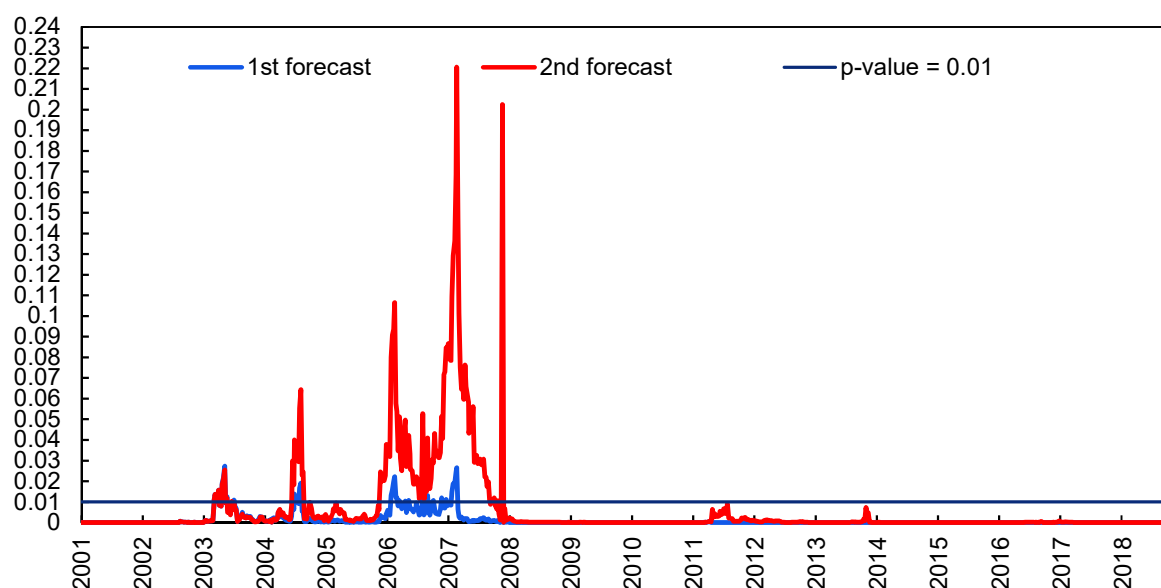
- The realized value should be perfectly elastic to the estimate: $\beta = 1$. An estimated value different from one would indicate a bias conditional to the change in the forecast (that is, the bias change with the size of the autonomous factor change).
- The constant should be null: $c=0$. A non-null estimated drift would reflect an unconditional bias in the forecast. It would mean that the change in autonomous factors over the forecast period would be systematically over- or underestimated.

We propose testing the null hypothesis of both conditional and unconditional forecast bias together as the joint Wald test of $\beta = 1$ and $c = 0$. Acknowledging the likely presence of structural break, we estimate regression (1) and infer from it the p-value of the Wald joint test for a rolling window of 90 forecasting periods (about 90 weeks) from 2000 to 2019.

The test rejects the null assumption of conditional and unconditional unbiased forecast for 37 periods of 90 days out of 953 periods (4 percent) from 2000 to 2019 for the first forecast and for 119 periods (12.5 percent) for the second forecast (Figure 7). It is generally more

difficult to reject a bias in the 1st forecast than in the 2nd forecast, suggesting that the additional information has an impact not only on the accuracy of the forecast but also on possible bias in the forecast. Biased forecasts are noticeably more frequent after 2008 than before. The longest stretch of unbiased forecast corresponds to the period 2004 to 2008.

Figure 7. Forecast Bias Test P-value
(Rolling Basis)

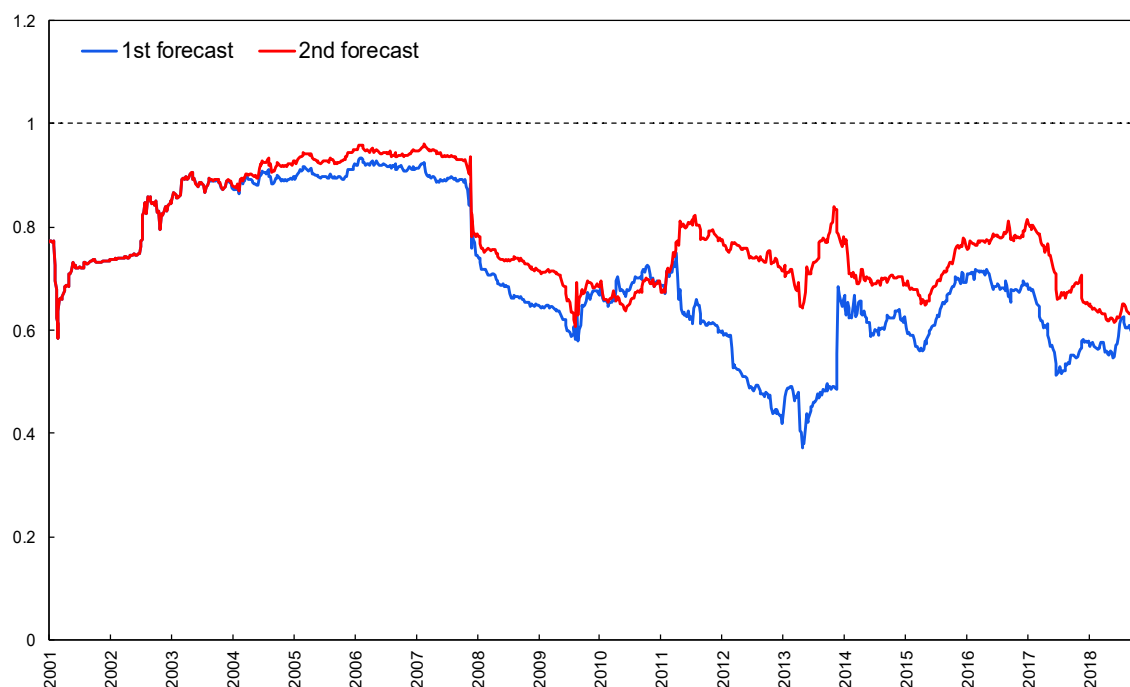


Sources: European Central Bank, authors' calculations.

Note: The figure presents the p-value of the joint test. A value above 5 percent means that the null hypothesis of no-bias could not be rejected.

The Eurosystem forecasts tend to overestimate the increase in autonomous factors. Figure 8 shows the estimates of the coefficient β , which represent the forecast conditional bias. An estimated coefficient of less than one means that the forecaster expected a larger change in the autonomous factor than the one that actually happened. A perfect forecast would require that β equal one. The estimated coefficient is significant for all periods in the rolling regression estimates and remains below one for each period. However, evidence of structural breaks in forecast errors suggests that the forecasting bias could have changed through time. It seems to converge to one from 2004 to 2008. After 2008, the coefficient fluctuated between 0.9 and 0.5, suggesting a larger and persistent overestimation bias.

The result suggests that Eurosystem forecasts are usually not subject to an unconditional bias, which means that they are not systematically off by a fixed amount. The Student statistic test for the constant c in equation 1 never exceeds a critical value of 1.5, which is low for this test.

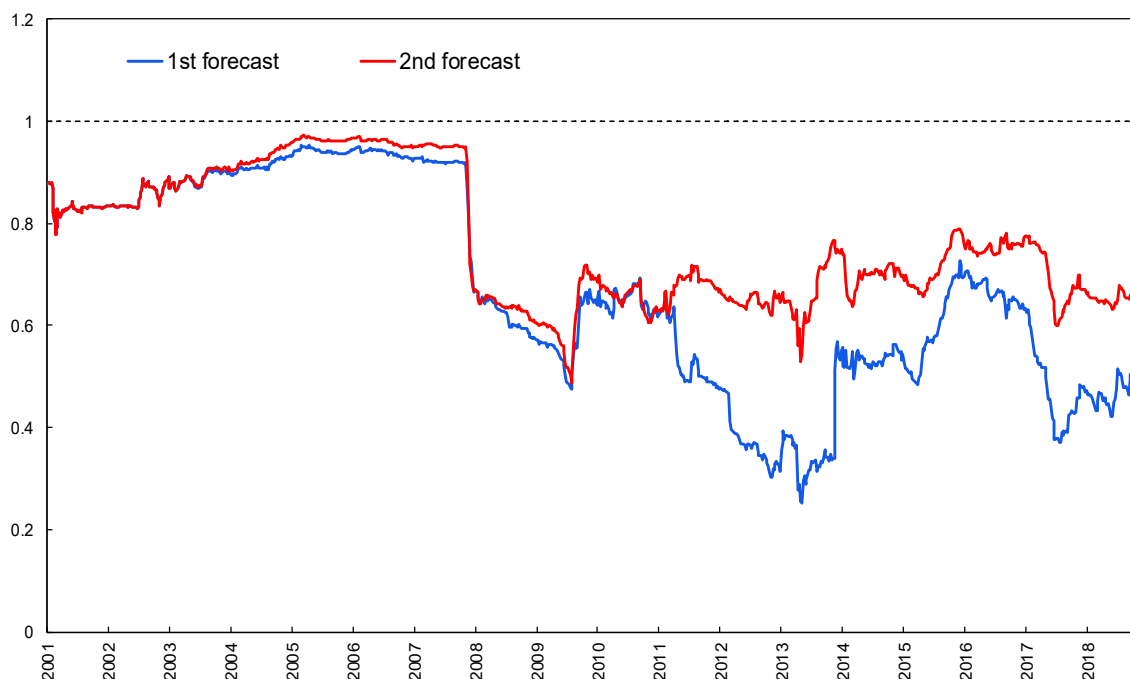
Figure 8. Conditional Bias Coefficient for 1st and 2nd Forecasts

Sources: European Central Bank, authors' calculations.

Note: A statistic above 1 or below -1 means that the null hypothesis that the unconditional bias (the constant) is null can be rejected.

An indication of forecast accuracy could be found in the R-square of the regression used to estimate the conditional and unconditional forecast bias. A higher R-square indicates smaller estimated forecast errors (e_t in equation 1) for a given forecasting bias. The accuracy of the forecast reached its highest level during the new system period and errors were minimal (Figure 9). During the same period, the assumption of a biased forecast was rejected, which suggests that the forecast was both unbiased and accurate. The accuracy then dropped after 2008, especially for the 1st forecast. Thus, during this period, the forecast presents both a bias and lower accuracy.

Figure 9. R-Square of Conditional and Unconditional Forecast Bias Regression



Sources: European Central Bank, authors' calculations.

Note: A statistic above 1 or below -1 means that the null hypothesis that the unconditional bias (the constant) is null can be rejected.

B. Forecast Reliability

Reliability is the persistence of accurate forecasts, or a low probability of significant “surprises.” If forecast errors are, on average, low but there are some significant deviations, this could induce a premium on the demand for excess reserves as an insurance against “surprises.”

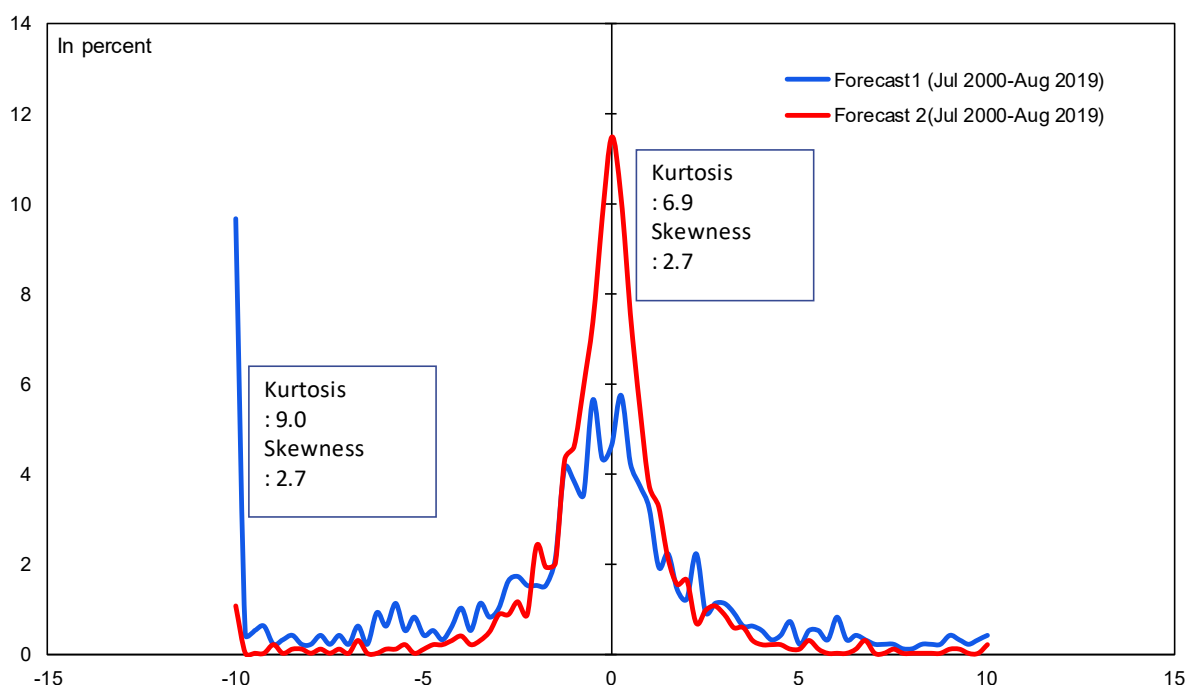
The distribution of forecast errors appears to be leptokurtic, meaning that the distribution peak is higher around the mean value and has higher densities of value at extreme ends than a normal distribution. Therefore, outlier errors are more frequent and more extreme than if the forecast errors were following a normal distribution.

The distributions are positively skewed, meaning the right tail of the distribution is long. Therefore, the likelihood of overestimating AFR (positive forecast errors) is higher than the likelihood of underestimating them (negative forecast errors). That said, the fat tail of the distribution is on the left as the largest forecast errors (“outliers”) underestimate AFR.

From July 2000 to August 2019, forecast errors are concentrated around smaller values for the second forecast than for the first forecast (Figure 10). The first forecast experienced larger (outliers) and more frequent underestimation errors than the second forecast. Besides

outliers, the distributions also indicate the same probability of overestimating AFR in the first and the second forecast.

Figure 10. Distribution of First and Second Forecast Errors

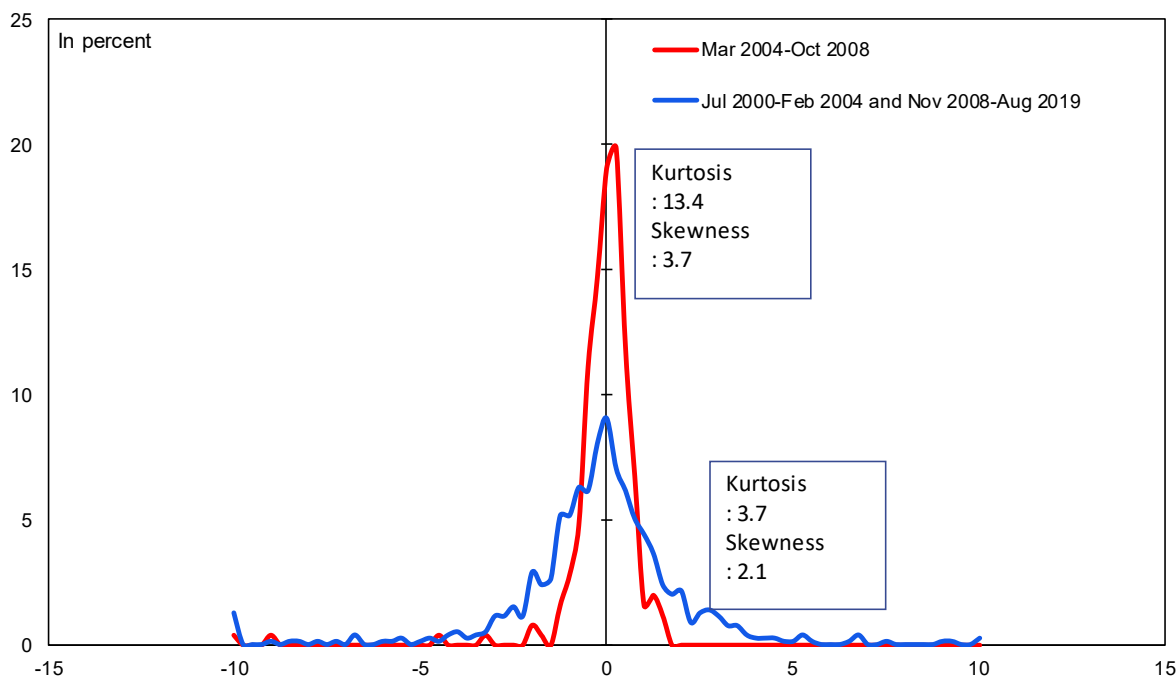


Source: European Central Bank, authors' calculations.

We use the period March 2004 to October 2008 (248 forecast) as a benchmark for high-forecast quality as it corresponds to the period following significant revision to the operational framework and before the major change in market conditions due to the global financial crisis. The rest of the sample include 804 forecasts prepared between July 2000 and February 2004 and between November 2008 and August 2019.

Forecast errors of the second forecast, which has the best forecasting capacity, are notably more concentrated around smaller values during the benchmark period than in the rest of the sample (Figure 11). While outlier underestimation errors are less frequent over the benchmark period, the difference between average errors and the outliers during the benchmark period makes the benchmark distribution more leptokurtic than the distribution of errors for the rest of the period. Besides outlier underestimation errors, the probability of overestimating AFR appear slightly higher during the benchmark period than the rest of the sample.

Figure 11. Distribution of Second Forecast Errors: Different Periods



Sources: European Central Bank, authors' calculations.

C. Factors Influencing Forecast Errors

In this subsection, we focus on explaining forecast errors by analyzing the correlates of the forecast errors. This analysis allows us to derive the supporting factors and the impediments to high-quality forecast. Using public information as correlates can be used to test the efficiency of the forecast (cf. Frankel and Froot 1987; and Patton and Timmermann 2012). We tested this by regressing forecast errors based on information that was known when the forecast was made. The forecast is said to be “strong” in efficiency if the forecast errors are not significantly correlated with the additional information (i.e., the forecaster has used all the information available). If public information can explain only part of the forecast errors, the forecast itself is not using all information that was available at the time. If the forecast is not efficient, it is not as useful as it could be.

The analysis of the changes in accuracy and bias indicators already hint at the factors that help explain forecast errors. The improvements from the old to the new system indicate that the parameters of the forecast, such as its length and the contemporaneousness of the information used, can influence accuracy and bias. In addition, assuming that the Eurosystem models used to predict currency in circulation perform well, most of the forecast errors should come from the accounts of non-financial clients of the Eurosystem (e.g., governments). This means that market conditions, which determine how well these clients can manage their accounts in the Eurosystem, are likely an important factor in forecast quality. For instance, the financial crisis, market segmentation, and a near-zero money

market interest rate environment reduced investment opportunities in the money market for NCB clients, which increased the likelihood of unexpected change in their accounts.

1st forecast (results presented in Table 1)

Equation 3 breaks down the sources of forecasting errors:

$$e_{1st,t} = c + \alpha_1 * d_L + \alpha_2 * dp + \alpha_3 * e_{1st,t-1} + \gamma X_t + \delta Z_t + \mu_t \quad (3)$$

Where,

- $e_{1st,t}$ is the absolute value of the forecast errors calculated as the difference between AFR and the 1st forecast.
- d_L stands for the length of the forecast in numbers of days. The forecast length is usually nine days, but is reduced to seven days for the first operation of the maintenance period. A longer forecasting horizon is expected to increase forecast errors.
- dp stands for the periods identified in the history of the Eurosystem AFF. The period March 2004–October 2008, during which the forecasts seem to have been at their best, is used as a reference period.
- X_t is a vector of exogenous variables, reflecting market segmentation, such as the sovereign spread (computed as the difference between German 10-year yields and the median of other euro area sovereign yields of the same maturity), excess reserves as a percentage of reserve requirements (under the assumption that excess reserves are an indication of money market segmentation), and overnight volumes as reported by the EONIA panel (under the assumption that higher volumes reflect a less segmented money market).
- δZ_t is the EONIA, which is expected to control for the low interest rate environment.

2nd forecast (results presented in Table 2)

$$e_{2nd,t} = c + \alpha_1 * d_L + \alpha_2 * dp + \alpha_3 * e_{1st,t} + \alpha_4 * e_{2nd,t-1} + \gamma X_t + \delta Z_t + \mu_t \quad (4)$$

Where,

- $e_{2nd,t}$ is the absolute value of the forecast errors, calculated as the difference between AFR and the 2nd forecast.
- e_{1st} is the forecast errors on of the 1st forecast introduced as an explanatory variable of the error of the 2nd forecast. This variable tests the use of the information obtained between the 1st and 2nd forecasts by the forecaster (akin to an error correction term). A coefficient significantly less than one but different from zero would reflect a reduction of the errors based on more contemporaneous information.

Both the 1st and 2nd forecast errors are significantly correlated with the set of variables presented above, suggesting that forecasts do not qualify as “strong” in efficiency. The 2nd forecast, while resulting in smaller errors and less biased, is less efficient than the 1st forecast, as reflected in a higher R-square for the full specification of the 2nd forecast error compared with the 1st forecast error (column 2 of Tale 1 and 2). This is due mainly to the contribution of the 1st forecast error as an explanatory variable of the 2nd forecast error. However, only part of the 1st forecast errors is reproduced in the 2nd forecast errors, showing that one day of additional information notably reduces forecast errors.

Using the full specification in equation 3, the 1st forecast errors are significantly correlated with the sovereign spreads and excess reserves—both of which are indicators of market segmentation. They have the expected signs as well as the dummy variable March 2004 to October 2008, during which forecast errors were lower, as anticipated (column 2 in Table 1). The 2nd forecast errors (equation 4 and column 2 in Table 2) are significantly correlated with excess reserves and EONIA volumes—both of which are also indicators of market segmentation, the 1st forecast errors (as discussed earlier), and the dummy variable March 2004 to October 2008. These results corroborate the assumption that segmentation increases forecast errors.

Two differences between 1st and 2nd forecast errors regressions are worth noting. First, the 1st forecast errors appear somewhat correlated with the previous period 1st forecast errors, indicating that the information arising from previous forecast errors is not fully factored in the forecast exercise. This would suggest some degree of inefficiency in the forecasting model in the spirit of Frankel and Froot (1987). This result is not corroborated, though, for the 2nd forecast errors. Second, the 2nd forecast errors are negatively correlated with EONIA levels, reflecting the possible contribution of the low interest rate environment to forecast errors. This result is not corroborated, though, for the 1st forecast errors.

Finally, columns 3 to 9 in Table 1 and Table 2 present the bivariate correlates of each variable and the forecast errors. They all show significant correlations with the expected signs, except for the correlation between the length of the forecast horizon and the 1st forecast errors. Looking at the R-squares of the full specification with those of the bi-variate correlates, it appears that the main contribution arises from the market segmentation indicators (either excess reserves or EONIA volume) for the 1st forecast errors, and from the 1st forecast errors itself for the 2nd forecast errors.

Table 1. Correlation Between 1st Forecast Errors and Other Variables

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Sovereign spread	1.988*** (0.463)	1.836*** (0.501)	3.160*** (0.379)						
EONIA	-0.192 (0.151)	-0.180 (0.152)		-1.989*** (0.125)					
Excess reserves	0.981*** (0.137)	0.987*** (0.137)			1.282*** (0.0640)				
EONIA volume	-0.0143 (0.0168)	-0.00699 (0.0178)				-0.257*** (0.0140)			
Length of forecast horizon	-0.00360 (0.188)	0.0262 (0.194)					0.397*** (0.139)		
L1. 1st forecast error	0.118* (0.0658)	0.115* (0.0653)						0.402*** (0.0285)	
Mar 2004/Oct 2008		-0.716** (0.308)							-5.282*** (0.309)
Constant	2.475 (2.023)	2.239 (2.066)	3.445*** (0.324)	8.376*** (0.289)	2.966*** (0.234)	13.04*** (0.469)	1.927 (1.209)	3.179*** (0.266)	6.524*** (0.297)
Observations	1,029	1,029	1,030	1,036	1,036	1,036	1,036	1,035	1,036
R-squared	0.333	0.334	0.063	0.197	0.280	0.246	0.008	0.161	0.084

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Sources: European Central Bank, authors' calculations.

Note: EONIA refers to the Euro Overnight Index Average. *L1* indicates the lag by one period of a variable.

Table 2. Correlation between 2nd Forecast Errors and Other Variables

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Sovereign spread	0.737** (0.311)	0.146 (0.380)	1.647*** (0.358)							
EONIA	0.230 (0.172)	0.977*** (0.350)		-1.587*** (0.148)						
Excess reserves	0.258** (0.125)	0.249** (0.124)			0.866*** (0.0605)					
EONIA volume	-0.0368** (0.0162)	-0.0472*** (0.0174)				-0.188*** (0.0136)				
Length of forecast horizon	-0.145 (0.203)	-0.135 (0.199)					-0.0193 (0.183)			
1st forecast error	0.440*** (0.0655)	0.430*** (0.0633)						0.519*** (0.0208)		
L1. 2nd forecast error	0.00894 (0.0494)	-0.00593 (0.0519)							0.297*** (0.0337)	
Mar 2004/Oct 2008		-3.080*** (1.031)								-5.395*** (0.310)
Constant	2.764 (2.032)	3.706* (2.097)	3.555*** (0.345)	6.293*** (0.263)	2.680*** (0.251)	9.854*** (0.428)	4.878*** (1.612)	1.381*** (0.219)	3.316*** (0.273)	6.311*** (0.305)
Observations	797	797	799	805	805	805	805	804	804	805
R-squared	0.463	0.470	0.026	0.125	0.203	0.191	0.000	0.437	0.088	0.140

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Sources: European Central Bank, authors' calculations.

Note: EONIA refers to the Euro Overnight Index Average. *L1* indicates the lag by one period of a variable.

IV. CONCLUSION

Central banks could usefully expand their evaluation methods for AFF. The proposed test of forecast bias would be simple to implement and would provide important additional information, which could have a major impact on the credibility of the forecast. The test could be conducted according to different types of autonomous factors, enhancing the analysis of forecast results. The work on explaining forecast errors, while not a comprehensive efficiency test, provides useful hindsight on which external factors influence forecast quality the most. Again, the analysis could be broken down by different factors based on more granular data.

The analysis of errors suggests that market conditions take a toll on forecast quality. The correlation between forecast errors, indicators of market segmentation, and indicators of low interest rate environment corroborate the influence of the market environment on the forecast. For instance, from 2004 to 2008, the Eurosystem forecast reached a high level of accuracy and reliability, but forecast quality declined afterward in the aftermath of the global financial crisis.

Looking forward, the publication of AFF may be a finer focus in the market when excess reserves decline. Accurate forecasts are necessary to guide counterparty bidding at Eurosystem refinancing operations, especially under fixed rate and full allotment, when high reserves do not absorb the consequence of coordination failures. Improvements in market functioning and higher policy rates in the future, inasmuch as they drive money market rates away from zero and help NCB clients to actively manage their reserves in the market, may help improve forecast quality without actions from the Eurosystem.

The aim of this paper was not to advocate for publishing autonomous factors. Rather, it was to ease central bank concerns over publishing forecasts by offering an expanded forecast evaluation method. Assuming good forecast quality, we argue that there are only benefits in publishing AFF, and that central banks should be encouraged to do so. The proposed evaluation method could help central banks test the quality of forecasts during a dry-run period before publication. They could then start publishing forecasts once they become confident enough in their quality, thereby protecting central bank credibility. Finally, the evaluation method could be a factor in determining the maturity of central banks' regular OMOs as it would indicate the horizon of high-quality forecasts.

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APPENDIX I. SAMPLE FOR INTERNATIONAL COMPARISON

Economies	Group 1	Group 2*	Exchange Rate Regime	Monetary Policy Framework	Interest Rate Regime	Allotment Mechanism
Albania	EU candidate	EMDE	Floating	Inflation targeting	Corridor system	Calibrated allotment
Australia	Advanced economies	AE	Free floating	Inflation targeting	Floor system	Calibrated allotment
Brazil	OECD partnership	EMDE	Floating	Inflation targeting	Floor system	Calibrated allotment
Bulgaria	EU non-euro	EMDE	Currency board	Exchange rate anchor	Other	N/A
Canada	Advanced economies	AE	Free floating	Inflation targeting	Floor system	Calibrated allotment
Chile	OECD member	EMDE	Free floating	Inflation targeting	Corridor system	Calibrated allotment
China	OECD partnership	EMDE	Crawl-like arrangement	Monetary aggregate target	Floor system	N/A
Colombia	OECD accession	EMDE	Floating	Inflation targeting	Corridor system	Calibrated allotment
Costa Rica	OECD accession	EMDE	Crawl-like arrangement	Other	Other	Calibrated allotment
Croatia	EU non-euro	EMDE	Stabilized arrangement	Exchange rate anchor	Other	Calibrated allotment
Czech Republic	EU non-euro	AE	Floating	Inflation targeting	Corridor system	Calibrated allotment
Denmark	EU non-euro	AE	Conventional peg	Exchange rate anchor	Corridor system	Fixed-rate full allotment
Euro area	Euro area	AE	Free floating	Other	Corridor system	Fixed-rate full allotment
Hong Kong SAR	Advanced economies	AE	Currency board	Exchange rate anchor	Other	N/A
Hungary	EU non-euro	EMDE	Floating	Inflation targeting	Corridor system	Fixed-rate full allotment
Iceland	Advanced economies	AE	Floating	Inflation targeting	Corridor system	Fixed-rate full allotment
India	OECD partnership	EMDE	Floating	Inflation targeting	Floor system	Fixed-rate full allotment
Indonesia	OECD partnership	EMDE	Stabilized arrangement	Inflation targeting	Corridor system	Calibrated allotment
Israel	Advanced economies	AE	Floating	Inflation targeting	Corridor system	Calibrated allotment
Japan	Advanced economies	AE	Free floating	Inflation targeting	Floor system	Calibrated allotment
Korea	Advanced economies	AE	Floating	Inflation targeting	Corridor system	Calibrated allotment
Mexico	OECD member	EMDE	Free floating	Inflation targeting	Corridor system	Calibrated allotment
New Zealand	Advanced economies	AE	Floating	Inflation targeting	Floor system	Calibrated allotment
Norway	Advanced economies	AE	Free floating	Inflation targeting	Floor system	Fixed-rate full allotment
Poland	EU non-euro	EMDE	Free floating	Inflation targeting	Corridor system	Calibrated allotment
Romania	EU non-euro	EMDE	Floating	Inflation targeting	Corridor system	Calibrated allotment
Russia	OECD accession	EMDE	Free floating	Inflation targeting	Corridor system	Calibrated allotment

Serbia	EU candidate	EMDE	Crawl-like arrangement	Inflation targeting	Corridor system	Calibrated allotment
Singapore	Advanced economies	AE	Crawl-like arrangement ^{1/}	Exchange rate anchor	Corridor system	Calibrated allotment
South Africa	OECD partnership	EMDE	Floating	Inflation targeting	Corridor system	Calibrated allotment
Sweden	EU non-euro	AE	Free floating	Inflation targeting	Floor system	Calibrated allotment
Switzerland	Advanced economies	AE	Floating	Other	Corridor system	Calibrated allotment
North Macedonia	EU candidate	EMDE	Stabilized arrangement	Exchange rate anchor	Corridor system	Calibrated allotment
Turkey	EU candidate	EMDE	Floating	Inflation targeting	Corridor system	Calibrated allotment
United Kingdom	EU non-euro	AE	Free floating	Inflation targeting	Corridor system ^{2/}	Calibrated allotment
United States	Advanced economies	AE	Free floating	Other	Floor system	Calibrated allotment

Source: Central Banks, Annual Report on Exchange Rate Arrangements and Exchange 2018, OECD.

1/ 2019 classification.

2/ refers to the framework prior 2009.

Note: AE = advanced economy, EMDE = emerging market and developing economy.

APPENDIX II: INTERNATIONAL COMPARISON OF PUBLICATION PRACTICES

Economies	Content	Details	Frequency	Horizon / Tenor	OMO match	Timing	Source
Albania	Liquidity forecast	The Bank of Albania publishes weekly liquidity forecast.	Weekly	1-week	Yes	OMO announcement	https://www.bankofalbania.org/Markets/Operations_of_the_Bank_of_Albania/Interventions_in_the_money_market/
Australia	Liquidity forecast	Publication of estimated cash positions with announcement for OMOs.	OMO (intra-day)	Today	Yes	OMO announcement	http://www.rba.gov.au/mkt-operations/resources/tech-notes/open-market-operations.html
Brazil	Liquidity history	Remaining in a structural liquidity surplus, BCB absorbs liquidity via security-selling auctions and overnight borrowing. Publication of results.	OMO	History only	N/A	OMO allotment	https://www.bcb.gov.br/acessoinformacao/legado?url=https:%2F%2Fwww.bcb.gov.br%2Fhtms%2Ffinfecon%2Fdema%2Fma201909%2Findex.asp
Bulgaria	Liquidity history	The Bulgarian National Bank publishes data for banking system liquidity and its foreign exchange operations with banks	Daily	History only	N/A	Two days (lagged)	http://www.bnb.bg/Statistics/StOperationalDataManagement/index.htm
Canada	Liquidity target	Publication of a target for balance of the CAD settlements system (LVTs), which is also based on the internal projection of changes in autonomous factors.	Daily	Tomorrow	No	Market close	http://www.bankofcanada.ca/markets/market-operations-liquidity-provision/framework-market-operations-liquidity-provision/
Chile	Liquidity history	Publication of monetary aggregates.	Monthly	History only	N/A	Month-end (lagged)	https://si3.bcentral.cl/Siete/secure/cuadros/home.aspx
China	Liquidity history	Publication of results of OMOs (every Tuesday and Thursday) and daily short-term liquidity operations. Centralized treasury cash management through which the PBOC injects term fiscal deposits into the market.	OMO	History only	N/A	OMO allotment	http://www.pbc.gov.cn
Colombia	Liquidity history	Liquidity allotment and weekly reserves.	OMO	History only	N/A	OMO allotment	https://www.banrep.gov.co/es/estadisticas/reservas-internacionales-y-operaciones-banrep-en-el-mercado
Costa Rica	Liquidity history	Liquidity provision/absorption after OMO.	OMO	History only	N/A	OMO allotment	https://www.bccr.fi.cr/SitePages/default.aspx
Croatia	Liquidity history	Liquidity provision/absorption after OMO.	OMO	History only	N/A	OMO allotment	https://www.hnb.hr/en/core-functions/monetary-policy/monetary-policy-implementation
Czech Republic	Liquidity forecast	The CNB publishes “Daily banking sector liquidity” including the estimate of the current business day’s liquidity in the banking sector and also the previous business day’s realized liquidity and forecast error.	Daily	Today	No	Market open	https://www.cnb.cz/en/financial-markets/money-market/daily-banking-sector-liquidity/
Denmark	AFF	Publication of liquidity projection of government payments, for which a monthly and daily breakdown is provided. The liquidity projection forms the basis for DNB’s planned purchase and sale of certificates of deposit. Publication daily and four times a year based on Government Budget plan (August, December) and Treasury Economic Survey (May, August).	Daily / Monthly	2-months / 1-year	No	Market open / Quarter-start	http://www.nationalbanken.dk/en/marketinfo/marketoperations/Pages/Government-payments.aspx ; http://www.nationalbanken.dk/da/markedsinfo/markedsoperationer/Documents/Likviditetssprognoze_2017_07.xlsx

Euro area	AFF	Publication of forecast of autonomous factors at the time of announcement and allotment of main refinancing operation as well as benchmark allotment, implying a liquidity target.	Weekly	1-week	Yes	Mondays / Tuesdays	http://www.ecb.europa.eu/mopo/liq/html/index.en.html
Hong Kong SAR	Liquidity forecast	HKMA operates in a currency board system. Under normal circumstances, all changes to liquidity reflect autonomous flows from and into HKD. Publication of aggregate balance of interbank liquidity by Forex transactions, other market activities, reversal of discount window, int. PMT / issuance of Exchange Fund Bills & Notes (EFBN).	Daily	Next 3 business days and beyond	No	Market close	https://www.hkma.gov.hk/eng/data-publications-and-research/data-and-statistics/daily-monetary-statistics/
Hungary	AFF	Publication of the average effect of instruments influencing level of HUF liquidity concerning the next seven days matching the maturity of the MNB deposit tender, usually on Tuesday with reference to the tender dates from Wednesday to Tuesday.	Weekly	1-week	Yes	OMO announcement	http://www.mnb.hu/en/monetary-policy/monetary-policy-instruments/liquidity-forecast
Iceland	Liquidity history	Monetary policy implementation based on target interbank rate.	Monthly	History only	N/A	Month-end (lagged)	https://www.cb.is/monetary-policy/markets/
India	Liquidity history	Indian banks' daily cash balances with RBI.	Daily	History only	N/A	N/A	https://www.rbi.org.in/Scripts/WSSViewDetail.aspx?TYPE=Basic&PARAM1=11/15/2019
Indonesia	Liquidity forecast	Liquidity projection of total net liquidity and excess reserves.	Daily	Today	No	Market open	https://www.bi.go.id/en/moneter/operasi/penjelasan/Contents/Default.aspx
Israel	Liquidity history	Monthly publication of central bank balance sheet items.	Monthly	History only	N/A	Month-end (lagged)	https://www.boi.org.il/en/Markets/DomesticMarketMonetaryTools/Pages/Default.aspx
Japan	AFF	Publication of projection of "Sources of Changes in Current Account Balances at the Bank of Japan and Market Operations," distinguishing "Banknotes" and "Treasury Funds and Others," along with preliminary and final results. (1) Daily projection for the next business day and preliminary results of the current business day in the evening; (2) Monthly projection on the first business day of the month.	Daily / Monthly	Today / 1-month	No	Market close / Month-start	http://www.boj.or.jp/en/statistics/boj/fm/juq/index.htm/
Korea	Liquidity history	Outstanding liquidity instruments.	Weekly	History only	N/A	Week-end	https://www.bok.or.kr/eng/main/content_s.do?menuNo=400027
Mexico	Liquidity forecast	Mexico targets a zero overnight reserve balance, requiring frequent open-market operations. Correspondingly, daily publication of domestic current account balances of banks at opening at Banco de Mexico, expected change in liquidity, programmed daily intervention in the money market settled SD.	Daily	Today	Yes	Market open	https://www.banxico.org.mx/politica-monetaria/operaciones-objetivos-mecanis.html
New Zealand	Liquidity target	Publication of liquidity projections implicitly by publication of target for settlement cash and tender announcements. Internal projection of changes in government account based on information from New Zealand Debt Management Office as well as larger government departments up to a year ahead (July 1–June 30) with monthly, weekly, and daily updates.	Weekly	2-weeks	Yes	Week-end	https://www.rbnz.govt.nz/news/2014/12/latest-reserve-bank-bulletins-released
Norway	Liquidity forecast	Publication of a structural liquidity forecast on the NB website, with updates every Monday and Thursday.	Weekly twice	2-months	No	Mondays / Thursdays	http://www.norges-bank.no/en/Liquidity-and-markets/The-liquidity-management-system/Liquidity-forecast/

Poland	Liquidity conditions	Publication of liquidity conditions; current accounts and standing facilities	Daily	Today	No	Market open	https://www.nbp.pl/homen.aspx?c=/ascx/sytuacja_plynosciowa_en.ascx
		OMO allotment (main and fine-tuning operations) – update after auction					
		Survey of banking sector liquidity for the previous year	Weekly, on Fridays Yearly	7 days and others History	N/A N/A	Market open	https://www.nbp.pl/homen.aspx?f=/dzienne/przetargi_na_bony_en.html https://www.nbp.pl/homen.aspx?f=/en/publikacje/instruments/instruments.html&navid=5508
Romania	Liquidity history	OMO allotments. http://www.norges-bank.no/en/Liquidity-and-markets/The-liquidity-management-system/Liquidity-forecast/	OMO	History only	#N/A	OMO allotment	http://www.bnr.ro/Monetary-Policy-Instruments-3647.aspx
Russia	AFF	Publication of “Forecast of factors affecting banking sector liquidity used to determine the limit on the CBR 1-week auction-based operations,” distinguishing “Change in cash in circulation (outside the CBR),” “Change in general government accounts with the CBR and other items net” besides “Change in required reserve accounts with the CBR.” Realized factors are published daily.	Weekly	1-week	Yes	OMO announcement	http://www.cbr.ru/eng/statistics/default.aspx?prtid=pffl
Serbia	AFF	Publication of weekly (Wednesday to Tuesday) forecast of average autonomous factors. AFR are updated daily.	Weekly	1-week	No	Wednesdays	http://www.nbs.rs/internet/english/33/33_5/likvidnost/index.html
Singapore	Liquidity history	Managed float against a trade-weighted basket of currencies of major trading partners. Monetary operations aim to meet banks’ demand for reserves and settlement balances but not steering domestic interest rates. Publication of MAS balance sheet.	Monthly	History only	#N/A	Month-end (lagged)	https://www.mas.gov.sg/statistics/monthly-statistical-bulletin/money-and-banking
South Africa	Liquidity forecast	Publication of average “Liquidity Estimated For The Week” with the tender announcement.	OMO	1-week	Yes	OMO announcement	https://www.resbank.co.za/Markets/DataAndAuctionResults/Pages/Auctions,-valuations-and-other-information-.aspx
Sweden	Allotment target	Offered emission volume of Riksbank certificates “are calculated with the help of a forecast of the banking system’s liquidity surplus (or previously deficit) for the coming week.” While the projection is not published explicitly, the intended amount is.	Weekly	1-week	Yes	OMO announcement	Sveriges Riksbank (2014), The Riksbank’s operational framework for the implementation of monetary policy – a review, Riksbank Studies, March 2014.
Switzerland	Liquidity history	No projection is published. Publication of “Important monetary policy data,” which currently includes realized sight deposits and minimum reserves.	Weekly	History only	#N/A	Mondays	https://www.snb.ch/en/for/finmkt/operat/mopodata/id/statpub_impdata_hist_1
North Macedonia	Allotment target	Intended amount published with some OMOs and daily liquidity conditions published.	OMO	Matching tender	Yes	OMO announcement	http://www.nbrm.mk/sproviduvanje_na_monietarnata_politika-en.nspix
Turkey	Allotment target	Intended amount published with some OMOs and daily liquidity conditions published.	OMO	Matching tender	Yes	OMO announcement	https://www.tcmb.gov.tr/wps/wcm/connect/EN/TCMB+EN/Main+Menu/Statistics/Markets+Data/
United Kingdom	Liquidity forecast ^{1/}	Publication of the week’s short-term OMO, being the forecast weekly liquidity position adjusted for errors in the previous week’s forecast. After 2009, OMOs were discontinued as well as the OMO liquidity publication.	Weekly	1-week	Yes	OMO announcement	https://www.bankofengland.co.uk/markets
United States	Liquidity history	The FRBNY publishes the factors affecting reserve balances.	Weekly	One week	No	Thursday 4.30 pm	https://www.federalreserve.gov/releases/h41/

AFF	The Treasury publishes with its quarterly refunding announcements a forecast of the end-of-period Treasury cash balance at the FRBNY (TGA).	Quarterly	Quarter	https://home.treasury.gov/news/press-releases/sm808
Liquidity demand	Senior Financial Officer Survey. Question 1 ask 80 banks the lowest level of reserve balances that they would be comfortable holding before they began taking active steps to maintain or increase their reserve balance position.	Semesterly	Today	https://www.federalreserve.gov/data/sfos/sfos.htm

Source: Central Banks.

^{1/} Reference to framework until 2009: