INTERNATIONAL MONETARY FUND

IMF Country Report No. 22/236

UNITED ARAB EMIRATES

TECHNICAL ASSISTANCE REPORT – LIQUIDITY MANAGEMENT AND FORECASTING

July 2022

This Technical Assistance Paper on the United Arab Emirates was prepared by a staff team of the International Monetary Fund. It is based on the information available at the time it was completed in July 2021.

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Price: $18.00 per printed copy

International Monetary Fund
Washington, D.C.

TECHNICAL ASSISTANCE REPORT

UNITED ARAB EMIRATES

Liquidity Management and Forecasting

July 2022

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Contents Page

Figures

Contents Page

Figures (continued)

Contents Page

Figures (continued)

Tables

Contents Page

GLOSSARY

AED	Emirati Dirham
AF	Autonomous Factors
CBUAE	Central Bank of the UAE
CIC	Currency in Circulation
CLIF	Contingent Liquidity Insurance Facility
CSD	Central Securities Depository
DoF	Abu Dhabi Department of Finance
DONIA	Dirham Overnight Index Average
DMS	Debt Management Strategy
DTI	Deposit Taking Institutions
EC	Euroclear
EIBOR	Emirates Interbank Offered Rate
ELA	Emergency Liquidty Assistance
ELAR	Eligible Liquid Assets Ratio
FX	Foreign Exchange
GCC	Gulf Cooperation Council
HQLA	High Quality Liquid Assets
ICD	Islamic Certificate of Deposit
ILF	Intraday Liquidity Facility
IMF	International Monetary Fund
IOER	Interest on Excess Reserves
IORB	US Federal Reserve's Interest on Reserves Balance
ISIN	International Securities Identification Number
LCR	Liquidity Coverage Ratio
M-Bill	Monetary Bill
MCM	Monetary and Capital Markets Department
MoF	United Arab Emirates Federal Ministry of Finance
MoU	Memorandum of Understanding
NFA	Net Foreign Assets
ODF	Overnight Deposit Facility
OLF	Overnight Lending Facility
OMO	Open Market Operations
PD	Primary Dealer
RMP	Reserve Maintenance Period
RR	Reserve Requirements
RTGS	Real Time Gross Settlement
SAB	State Account Balance
SLA	Service Level Agreements
SRR	Statutory Required Reserves
TA	Technical Assistance
T-Bill	Treasury Bill
T-Bond	Treasury Bond

GLOSSARY

UAE	United Arab Emirates
UBF	United Arab Emirates Banking Federation
UIP	Uncovered Interest Rate Parity
USD	United States Dollar

PREFACE

At the request of the Central Bank of the United Arab Emirates (CBUAE), a virtual Monetary and Capital Markets (MCM) Department mission was conducted from June 28 to July 26, 2021, to assist the authorities in strengthening the liquidity management and forecasting frameworks.

The mission met with Wassim Slama (Director of Monetary Policy), Khalifa Alfaheem (Director of Monetary Operations), and Michael Creed (Assistant Director—Monetary Management Framework) as well as other relevant staff from the Monetary Management Department. The mission held meetings with several foreign commercial banks and a state-owned bank. The mission wishes to thank the authorities, in particular Wassim Slama, for their cooperation and productive discussions.

EXECUTIVE SUMMARY

The new Dirham Monetary Framework is largely consistent with an operational framework under a fixed exchange rate regime and capital mobility. In line with previous MCM technical assistance (TA) advice and following extensive consultation with key stakeholders, the CBUAE made good progress in the implementation of the needed reforms. A floor interest rate corridor system was implemented to steer the O/N interbank rate towards the policy rate set at a level consistent with the currency peg. It is complemented by the conduct of open market operations (OMOs) to drain the structural liquidity surplus and support money market development. The CBUAE still needs to strengthen its capacity in identifying and absorbing the volatility that does not represent a fundamental change in the exchange rate equilibrium. This would require the anticipation of the changes in the supply of banks reserves through the forecast of the autonomous factors (AF) and the assessment of the precautionary demand for banks reserves to better calibrate the needed monetary policy instruments to offset the impact on interest rates from non-fundamental liquidity shocks.

The foreign exchange (FX) swap facility should be discontinued once the eligible collateral for the OLF is broadened to include US dollars (USD). The one-way swap facility is currently priced at a lower level than the OLF. Moreover, the current pricing of the various tenors requires from the CBUAE to set the term interest rate differential rather than letting the market price it through a price-discovery auction system. The CBAUE may want to consider paying an interest on the US dollars collateral taking into consideration the returns from the overnight reserves management taking into account the operational cost, and the rates on other alternatives for banks to prevent the usage as an investment vehicle.

Some improvements can be introduced to the structural OMOs. The advantages from the primary dealer arrangements for M-Bills issuances on the development of the secondary market outweigh the potential risks stemming from an increased two-tier banking system but require a tightening of the underwriting obligation. Volumes of monetary bills (M-Bills) should be however calibrated according to the projections of the autonomous factors and allocate it fully. The feasibility of pre-registering and getting the International Securities Identification Number (ISIN) for the M-Bills one quarter ahead should be evaluated to reduce the eight-day window between the collection of the order book and auction. Non-competitive, bilateral operations should be avoided to the extent possible which may require the relaxation of the current 45 percent cap of holdings by a single primary dealer (PD) per issuance line. The calendar of M-Bills should be aligned with the reserve maintenance period (RMP) by allowing the settlement of the M-Bills on the initial day of the RMP to enhance bank's liquidity management.

The CBUAE fine-tuning OMOs should be implemented to manage unexpected liquidity fluctuations during the RMP. They can correct any deviation in the liquidity forecast as well as overbidding/underbidding behaviors which can't be allocated in the interbank market. Fine-tuning OMOs should be carried, whenever deemed necessary, at the end and/or on any day of the RMP**.** The CBUAE may use FX Swaps and Repurchase agreements on AED. If the monetary

coverage rule is not constraining, both auctions should be conducted simultaneously in the same direction through a fixed-volume variable-rate allotment system**.** For FX Swap auctions, the Deposit Takers Institutions (DTI) will bid in terms of forward points for the term of the swap and in terms of interest rates for the Repo auctions. The spot rate for this instrument should be the same as the rate offered in the CBUAE spot facility considering the long leg of the swap. In the case of the Repo transactions all the rates allotted should be in the corridor. Finally, the CBUAE should keep a minimal discretion to reject bids that do not represent the market conditions.

Reserve requirements (RR) in the UAE are mainly a tool for monetary policy and liquidity management purposes but their nonremuneration is acting as an indirect tax on financial intermediation. On one hand, reserve requirements create a minimum demand for local currency reserve and on another hand, complement other monetary tools for calibrating the appropriate level of system liquidity. Reserve averaging provides an additional channel to limit interbank rate volatility and reduce the frequency of OMOs. Given the current largest confidence interval of the autonomous factors' forecasts, optimal reserves requirements should be in the range of AED 55 billion to act as a buffer against autonomous factors' fluctuations, which corresponds approximately to the current seven percent ratio. The extension of the reserve maintenance period to two weeks simplifies liquidity management for banks and could be extended in the medium term up to 28 days. It would be prudent for the CBUAE to reinstate gradually the fulfillment of the RR on FX deposits in USD to avoid the current distortions on financial intermediation and reinforce the prudential objective. The CBUAE should consider remunerating the required reserves after a careful assessment of the balance sheet implications.

The CBUAE should implement the designed state-of-the-art, full-fledged forecasting framework for each of the three main autonomous factors, as well as a reconciliation strategy to forecast the sum of the autonomous factors with an estimation of the confidence interval. The International Monetary Fund (IMF) framework is based on the most recent advances in statistical literature: it tests different families of forecasting models, with an integrated selection of the best performer based on information criteria and out-of-sample performance. It also allows to automatically reparametrize the models to account for structural breaks and new data developments.

The new liquidity forecasting framework provides several important features for liquidity management. First, it goes beyond the projection of currency in circulation and instead allows the CBUAE to use a probabilistic model to forecast the net liquidity injection stemming from the autonomous factors, including the net foreign assets. Second, the framework implements model dynamic selection and model averaging to improve forecasting accuracy and reduce modeling risk. Third, the model automatically estimates the probabilistic confidence interval of the projection at a given tolerance level, which can then be used to calibrate the operations. These features are key to articulate liquidity projection with liquidity management in a consistent and integrated operational approach.

The CBUAE has been recently operating an excessive liquidity surplus, which is detrimental to the activity of the interbank money market and the establishment of a sovereign yield curve. Although the interbank rate has been well anchored to the policy rate over the last years, excessively liquid banks are not trading among each other and instead deposit their excess liquidity at the CBUAE. Consequently, the UAE interbank market turnover has shrunk over the last two years by around two thirds. Insufficient liquidity absorption is also limiting CBUAE's issuance of securities, thereby weakening the estimation of the sovereign yield curve and complicating risk-free pricing.

According to the IMF mission's estimations, the CBUAE should operate a structural liquidity surplus of around AED 50 bn. This estimate derives from a comprehensive econometric model with conditional analysis based on non-linear, instrumented and cross-validated estimator. A series of robustness analysis confirm the result. The CBUAE should reach this level by progressive sterilization and should monitor market reactions along the way.

The CBUAE should calibrate the operational mix between short-term securities issuances, structural operations, and the optimal level of statutory reserves. The team has designed an integrated approach which articulates the CBUAE monetary objectives, market development and liquidity forecasting to determine the optimal combination of each sterilization instrument. This transparent approach offers clear guidance to the policymakers and provides robustness and consistency over-time to the new Dirham monetary framework.

Money markets development is key for enhancing the transmission of monetary policy. The transition from the Emirates Interbank Offered Rate (EIBOR) to the Dirham Overnight Index Average (DONIA) benchmark is advisable mainly for the overnight market and the calculation of DONIA should integrate bank borrowing from a wide range of non-bank wholesale counterparties. The M-Bills secondary market has started to develop but still faces problems of liquidity and deepness. The PDs program can be further adapted to encourage a greater activity in the secondary market. The CBUAE should try to allocate higher amounts in the long term M-Bills as well as re-tranch them to increase the amount outstanding that may promote more transactions in the secondary market. The FX Swap market is the most developed and would greatly benefit from a common agreement on market conventions for pricing of FX SWAP and tracking the implicit AED rate derived from FX SWAP points, in addition to the adoption of the FX market global code of conduct. The onshore repurchase agreements (Repo) market is at its infancy stage. The development of a risk-free yield curve in AED jointly between the CBUAE and the Ministry of Finance (MoF) should be pursued as a building block for the secondary markets. More disclosures are needed to enhance the price discovery mechanism in the secondary markets.

In the medium term, the CBUAE should estimate the interest rate pass-through to assess the channels of monetary policy transmission. It should collect the average monthly rates applied on various categories of deposits and loans on a bank-by-bank basis and compile a weighted average monthly rate for each category for all the banking system.

Table 1. United Arab Emirates: Key Recommendations

Recommendation	Agency	Timeframe[1]
Operational Framework		
Allocate the M-Bills fully in line with the calibration exercise.	CBUAE	NT
Evaluate the feasibility to pre-registry and get the ISIN for the M-Bills that will auction one quarter ahead.	CBUAE	NT
Discontinue practice to use bilaterally negotiated operations or non-competitive auctions. Consider a relaxation of the 45 percent cap on a single PD holdings per issuance and a tightening of the underwriting obligation. Consider increasing the issuance of the three-month M-Bills.	CBUAE	NT
Alignment of the Calendar of M-Bills with RMP allowing the settlement of the M-Bills on the initial day of the RMP.	CBUAE	NT
Discontinuation of the FX Swap Facility and Acceptance of US dollars as collateral for OLF. Consider remuneration of US collateral.	CBUAE	NT
The CBUAE should carry out fine-tuning OMOs at the end and/or on any day of the RMP as deemed necessary: • The CBUAE should conduct FX swaps and Repurchase agreements (Repo) on AED simultaneously. • The CBUAE auction mechanism for these operations should have transparency and consistency. • In the CBUAE FX Swap auctions, the DTIs will bid in terms of forward points for the term of the swap an in terms of interest rates for the Repo auctions.	CBUAE	NT
Settle all fine-tuning OMOs instruments for value T+0.	CBUAE	NT
Reserves Requirements		
Calibrate the required reserves to create a buffer to absorb the CBUAE autonomous factors forecasting errors. Currently, this translates into an unchanged ratio of 7 percent.	CBUAE	NT
Reinstate gradually the fulfillment of the RR on FX deposits in USD starting with a specified fraction of the FX liabilities.	CBUAE	MT
Extend the reserve maintenance period up to 28 days.	CBUAE	MT

[1] Near term: < 12 months; Medium term: 12 to 24 months.

Recommendation	Agency	Timeframe
Remunerate the required reserves after a careful assessment of the balance sheet implications.	CBUAE	MT
Liquidity Forecasting		
Forecast all the autonomous factors separately, as well as the net liquidity injection, using the forecasting framework designed by the IMF. In particular, model dynamic selection and averaging should be used to improve the forecasting accuracy and reduce the modeling risk. Use the model to generate the probabilistic confidence interval for net liquidity injection.	CBUAE	NT
Staff a analytical section of modelers and econometricians to estimate and fine-tune the liquidity forecasting framework, and analyze market developments. The team could also refine the calibration of the instruments (see below).	CBUAE	NT
Implement a robust analytical and data management framework to support the operations, with comprehensive daily data analyzed through statistical software (more details in Annex VII).	CBUAE	NT
Enhance the forecasts by incorporating expert jugdement and granular knowledge of the CBUAE experts.	CBUAE	NT
Publish both the whole liquidity forecast and associated methodology to help anchoring market expectations and support liquidity management for market participants.	CBUAE	NT
Operationalize a MoU with the Federal MoF and other Departments of Finance (DoFs) to share information about the Treasuries future cash-flows.	CBUAE & UAE MOF	NT
The Federal and local Treasuries should operate a Treasury Single Account to consistently manage its cash flows and simplify the CBUAE liquidity management. Remuneration and fees terms of Federal and local treasuries accounts at the CBUAE should be set.	CBUAE & UAE MOF	NT
Calibration of the Monetary Operations		
Operate a liquidity surplus at around AED 50 bn. The adjustment towards the optimal level should proceed gradually, with a close market monitoring and should be adjusted if necessary.	CBUAE	NT
Calibrate the structural issuances based on a filtering approach to guarantee both stable and large enough issuances of securities.	CBUAE	NT
Closely monitor market developments, using the tools presented in this TA report, and staff the market surveillance team with quantitative researchers.	CBUAE	NT

Recommendation	Agency	Timeframe
Assess and project the monetary policy costs of the monetary framework.	CBUAE	NT
Markets Development		
Transition from the EIBOR to the DONIA benchmark for the overnight market and Integrate in the DONIA calculation bank borrowing from a wide range of non-bank wholesale counterparties.	CBUAE	MT
As derivative-markets linked to the new benchmark develop, forward-looking term rates could be constructed.	CBUAE	LT
Adapt the PDs program and allocate higher amounts for long terms M-Bills as well as re-tranch them to promote more transactions in the secondary market.	CBUAE	MT
Set market conventions for pricing of FX SWAP and track the implicit AED rate derived from FX SWAP points.	CBUAE	ST
Adopt FX market global code of conduct.	CBUAE	MT
The development of a risk-free yield curve in AED jointly between the CBUAE and the Federal MoF should be pursued as a building block for the secondary markets.	CBUAE	MT
More disclosures are needed to enhance the price discovery mechanism in the secondary markets.	CBUAE	MT
Monetary Policy Transmission		
Collect the average monthly rates applied on various categories of deposits and loans on a bank-by-bank basis and compile a weighted average monthly rate for each category.	CBUAE	MT
Assess the interest rate pass-through from the Base Rate to DONIA and then to short term banks rates.	CBUAE	MT

I. INTRODUCTION

1. The CBUAE operates a conventional peg to the US dollar under an open capital account. Over the course of 2020/2021, key reforms to the operational framework have been introduced. The CBUAE endorsed a new floor-rate corridor system in order to: (i) align the domestic money market interest rate with prevailing US levels in support of the peg arrangement; (ii) improve the CBUAE's capacity to manage liquidity and support money market development and collateralization; and (iii) create incentives for banks to proactively manage their day-to-day liquidity stance. Hence, the signaling of the stance of the CBUAE's monetary policy is now made through the interest rate applied on the new overnight standing deposit facility (ODF) and this Base Rate has been anchored on the US Federal Reserve's Interest on Reserves Balance (IORB) since July 29, 2021.[2]

2. The transition to the new operational framework has been smooth and well received by market participants. A thorough implementation plan has been prepared by the Monetary Management Department of the CBUAE in consultation with key external stakeholders. The implementation has been largely consistent with the thrust of recommendations provided in the 2017 and 2018 MCM's technical assistance missions (see Annex I). Banks operating in the UAE indicated that they are comfortable with the new monetary policy framework and its transition.

3. The new operational framework is largely consistent with a monetary policy framework under a fixed exchange rate regime and capital mobility. While, in theory, capital flows alone could manage domestic liquidity and stabilize short-term rates at the right level, short-term rate volatility could arise in the absence of the CBUAE intervention in the domestic market. The friction costs between the local and international money market, counterparty risk perception in the domestic market, and prudential liquidity regulations are the main drivers behind short-term rates volatility. Therefore, the specific challenges of the CBUAE's liquidity management are to: (i) identify fundamental changes in the exchange rate equilibrium without absorbing them; and (ii) identify and absorb the volatility that does not represent a fundamental change in the exchange rate equilibrium. The former entails the determination of the changes in the risk premium and the assertion of frictions costs by looking at whether capital flows respond promptly to fundamental adjustments. The latter would require: (i) the assessment of the precautionary demand for banks reserves; (ii) the anticipation of the changes in the supply of banks reserves; and (iii) the determination of the instruments needed to *offset* the impact on interest rates from non-fundamental liquidity shocks.

4. In response to a request from the CBUAE, a virtual TA mission was conducted during June 28–July 26, 2021, to support the authorities in further strengthening their liquidity management and forecasting frameworks. The mission reviewed the newly-introduced monetary policy implementation framework and assisted in: (i) the design and calibration of various monetary instruments for fine-tuning liquidity management; (ii) the

[2] It was previously anchored on the US Federal Reserve's Interest on Excess Reserves (IOER).

forecasting of the demand for banks reserves and the profile of the reserves requirements' constitution within the maintenance period; and (iii) the forecasting of the autonomous factors of the supply of banks reserves.

5. The remainder of this report is arranged as follows: Section I describes the objectives and features of the new operational framework and suggests some recommendations. Section II discusses the liquidity forecasting framework. Section III discusses the calibration of the monetary policy instruments. Section IV discusses the status of the money markets' development. Section V briefly discusses the assessment of the interest rate channel for monetary policy transmission.

II. Operational Framework

A. Objectives

6. The main objective of the new framework is to steer the overnight (O/N) interbank rate towards the policy rate (base rate) set at a level consistent with the currency peg. To achieve its operational target, the CBUAE implemented a floor interest rate corridor system with excess reserves, placed at the Overnight Deposit Facility (ODF), remunerated at the base rase. The choice of the floor system was driven by its capacity to provide a stable anchor to interbank rates without requiring accurate liquidity forecasting of the autonomous factors, given the high volatility of the Net Foreign Assets. Following previous IMF TA advice,[3] the CBUAE has set the level of the base rate in line with the US Federal Reserve's Interest on Excess Reserves (IOER) rate since July 12, 2020.[4] This alignment is based on the Uncovered Interest Rate Parity (UIP). Currently, the Base Rate is higher that the Fed Fund rates, implying the existence of a small risk premium to balance FX flows in support of the peg.

7. As a secondary objective, the CBUAE aims to promote market development, increasing incentives for banks to manage liquidity more actively. The floor system has been complemented by a regular program of central bank M-Bill's issuances to support the primary and secondary money market development. The operational framework requires from banks an active allocation of their reserves across the different instruments as well as an estimation of their precautionary unremunerated reserves.

8. Financial stability considerations have remained a subsidiary objective. The CBUAE designed a Contingent Liquidity Insurance Facility (CLIF) to provide liquidity for potentially a

[3] Please see the previous 2018 TA report on "Bank Liquidity Risk Management and Liquidity Forecasting" and the 2019 TA report on "Developing Monetary Policy Operations and The Local Currency Government Bond Market," for a discussion on the merits of the new implementation framework.

[4] The adjustment of the base rate is carried the next day following the US Federal Reserve Board's announcement. See CBUAE Raises the Base Rate by 5 Basis Points.

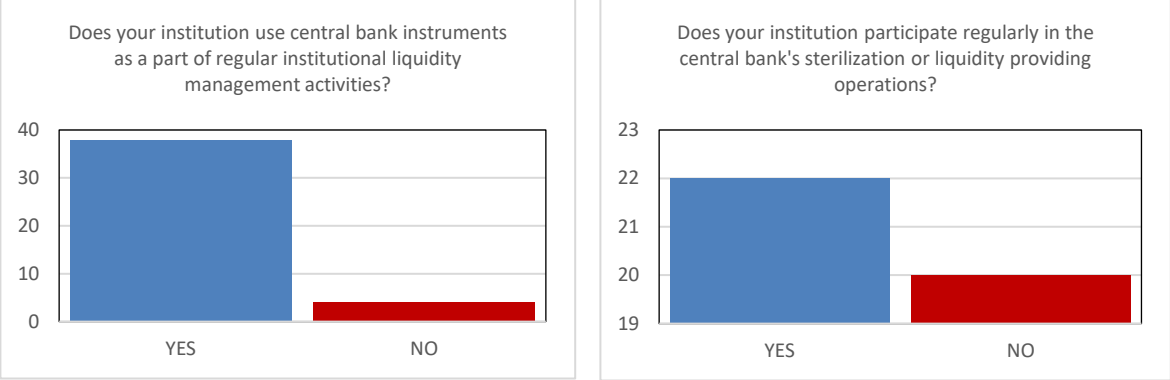
long maturity during stress that could be idiosyncratic or market wide. This facility is collateralized with broader range of collateral including foreign sovereign, corporate and banks bonds. Depending on the level of stress the liquidity would be provided by uniform priced auctions or bilaterally to all DTI. The CLIF is scheduled to be activated by end of 2021.

9. Other objectives have been pursued to contain the repercussions of the COVID-19 pandemic without endangering the stability of the peg. A Targeted Economic Support Scheme (TESS), offering payments holiday to banks customers, has been put in place to ease stress in the short-term funding markets while supporting economic growth during the COVID-19 pandemic.[5] The allocated AED 257 billion volume was set in line with the monetary base coverage rule.[6] The take-up for this facility was about 37 percent which led the CBUAE to extend the deferrals of payments to end of December 31, 2021, and those related to working capital loans to June 30, 2022.

B. Features of the Operational Framework

10. The key features of the new monetary policy implementation framework include the following four pillars: standing facilities, OMOs, liquidity insurance, and reserve requirements. Most of the banks have indicated that they have been using the CBUAE instruments as part of their liquidity management activities and are participating regularly in the OMOs (Figure 1).

Figure 1. Banks' Usage of CBUAE Instruments



Source: IMF Mission Banks' Survey

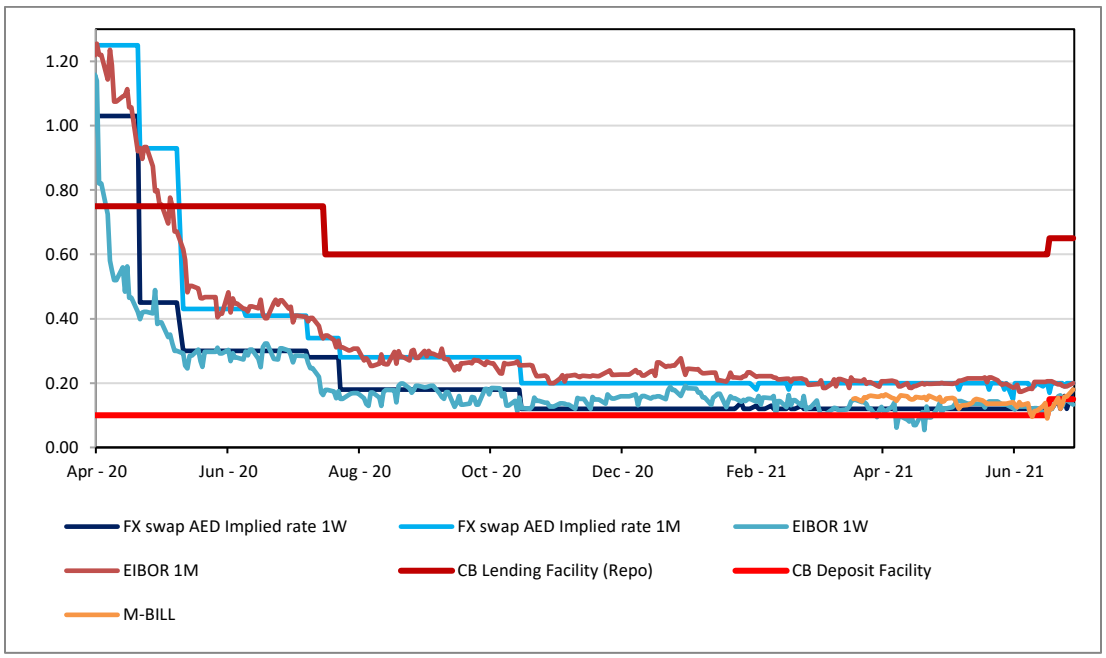
[5] For further information about the TESS, see here and here.

[6] By law, the market value of balance of the Foreign Reserves shall not, at any time, be less than 70 percent of the value of the Monetary Base. The latter is defined as per the following: (i) Issued Currency; (ii) Aggregate balances of current accounts of Licensed Financial Institutions with the CBUAE, including the Reserve Requirements, in addition to any other funds deposited with the CBUAE for the purpose of clearing and settlement operations; and (iii) the outstanding balance of securities and financial instruments issued by the CBUAE.

Standing Facilities

11. The interest rate corridor is bounded by two standing facilities (Figure 2). A third Intraday Liquidity Facility (ILF) has been also introduced. The width of the corridor was initially set at 100 bps and was subsequently reduced to 50 bps on January 11, 2021 (date of the launching of M-Bills).

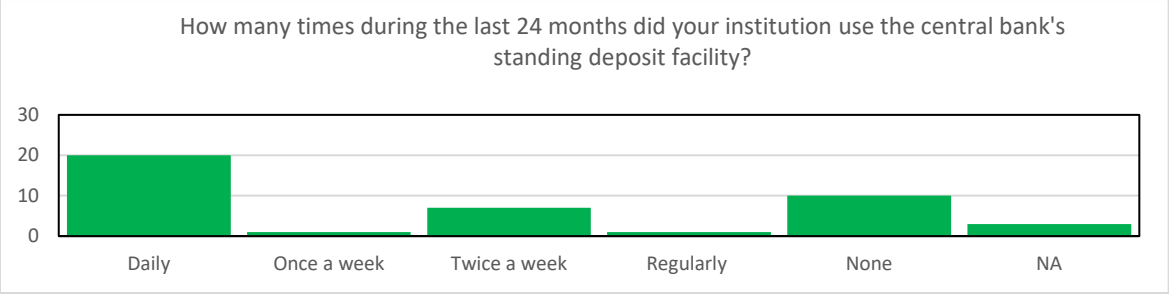
Figure 2. Key Short-term Interest Rates in the UAE (in percent)



Source: CBUAE and IMF staff

- **The ODF, introduced on July 12, 2020, sets the floor rate for overnight money market rates signaling the monetary policy stance.** The rate applied to the ODF is the main policy rate (base rate) was initially anchored on the IOER and was then aligned to the IORB since July 29, 2021. This facility has been well accepted by the market participants and most banks used daily (Figure 3).

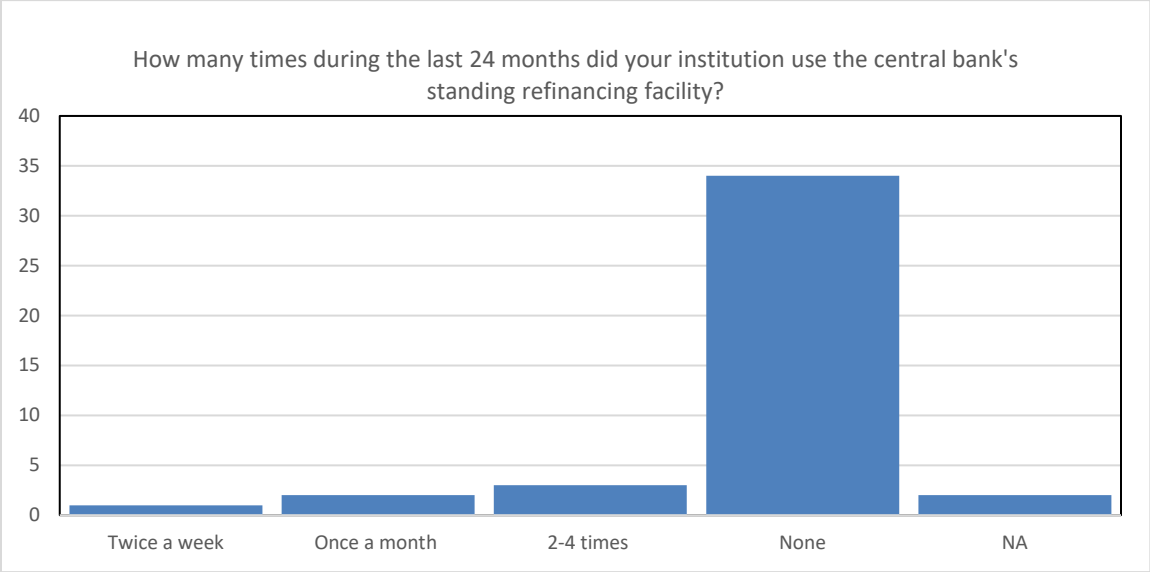
Figure 3. Banks' Usage of the ODF



Source: IMF Mission Banks' Survey

- **The Overnight Lending Facility (OLF)/Collateralized Murabaha Facility sets the ceiling for short-term money markets rates.** The OLF and REPO facility have been consolidated into a single overnight lending facility. Since the banking system in the UAE continues to be in a structural excess liquidity, only few banks have been using the OLF. The eligible collateral for OLF could be Monetary Bills (M-Bills)/Islamic CDs issued by CBUAE or T-Bills issued by UAE Federal or Local governments, USD currency, and UAE and Foreign Securities rated with a minimum AA rating.

Figure 4. Banks' Usage of the OLF



Source: IMF Mission Banks' Survey

- **The ILF** provides collateralized intraday liquidity at zero cost that allow banks to manage unforeseen payments disruptions or gridlocks, avoiding delays in payment submission and settlement. The collateral for ILF could be Monetary Bills (M-Bills)/Islamic CDs issued by CBUAE or T-Bills issued by federal or local governments.

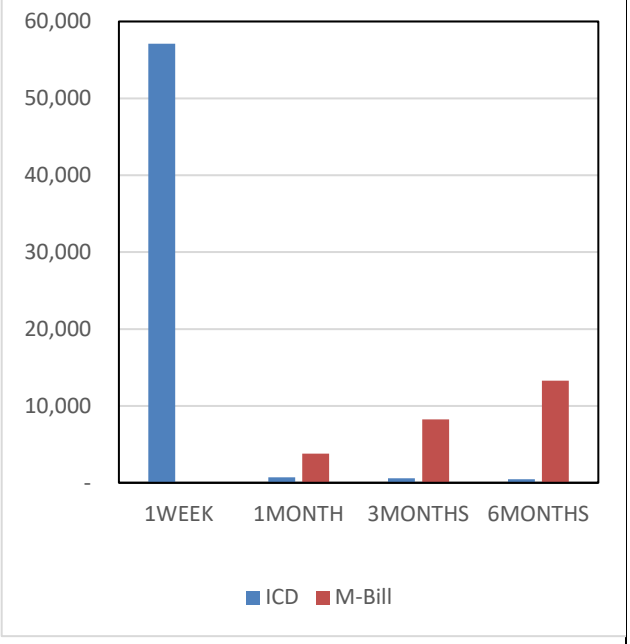
Open Market Operations

12. The structural OMOs play an important role in the implementation of the monetary policy framework draining the structural surplus of liquidity and smoothing short-term liquidity imbalances that may influence the interest rates. The CBUAE has launched a new tradable securities issuance program (M-Bills) in replacement of the Certificate of Deposits. It announced an issuance calendar with the dates and the tenors of M-Bills that will be allocated through auctions for primary dealers (PDs).[7] The CBUAE will continue running the Islamic CDs

[7] The weighted average yield on M-Bills across all tenors is 0.16 percent and a duration of 47 days.

program,[8] until the launch of the Islamic M-Bill. The CBUAE is working on the development of the Islamic M-Bill that may have an environmental, social and governance (ESG) framework, and it is expected to be released in a couple of years according to the conversations with the CBUAE. The CBUAE is replacing a percentage of the CD that mature with issuance of M-Bills. Currently the CBUAE performs a market intelligence with the dealers eight days before the auction to estimate the potential demand; based on this estimation it allotted a percentage below 100 percent to promote competition in the auction (Figure 6). In addition, the CBUAE may conduct buy-backs or repurchase operation for liquidity provision.

Figure 5. ICD and M-Bills Allottments per Tenor, June 2021



Source: CBUAE and IMF staff

Figure 6. Percentage Allotted in the M-Bills Auctions

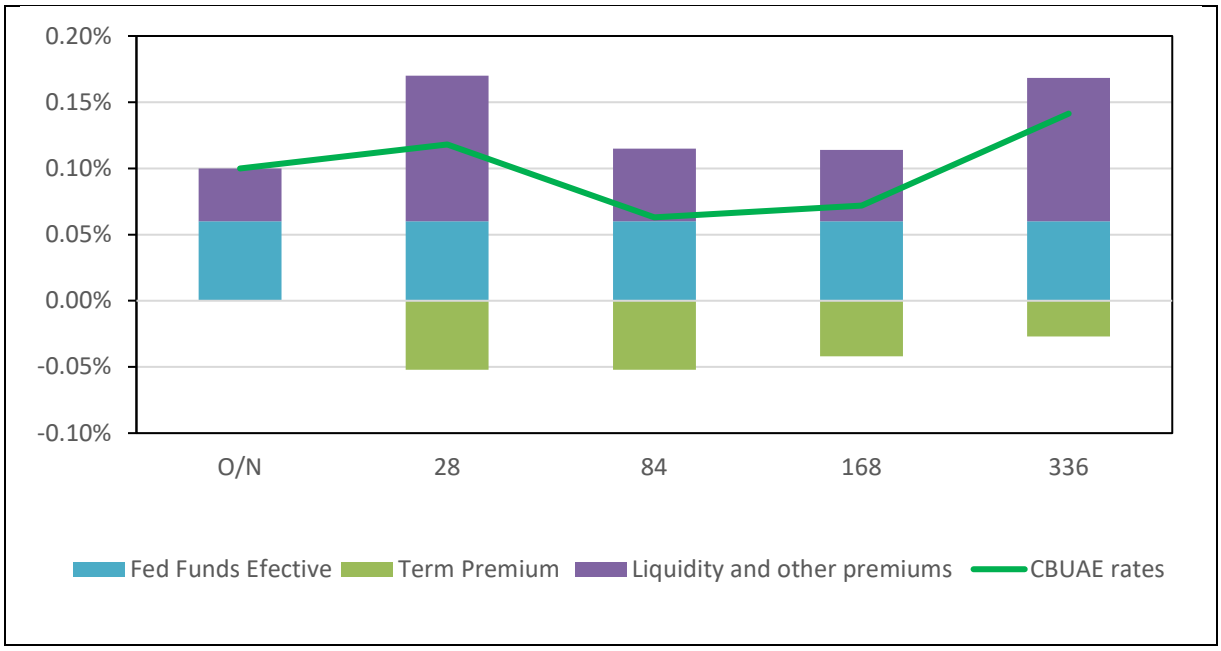
	168 days	28 days	336 days	84 days
1/11/21	75%	68%		99%
1/25/21	68%	94%		74%
2/ 8/21	48%	65%		73%
2/22/21	100%	53%		98%
3/ 8/21	60%			50%
3/22/21	66%	85%		87%
4/ 5/21	0%		0%	0%
4/19/21	51%	70%	85%	56%
5/ 3/21	55%		50%	71%
5/17/21	85%	61%	77%	61%
5/31/21	48%		87%	50%
6/14/21	53%	62%	52%	70%
6/16/21	93%		98%	
6/28/21	60%		54%	68%

Source: CBUAE and IMF staff

13. The flattening of the M-Bill curve is an indication of an excess liquidity beyond the optimal liquidity surplus in the system. The decomposition of the M-Bill primary yield curve gives an indication of the term, liquidity, and other premiums in the UAE market. In this case the flattening of the curve implies that banks are less risk averse in their search of yield.

[8] Islamic CDs duration is only 18 days and the weighted average YTM is 0.13 percent. The lower profits payed are attributed to the compliance costs.

Figure 7. CBUAE's M-Bill Yield Curve Decomposition as of June 14, 2021 (in percent)



Source: CBUAE and IMF staff

Note: The M-Bill rate is descomposed in the risk free rate (effective fed funds rates), the term premium for tenor t that is the difference between the US T-Bill for tenor t and the risk free rate, and finally the liquidity and other premiums are the difference of the M-Bill rate for the tenor t minus the risk free rate and the term premium for tenor t. If the tenor of the M-Bill and the US T-Bill does not match the US T-Bill rates are interpolated to get a proxy for the tenor needed.

14. The CBUAE fine-tuning OMOs will be used to manage unexpected liquidity fluctuations that can increase the volatility of domestic money market interest rates. So far, fine-tuning operations have not been conducted as accurate liquidity forecasts are not yet available. Once these would be available, the purpose of these operations is to ensure that there is an appropriate amount of liquidity in the banking system correcting any deviation in the liquidity forecast that can take place during the RMP. Fine-tuning OMOs will also adjust for Banks' overbidding or underbidding behaviors which cannot be reallocated in the interbank market. The CBUAE may use the following operations according to the market conditions and with high degree of flexibility: (i) repurchase transactions at different tenors; and (ii) matched transactions of securities and FX transactions including FX swaps. Appendix I describes the CBUAE's proposed framework.

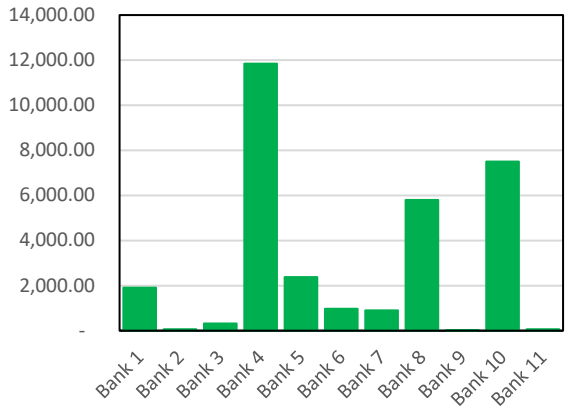
FX Swap Facility

15. FX Swap Facility was introduced by the CBUAE during the 2008–2009 financial crisis to provide liquidity to the Deposit Takers Institutions (DTIs) from seven days up to 12 months. It has been used during stress periods in the financial markets. Recently only three banks are capturing 80 percent of the facility's volume. It is perceived by the DTIs as useful

since it puts a cap for the FX Swap market especially in stress times such as during the COVID-19 turmoil in 2020. It is important to highlight the FX Swap market implied rates,[9] which are used as reference to quote other instruments such as M-Bills.

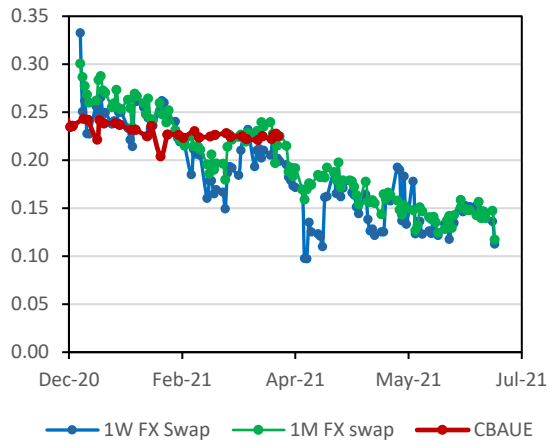
16. In the next phase, the CBUAE FX swap facility will be absorbed by the OLF in which the banks can get liquidity using US dollars as collateral. This operation will be equivalent to a synthetic overnight FX swap, settled at T+0. On average during 2021, the implied rate in the FX swap facility was around 22 bps that is lower than the OLF rate which could disincentivize the use of the OLF.

Figure 8. FX Swap Facility: Amount Alloted in Million Dollars by Bank (2020–21)



Source: CBUAE

Figure 9. CBUAE FX Swap Facility AED Implied Rate



Source: IMF Mission Calculations

Reserve Requirements

17. The CBUAE imposes reserve requirements on all deposit-taking licensed financial institutions.[10] The deposit base also includes government deposits. The RR ratio is lower for time deposits (1 percent) than for demand deposits (7 percent). To prevent distortions, the same RR ratio as on local currency deposits applies to foreign currency deposits which account for around 30 percent of total deposits (see Figure 10, upper left panel).

18. The penalty for non-compliance is significant. Banks face a penalty rate of the CBUAE's base rate plus 400 bp on any shortfall in required reserve—well above the lending facility. The penalty incentivizes a conservative reserve management by banks.

[9] Implied rates are calculated assuming 3.6730 in the Spot and Libor as a USD rate.

[10] For a detailed discussion on the purpose of the reserve requirement in the UAE, please see Appendix V.

19. The reserve requirements saw three important changes in 2020:

- *Lower RR ratio:* As part of the COVID-19 measures, the CBUAE lowered the required reserve ratio on demand deposits from 14 percent to 7 percent on April 5, 2020. The RR ratio remained at 1 percent for time deposits.

- *Introduction of the ODF:* Since July 12, 2020, banks have the option to hold excess reserves in the ODF which is remunerated at the IOER.

- *Extension of the reserve maintenance period:* Within the reform of the monetary framework, the CBUAE has extended the reserve maintenance period from 7 to 14 days starting on a Wednesday and ending on a Tuesday (effective October 28, 2020). Full reserve averaging is allowed over the reserve maintenance period, aiming to simplify liquidity management.

- *Fulfillment of the FX reserve requirement in Dirham:* With the introduction of the new monetary policy framework, the fulfillment currency for the reserve requirements has changed to dirham for both local and foreign currency required reserves.

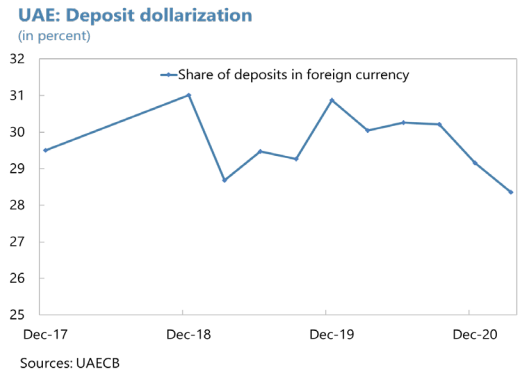
20. Required Reserves are unremunerated, but the recent introduction of the ODF offers remuneration on excess reserves at the IOER. Under the new system, banks manage their reserves at the CBUAE between two accounts—the Reserve Account and the ODF. Only reserves held overnight in the ODF are remunerated whereas only those in the Reserve Account count towards fulfilling the RR. Banks choose how much to transfer to the ODF by 8:00 pm each day, one hour before the closing of the payment system. Nevertheless, the transfer to the ODF is usually a bank's last transaction of the day as liquidity needs for payments are limited at this time of the day.

21. Banks take a conservative approach to meeting the RR and generally hold ample reserves. The overall level of reserves far exceeds the requirement and remains stable over the maintenance period. Bank-level data since the extended RMP does show neither front nor back-loading of reserve fulfillments. However, many banks do not shift funds into the ODF on Saturdays as trading desks are closed that day, over-fulling the RR which allows them to move more funds into the ODF on weekdays. Figure 10, lower right panel, highlights the fulfillment pattern across the maintenance period.

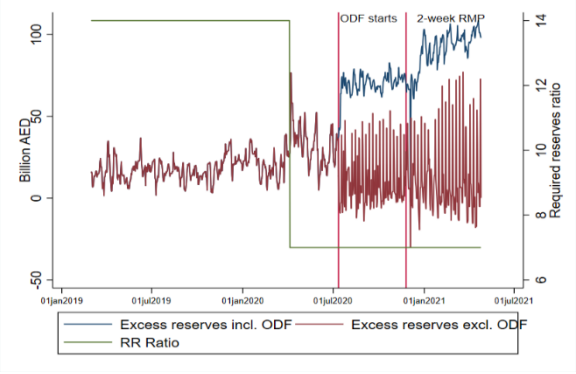
22. The distribution of reserves reflects the heterogeneity of the UAE's banking system. A few large banks, especially First Abu Dhabi Bank, naturally also play an outsized role in the reserve distribution due to their size. Some smaller banks on the other side, do not appear to manage their reserves very actively on a day-to-day basis, often maintaining large amounts on the reserve account forgoing the remuneration on excess reserves to be obtained in the ODF. Equally, the reserve position varies widely across banks with some banks facing tighter liquidity despite the overall surplus.

Figure 10. Reserve Requirements in the UAE

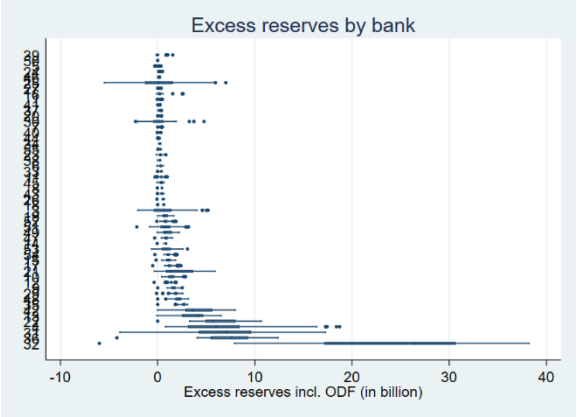
Deposit dollarization hovers around 30 percent.



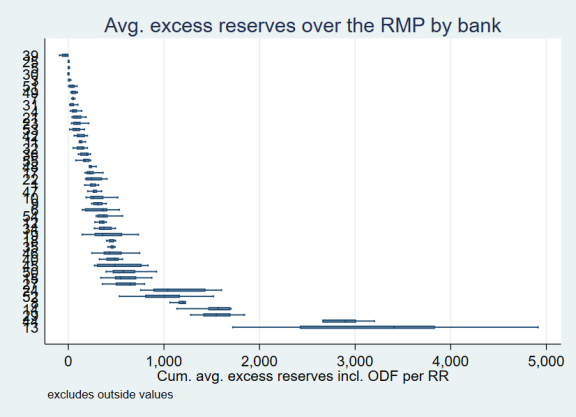
2020 saw important changes to the reserves requirements.



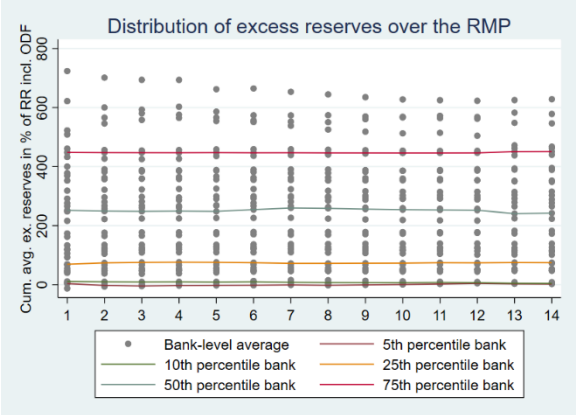
Distribution of excess reserves across is skewed—a few key players and many small banks…



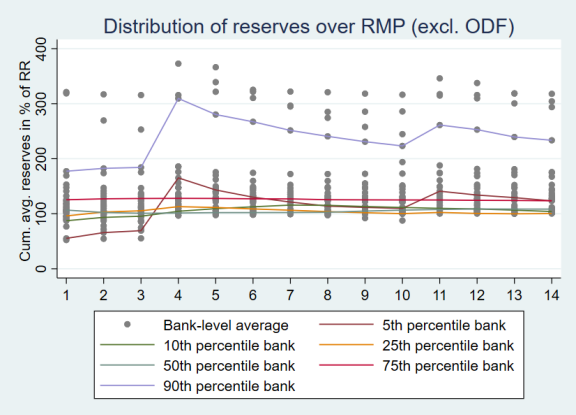
… and the level of excess liquidity also varies substantially across banks.



Excess reserves including funds held at the ODF remain broadly constant over the maintenance period…



… banks shift out of the ODF on Saturdays.



Source: CBUAE and IMF Mission Calculation

C. Recommendations

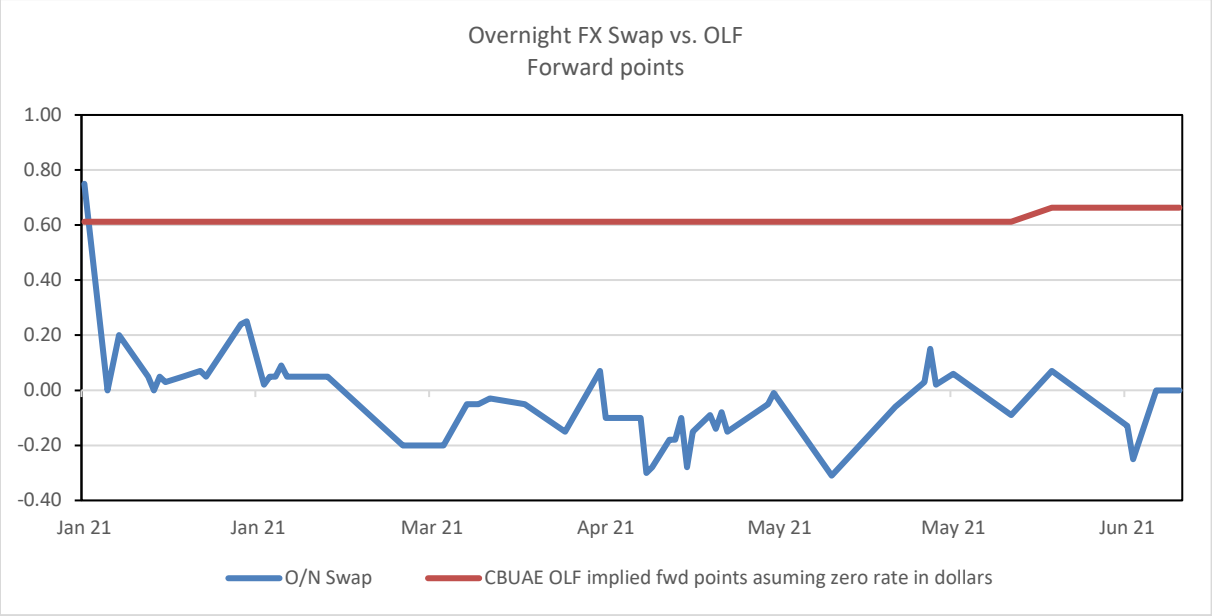
OLF and FX SWAP Facility

23. The mission supports the decision to discontinue the FX Swap Facility. The current one-way SWAP facility is priced at a lower level than the OLF which can create distortions since liquidity provision for the O/N tenor is being priced differently (see Figure 11). Moreover, the pricing of the FX SWAP for the remaining tenors requires from the CBUAE to set the term interest rate differential rather than letting the market price it through the conduct of a price-discovery auction system. In the interim period, the SWAP facility shall remain as a liquidity-provision tool. The CBUAE should announce to the market at least three months before the discontinuation of this facility and once the OLF accept dollars as collateral.

24. The eligible collateral for the OLF should be broadened to include US dollars. Some operating banks in the UAE have long positions in USD and may be at times short in Dirham. The CBAUE may pay an interest for this type of collateral taking these into consideration:

- The rates at which the CBAUE may invest these amounts overnight minus the adequate basis points to compensate the CBAUE for the related operational cost.
- The total rate will be lower than other alternatives for DTIs to prevent the use of this facility as an USD investment vehicle.

Figure 11. Overnight FX Swap versus OLF Forward Points (in basis points)



Source: CBUAE and IMF Mission Calculation

Structural OMOs

25. The mission recommends improving M-bills auctions by:

- Announcing the volume of M-Bills to be auctioned ahead according to the projections of the autonomous factors and allocate it fully,[11] without surprising the market. A minimal discretion to reject an out-of-market bid can be retained. However, this should be set through an internal rule without being disclosed to the public. The mission suggests to reject the bids which fall beyond the thresholds defined by the last price or mid price before the auction plus or minus (depending if they are draining or injecting liquidity) the bid-ask average plus two standard deviation divided by 2.

- Evaluating the feasibility of pre-registering and getting the ISIN for the M-Bills one quarter ahead to reduce the eight-day window between the collection of the order book and auction. Currently, the CBUAE monitors the size of the order book eight days before the auction which can alter the quality of the estimations, especially regarding those of the PD's clients. This piece of information will remain relevant and will need to be cross-checked with the liquidity forecasts.

- Avoiding non-competitive, bilateral operations to the extent possible in order to avoid moral hazard and the undermining of price-setting in the primary auctions. A relaxation of the current 45 percent cap of holdings by a single PD per issuance line should be considered to better reflect the skewedness of liquidity holdings across PDs. Such a relaxation should be conditional on inventories or past market-making activities to properly align incentives.

- Aligning the calendar of M-Bills/ICDs with RMP by allowing the settlement of the M-Bills/ICDs on the initial day of the RMP (see Figure 12).[12]

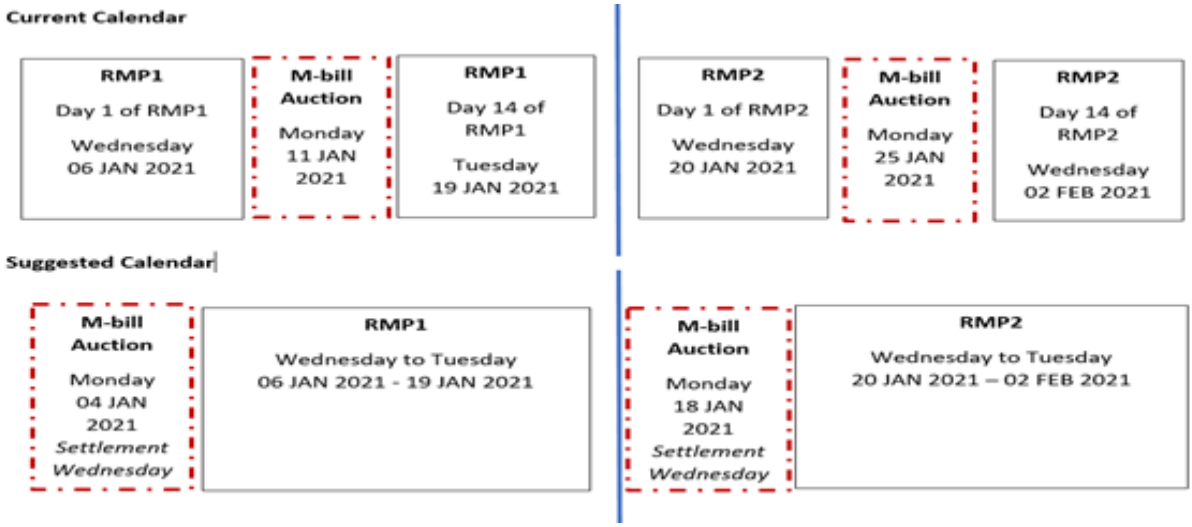
- Continuing the reoffering of auctioned M-Bills as these operations increase their liquidity in particular for M-Bills with longer tenors (please refer to paragaph 142) .

- Consider increasing the issuance of the three-month tenor M-Bills specifically as it creates an important money market benchmark that also falls within the HQLA classification of many banks, including the current Basel III prudential liquidity requirements.

[11] Please refer to section III on calibration of the monetary operations

[12] Until the one-week ICDs have been phased out and replaced by an Islamic ODF, these can still be offered on demand.

Figure 12. Current and Suggested Calendar for M-Bills Auction Within Two Consecutive RMPs



Source: CBUAE and IMF Mission

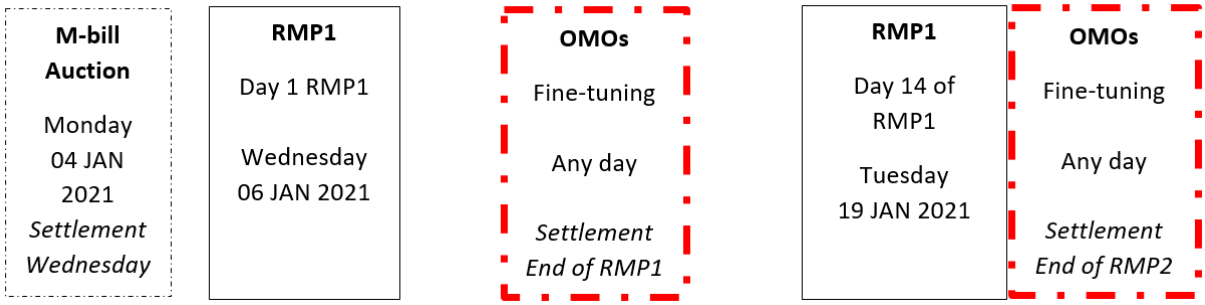
26. The mission recommends maintaining the primary dealer arrangement subject to a tightening of the underwriting obligation. Although this is not a common practice for central bank securities, the benefit of a primary dealers' program is the development of the secondary market through the obligation of making a two-way quotation. Currently, PDs do not seem to add any markup on their clients' bids in the primary market Nevertheless, to address the potential risks stemming from an increased two-tier banking system, the underwriting obligation should be made further explicit, for example, by specifying a certain percentage for secondary market operations. The mission welcomes also the planned assessment of the performance of each PD after the inaugural year and suggests covering the difference between the secondary and primary quotes as well as the bid-ask spread of secondary market operations among the assessment criteria.

Fine-Tuning OMOs

27. The mission recommends carrying fine-tuning OMOs at the end of the RMP and/or on any day of the RMP,[13] whenever deemed necessary (Figure 13). Fine-tuning operations should take place at the opening of the market and the announcement could be done in the afternoon of the previous day in order to allow DTIs to estimate their needs properly. Once banks have gained some operational experience and improved their internal liquidity forecasting process, fine-tuning operations could be announced couple of hours before execution (see Appendix III). The transactions should settle on the same day in order to have an immediate traction on the interbank rates.

[13] The mission advises against the conduct of too-often fine-tuning operations in the early stages of the implementation of the new liquidity forecasting and management framework, as several attempts to correct the liquidity surplus in the system within a specific RMP can be counter-productive.

Figure 13. Suggested Calendar for Fine-Tuning Auctions



Source: IMF Mission

28. The CBUAE may use FX swaps and Repurchase agreements (Repo) on AED to conduct fine-tuning operations. Several central banks use these instruments for liquidity management (see Appendix III for details). The following considerations should prevail:

- The monetary base coverage rule by foreign reserves should be the primary guide for the choice between FX swap and repo market fine-tuning operations. Repo operations would expand the CBUAE balance sheet while the FX swap would be recorded off balance sheet.

- If this rule is not constraining, the CBUAE should conduct FX swap and repo market auctions simultaneously with tenors up to 14 days for the FX swap and repo transactions. Both auctions should be in the same direction (absorption or injection).

- After deciding on the amount of liquidity to inject or withdraw from the system and the tenors, the CBUAE should distribute the allocation according to the received bids. At the time of the mission, the operations in the repo market were very scares and the CBUAE may encourage the use of repo transactions to develop this important market building block.

- The auction mechanism for these operations should be transparent and consistent to maximize participation, ensure efficient allocation and promote price discovery. Multiple price auctions generally work better and are more popular in practice. They are more robust to collusion and misinterpretation risks that are more prevalent in developing or less competitive markets, and in practice are very unlikely to generate a spread in prices that would be a cause for concern. On the other hand, single price auctions theoretically reduce the "winner's curse" and increase the incentive to bid competitively but may have serious drawbacks with increased incentives to collude.

- The CBUAE has developped a framework that provides significant transparency to the market and should continue for the case of the auctions for FX swaps and Repurchase agreements as ex-ante and ex-post transparency are essential. Ex-ante transparency

implies the publication of auction rules and access criteria, procedures for the refusal of bids and the size, timing and composition of operations is important to foster an environment that encourages maximum consistent participation from all eligible parties. It is also important in ensuring the results of the operation are accepted by the market as reflective of market conditions. Ex-post transparency includes the publication of the results that include some granular information that could be a reference for market participants for price discovery in underdeveloped financial markets (see Appendix III).

- In the case of CBUAE FX Swap auctions the DTIs will bid in terms of forward points for the term of the swap and in terms of interest rates for the repo auctions. The spot rate for this instrument should be the same as the rate offered in the CBUAE spot facility considering the long leg of the swap. In the case of the Repo transactions all the rates allotted should be in the corridor. Finally, the CBUAE should keep the discretionary right to reject bids that do not represent the market conditions. The main terms of these instruments are provided in Table 2.

Table 2. United Arab Emirates: OMO Instruments

	Structural OMO	Regular Fine-tuning OMO Instruments	
	M-Bill Issuances	Repo	FX swaps
Counterparty	Primary dealers	DTIs	DTIs
Collateral	N/A	A and C classes	USD and AED
Pricing	Auction determined Discounted price	Auction determined Rate quotes	Auctions determined Swap point quotes
Maturity	<= 12 months	<= 7 days	<= 14 days
Frequency of Operation	Fortnightly	Weekly	Weekly
Settlement	T+2	T+0	T+0

Source: CBUAE and IMF Mission

D. Reserve Requirements

Level of the RR Ratio and Remuneration

29. In general, the RR ratio should be no higher than necessary to meet its stated objectives. RR remain an important tool in the UAE to support the fixed exchange rate arrangement and manage liquidity. While the prudential objective is now largely achieved through macroprudential requirements, the RR—especially on FX deposits—may be beneficial as a second line of defense in the event of large shocks to liquidity.[14]

30. The optimal RR ratio depends on the desired level of overall liquidity in the system and how the liquidity management will be distributed across the toolkit. Starting in 2020, the high level of excess liquidity has decreased interbank market activity, suggesting that further sterilization may be warranted. A higher RR ratio combined with the reserve averaging provides a flexible tool to reduce the liquidity in the system. For example, re-instating the pre-crisis RR ratio of 14 percent could absorb a greater share of excess liquidity, especially if operational constraints make an increase in the M-Bill auction volumes difficult in the context of the small market.

31. However, more unremunerated RR are effectively a higher tax on the financial intermediation. A higher RR would increase the burden on banks which will need to hold a larger amount of liquidity in unremunerated reserves. To avoid distortions, required reserves should generally be remunerated at the opportunity cost—here the base rate of the ODF. A high level of unremunerated RRs especially if the IOER increases could lead to circumvention of the RR by shifts in the funding structure and risks a slowdown in credit growth as banks pass on the extra costs to their clients.

32. The CBUAE should consider remunerating the required reserves after a careful assessment of the balance sheet implications.[15] Central bank operations need to be sustainable and remunerating reserve will add an additional cost. Nevertheless, the alternative tools such as OMOs or the adverse impact on financial intermediations may prove to be more costly. If the balance sheet implications were to suggest that remuneration at the base rate is not feasible, even a remuneration at a lower rate could help alleviate the distortions.

Matching the Fulfillment Currency to Underlying Liabilities

33. Fulfilling the RR only in local currency can create distortions and undermines the prudential objective. If the RR on FX liabilities is fulfilled in foreign currency, the requirement is less distortionary for financial intermediation. Moreover, banks do not need to source

[14] Also see IMF Technical Assistance Report—Systemic Liquidity and Reserve Adequacy (2019) for further discussion.

[15] A follow-up IMF technical assistance mission on this topic is recommended.

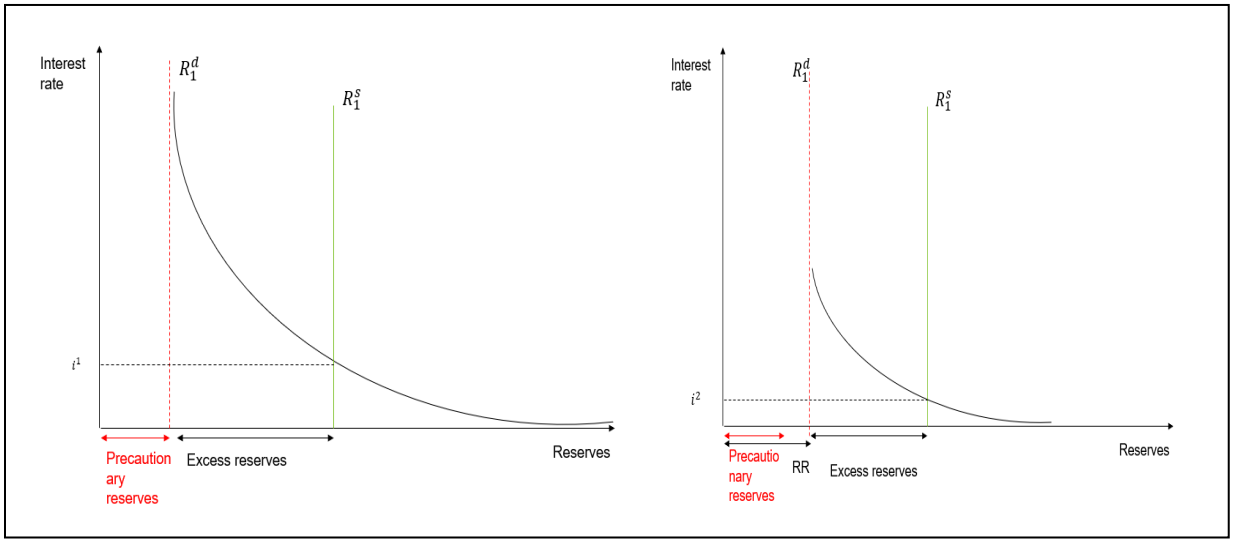
additional funding in local currency to meet the RR. Finally, only fulfillment in FX ensures that reserves function as an additional source of HQLA. The CBUAE has limited ability to act as a lender of last resort in foreign currency. Moving the fulfillment to local currency only has eliminated the RR as a second line of defense to FX liquidity shocks.

34. It would be prudent for the CBUAE to gradually reinstore the fullfilment of the RR on FX deposits in USD starting with the implementation on a specified fraction of the FX liabilities. Returning to the previous regulation on fulfillment would restore the prudential role of the FX RR, alongside other macropudential measures, and limit distortions to the financial system.

Reserve Averaging Reduces the Interbank Rate Volatility

35. The extension of the reserves maintenance period to two weeks simplifies liquidity management for banks. The longer maintenance period gives more flexibility to banks to smooth out liquidity shocks. Reserves can act as a buffer and banks do not accommodate swings in liquidity in the market immediately. Reserve averaging effectively flattens the reserve demand curve (see Figure 14). This cushions the interbank rate against high-frequency imbalances in supply and demand for reserves and thus supports the anchoring of the policy rate. However, given the still-short sample and parallel changes to the overall framework, empirical evidence on the extent of the reduction in volatility in the interbank rate is limited. Nevertheless, since the introduction of the ODF shortly followed by the extended RMP, the volatility in the interbank rate has fallen sharply. Moreover, the importance of averaging may become more salient once structural operations reduce the liquidity surplus more.

Figure 14. Demand for Reserves With and Without Averaging



Source: IMF staff

36. In the medium-term, the CBUAE could consider extending the RMP even further up to 28 days. Cross-country experience suggests that reserve maintenance periods of four to five weeks are most effective to reap the full benefits of reserve averaging. Once the system has fully adapted to the new operational framework, a gradual extension of the RMP could give banks even more flexibility in response to liquidity shocks. However, an RMP that is too long could undermine the prudential function of the RR, especially for FX RR.

Distribution of Reserves Across Banks Matters

37. A high concentration of reserves in a few banks can lead to spikes in the interbank rate. If some banks choose to hoard reserves to meet liquidity requirements for example, those funds may only flow at a premium to banks in need of fulfilling the reserve requirement.[16] Hence, high concentration may require a higher level of excess reserves to anchor the interbank rate to the policy rate.

38. Monitoring the distribution over excess reserves across banks should inform liquidity management in addition to aggregate variables. The distribution of reserves in the UAE is highly uneven and the high concentration is likely to impact the volatility of the interbank rate, especially has the liquidity surplus falls. A regular monitoring of the distribution across banks will help identify bottlenecks and can complement the aggregate analysis and inform liquidity operations.

III. Liquidity Forecasting Framework

A. Staffing and Organizational Arrangements

39. A useful way to organize the liquidity forecasting process is to assign the forecasting responsibility to a section within the CBUAE Monetary Management Department. This is to ensure, on the one hand, a close link between liquidity forecasting and liquidity management and, on the other hand, establish a clear accountability for the forecasting exercise. The forecasting section/unit is the "center" in which the information about the demand and supply components of bank reserves come together. The information has to be provided by different sources within and outside the CBUAE (e.g., the federal Ministry of Finance, the CBUAE's foreign exchange operations and accounting departments). The assignment of a liquidity forecasting division would thus comprise: (i) communicating with the different information sources and ensuring the timely receipt of the data; (ii) aggregating the analytical central bank's balance sheet to obtain the autonomous factors (see Appendix V); (iii) forecasting the individual liquidity components; (iv) supervising the consistency of the forecasted components; (v) preparing an overall liquidity projection to be updated on a daily basis; and (vi) assessing forecasting errors.

[16] See "Size Is Not All: Distribution of Bank Reserves and Fed Funds Dynamics" by Afonso et al. (2018), Liberty Street Economics, for a discussion of the potential impact in the United States.

40. The CBUAE is severely understaffed, and is not able to forecast liquidity using modern methods and to manage liquidity appropriately. The IMF team has provided the colleagues of the CBUAE with a full-fledged liquidity forecasting framework, using state-of-the-art methodology with a user-friendly interface. However, it is crucial that the CBUAE has in-house econometrics and statistical expertise to fine-tune and adjust the model to new market conditions and structural breaks. At a minimum, two people with a solid background in statistics, forecasting and programming would be necessary to produce regular liquidity forecasts for market operations.

41. The CBUAE needs to upgrade its data management system in order to ensure that databases can be accessed in a timely manner and on a high frequency basis. The liquidity forecasting exercise and calibration of OMOs necessitate the availability of the CBUAE balance sheet on a daily basis, in addition to the detailled monetary operations. The granular time-series should be stored in databases for ease of compilation of the autonomous factors and overall reconciliation (see Appendix VI).

42. The current draft Memorandum of Understanding (MoU) between the CBUAE and the DoF should be extended to the Federal and other local Treasuries from the different Emirates. MoUs should cover the regular exchange of granular information about future Treasuries cash flows, also covering public institutions, and be implemented within one year at latest. Although the net position of the government at the central bank is much smaller than other autonomous factors, it is important for the CBUAE to be regularly informed on the Treasury future cash-flows. The CBUAE has to manage liquidity to neutralize the potential disrupting volatility in the autonomous factors, and forward-looking information from the Treasury is key. The exchange of information should also include Treasury forecasts and methodology, as well as any relevant information for liquidity management purposes.

43. The Federal Treasury should operate a Treasury Single Account (TSA) at the CBUAE to optimize its cash management and enhance the CBUAE's liquidity management. Currently, the Federal Treasury manages its liquidity in large part through commercial banks, complicating substantially liquidity management for the CBUAE. A TSA would help the Treasury to streamline and strengthens its cash-flows management, while improving the CBUAE's forecasts of liquidity. The customer's account management of the CBUAE is equally efficient as in commercial/state-owned banks. The CBUAE should stand ready to remunerate outstanding balances on the government's account at the ODF rate. If advances were to be granted for non-cash management purposes, those should be granted at the OLF rate. It would also be advisable to apply a TSA for other local treasuries too.

B. Forecasting Framework

44. The IMF team has designed a state-of-the-art, full-fledged forecasting framework for each of the three main autonomous factors, as well as a reconciliation strategy to forecast the sum of the autonomous factors with an estimation of the confidence interval.

Over the last 20 years, the statistical literature has made substantial progress over the standard ARIMA model. It has proposed a wide range of different modeling approaches to model seasonality more accurately. Reflecting on these new methodologies, the IMF team provided a complete forecasting framework. This framework tests different families of forecasting models, with an integrated selection of the best performer based on information criteria and out-of-sample performance. It also allows to automatically reparametrize the models to account for structural breaks and new data developments.

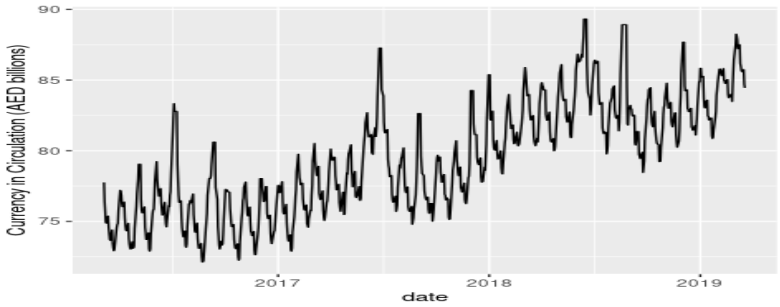
45. The mission provided a full-fledged software infrastructure to the authorities using a modern, open-source programming language. The forecasting framework has been entirely programmed under R, the leading free and open-source statistical software used in the forecasting industry. The IMF experts have designed a user-friendly infrastructure to help the authorities produce their forecasts smoothly and quickly. The programming infrastructure is entirely automatized and generates charts and tables on the fly for easy inspection and interpretation. The code is fully documented, using best programming practices to limit errors and bugs. Finally, the IMF experts can provide extra support and training to the authorities on how to use the software, ensuring that the CBUAE can readily produce forecasts for operational purposes.

46. This section is organized as per the following: It first presents the data, then discusses the empirical strategy and the models, for each autonomous factor (currency in circulation (CiC), State Account Balance (SAB), and net foreign assets (NFA)). The section also discusses advanced treatment, such as model averaging and dynamic selection, performance metrics, inference testing, forecast reconciliation, etc. It concludes by recommending a full-fledged empirical strategy for forecasting liquidity in the UAE.

Data Series

47. The data series on UAE currency in circulation is characterized by trends and other non-stationarity features, with strong weekly and monthly patterns and spikes around major religious and other public holidays. Such data are similar to the patterns found in other countries in the region.

Figure 15. Currency in Circulation Data

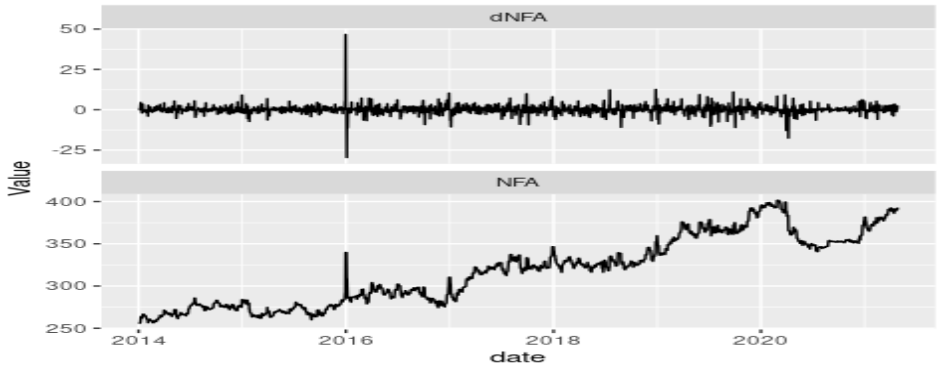


Source: CBUAE and IMF staff

48. Despite an increasing uptake of cashless transactions, the CiC exhibits an upward trend, which can possibly be attributed to an increase in tourism in the UAE. The weekly and monthly patterns are attributable to pay days, in particular many employees are paid on the 26th of the month. Also, a structural break appears in early 2020 at the onset of the COVID crisis. This may be related to individuals holding a higher level of cash as a precautionary measure or a policy of printing new banknotes due to fears of a higher risk of transmission for older notes.

49. Net foreign assets exhibit strong volatility without clear pattern for the mean. The mean is difficult to predict but some conditional heteroskedasticity is usually present. There is a clear outlier at the beginning of 2016 which can either be excluded from the analysis or handled using a dummy variable.

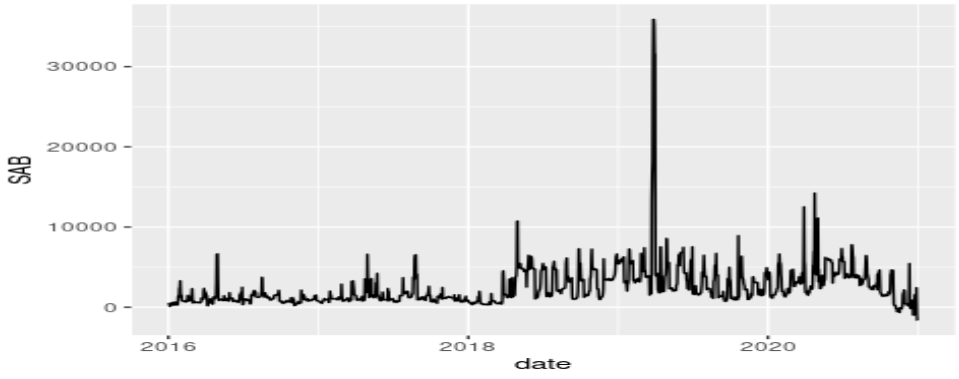
Figure 16. Net Foreign Assets Data
(Top Panel Shows the First Difference and the Bottom Panel Shows the Level)



Source: CBUAE and IMF staff

50. State account balance data exhibit some weekly and monthly seasonality, particularly in the latter half of the sample. Also noticeable are some outliers in early 2020 associated with the onset of the COVID-19 pandemic. These can easily be controlled for using dummy variables.

Figure 17. State Account Balance



Source: CBUAE and IMF staff

51. The IMF team has tested three main families of models to forecast the conditional mean of the autonomous factors: ARIMA models, ETS models, and TBATS models. Standard ARIMA is fitted alongside seasonal ARIMA and ARIMA with regression. For the ETS family models both with and without seasonality are considered. For the net foreign assets data, models for conditional heteroskedasticity are used. The models are presented in details in Appendix VII, including with preliminary fit on the UAE data.

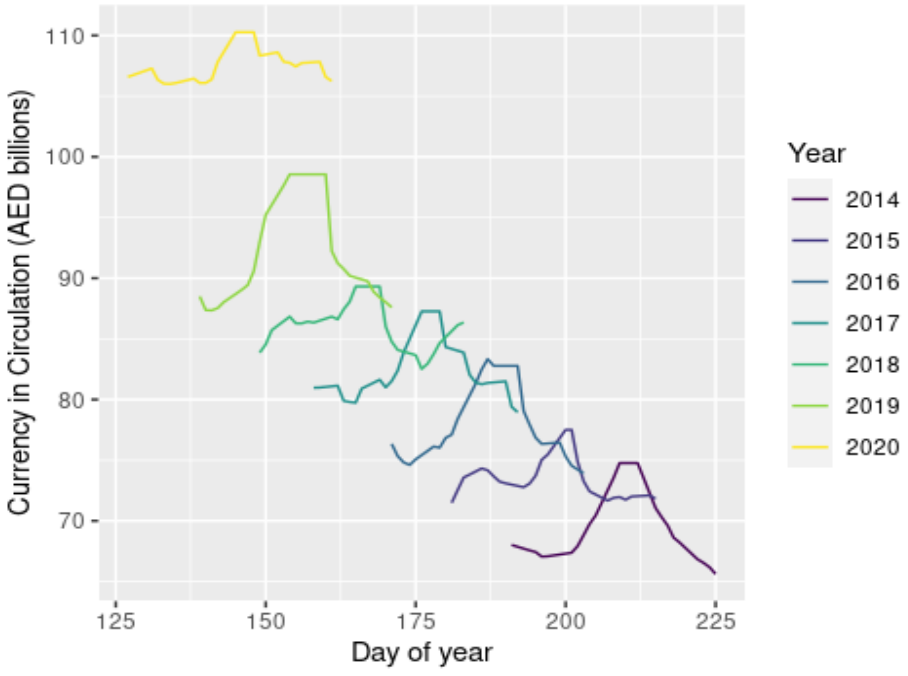
Structural Breaks

52. Structural breaks are present in some series, for example currency in circulation, which experienced a dramatic level shift at the onset of the Covid crisis. This pattern may be related to individuals holding a higher level of cash as a precautionary measure or a policy of printing new banknotes due to fears of a higher risk of transmission for older notes. Structural breaks can be controlled easily by introducing a dummy variable equal to zero before the structural break and one after the structural break.

Holiday Effects

53. A significant challenge is modeling the effect of important holidays. In particular, cash in circulation tends to rise in the lead up to holidays. The figure below presents the case of Eid-al-Fitr.

Figure 18. Currency in Circulation Around Eid-al-Fitr



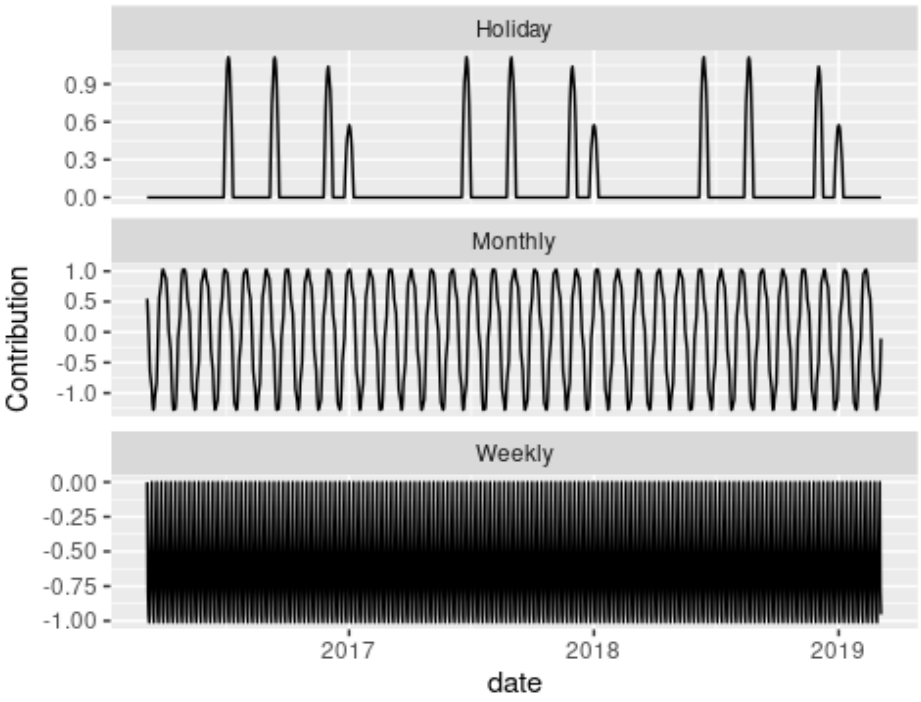
Source: IMF staff

While an approach based on dummy variables could be used here, given the smooth rise and fall in cash in circulation around public holidays the following approach is considered. A variable DaysToHoliday (DtH_t) is constructed. Using the example of Eid-al-Adha which fell on August 11 in 2019, the variable DtH_t takes a value of 0 on August 11, a value of 1 on August 12, a value of -1 on August 10, and so on. The Eid-al-Adha effect can be defined as

$$EaA_t = \max(0, (1 - DtH_t^2)/7)$$

This formulation creates a smooth hump for seven days around the holiday. Similar variables could be constructed for other major holidays, namely Eid-al_Fitr, UAE National Day, and New Years' Day. The top panel of Figure 19 shows the contribution of the holiday effect when modelled in this way.

Figure 19. Contribution to Fitted Values of A) Holiday Effects Modelled With a Quadratic Term (Top Panel), B) Monthly Effects Using Fourier Terms (Middle Panel), and C) Weekly Effect Using Dummies (Bottom Panel)

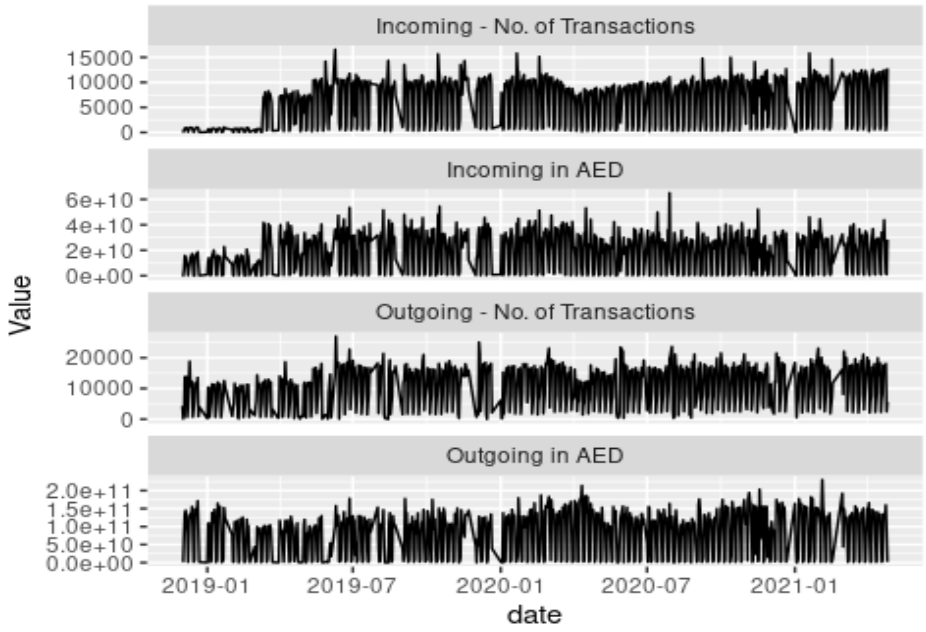


Source: IMF staff

Capital Flows

54. In the case of net foreign assets, capital flows data were considered as covariates. These are shown in Figure 20. It should be noted that the mean of net foreign assets is difficult to predict and these covariates did not improve forecasting performance.

Figure 20. Capital Flows Data (From Top to Bottom: Incoming Flows, Outgoing Flows, Incoming Number of Transactions, and Outgoing Number of Transactions)



Source: IMF staff

Model Selection (Regressions)

55. The covariates to use in forecasting each autonomous factor were selected by fitting all possible regression specifications. In each case the order of the ARIMA model was selected using the Hyndman and Kandakhar algorithm described in Hyndman and Khandakar (2008). The best model was chosen according to the Akaike Information criterion. The models selected for each autonomous factor and for the total are summarized in the table below:

Regressor	CIC	SAB	Total
Day of week (Dummies)	Yes	Yes	Yes
Day of Month (Fourier)	No	Yes	Yes
Day of Quarter (Fourier)	No	No	No
Day of Religious Year (Fourier)	No	No	No
Day of Civic Year (Fourier)	No	No	Yes
Holiday Effects	Yes	No	Yes
COVID-19 Dummy	Yes	Yes	Yes

For NFA, the random walk model was adequate for the mean, the more forecastable component of this time series is the variance. Also, for currency in circulation, and state account balance the

best specification was a seasonal ARIMA with $m = 7$ while for the total, standard ARIMA led to the lowest AIC.

Forecast Combination

56. To ensure robustness against model misspecification model averaging is used. Model averaging can be applied to both the point (mean) forecast as well as to the intervals. There are many alternatives schemes for model averaging. For point forecasts these can be based on regression while for interval forecasts these are based on quantile regression. These methods generally require a longer test sample to calibrate weight which is not available here due to the design of the forecast evaluation (forecasts are required for observations at the end of the fortnightly risk management period). Even more sophisticated dynamically changing weights are another possibility however require even longer samples of data to carry out an appropriate evaluation of the methods.

57. All model combinations reported in the results are simple averages of the best model from each model family. This approach is consistent with the well-established empirical result that simple averages often dominate more complicated weighting schemes, and due to some of the challenges regarding the data. It should be noted that dynamic model selection is carried out since for each evaluation period, the best model within each family or class of models is selected according to AIC. The only model combination takes place across different model families using simple averages.

Forecast Evaluation Design

58. The forecast evaluation is designed to closely match the structure of liquidity management as carried out by the CBUAE. The reserves maintenance period (RMP) is a two-week period beginning on Wednesday and finishing the following Tuesday. The target of interest is the value of the autonomous factors on the final day of the RMP. These must be forecast at a one-day horizon on the previous day, a two-day horizon two days before up to a 14-day ahead forecast at the outset of the RMP.

For each two-week period up to 10 (two working weekdays worth) of forecasts are generated. Point forecasts are evaluated using criteria such at root mean square error (RMSE) and mean absolute error (MAE). Prediction intervals are evaluated using the Winkler score, which for an $\alpha\%$ prediction interval (l, u) and realised value y is given by:

$$W = \begin{cases} (u-l) + \dfrac{2}{\alpha}(l-y) \text{ if } y < l \\ (u-l) \text{ if } l \leq y \leq u \\ (u-l) + \dfrac{2}{\alpha}(y-u) \text{ if } y > u \end{cases}$$

Forecast Reconciliation

Ultimately forecast (including prediction intervals) is available for:

- Currency in Circulation
- Net Foreign Assets
- State Account Balance

The net liquidity injection (Net Foreign Assets—Currency in Circulation—State Account Balance) is the main quantity of interest. One approach would be to simply add up the forecasts of the autonomous factors in a bottom up fashion while a second approach would be to develop a forecasting model for the total of the autonomous factors itself. Alternatively, forecasts can be produced of all autonomous factors and the total. An advantage of this approach is that it hedges against model misspecification in the forecasting of the total if the mis-specified features are captured in the forecasts of the individual autonomous factors, but also hedges against misspecification in the bottom level due to noise by forecasting the smoother total series. The downside of this approach is that the forecasts are no longer guaranteed to add up correctly.

Letting the vector of four points forecasts that do not add up according to the hierarchical structure be given by $\hat{y}$. Let the matrix

$$S = \begin{pmatrix} 1 & 1 & 1 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

be the summing matrix. By construction reconciled forecasts that are guaranteed to add up correctly can be found via

$$\tilde{y} = S(S'S)^{-1}S'\hat{y}.$$

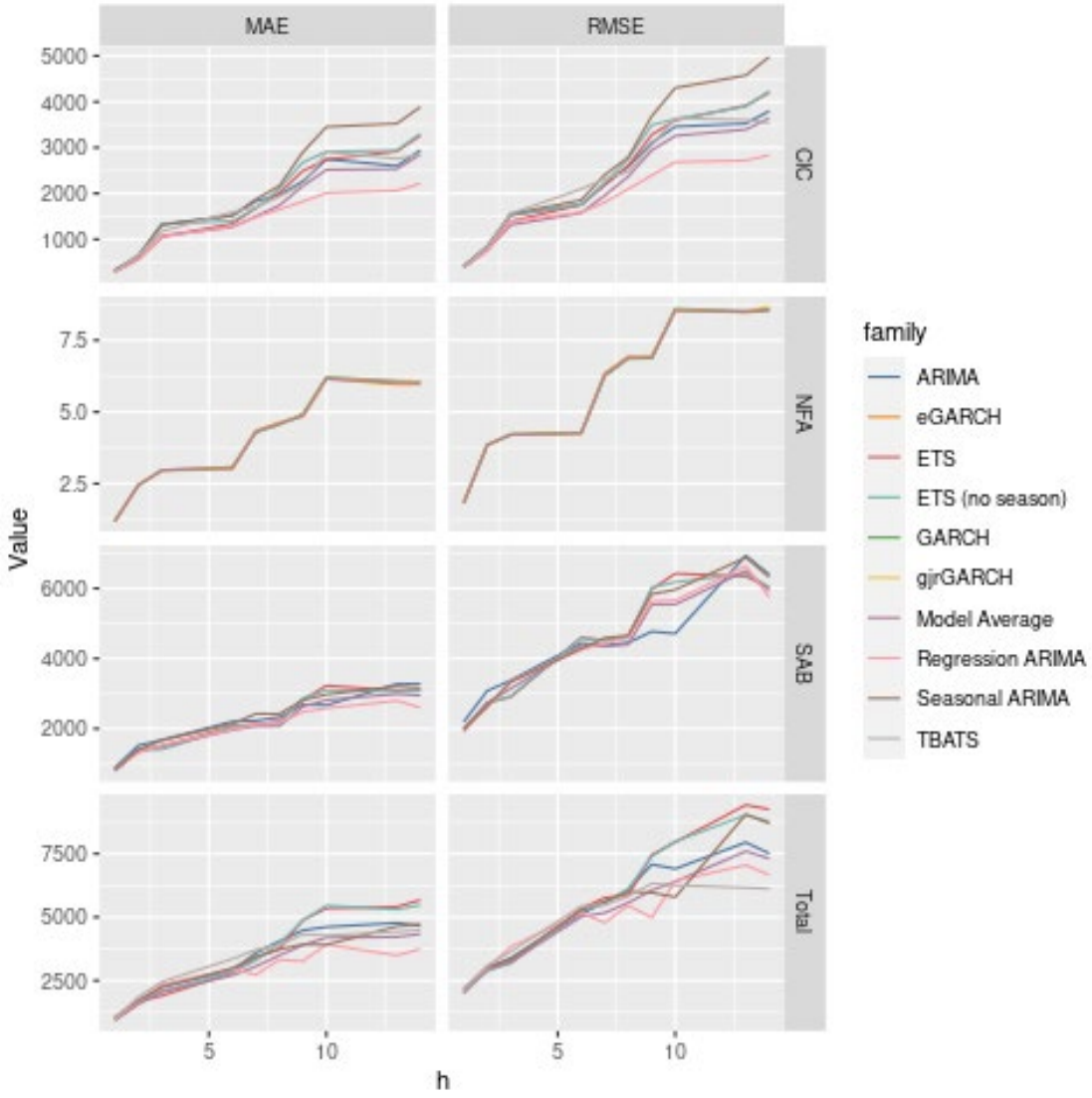
This approach is referred to an OLS reconciliation due to its resemblance with the matrix in Ordinary Least Squares regression that projects the data onto the fitted values.

An even better approach known as the MinT method exploits correlation between forecast errors. Forecasts that are guaranteed to add up correctly are found as $\tilde{y} = S(S'\Sigma^{-1}S)^{-1}S'\Sigma^{-1}\hat{y}$. The matrix Σ is the covariance matrix of one step ahead forecasting errors.

Point Forecasts Comparison

The figure below shows both the mean absolute error (MAE) and the root mean square error (RMSE) for each autonomous factor and the total and for the best model within each model class.

Figure 21. Mean Absolute Error (MAE) and Root Mean Square Error (RMSE) for Forecasting Models on the Total of the Autonomous Factors (Left Panels Show MAE and Right Panels Show RMSE)



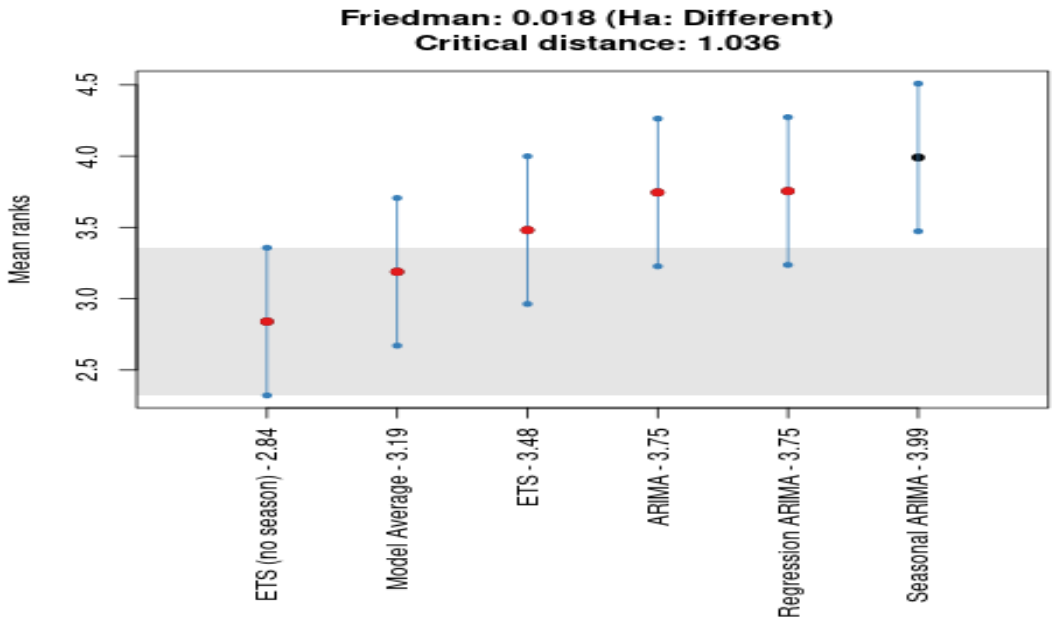
Source: IMF staff

These figures show how the RMSE naturally increases at longer forecasting horizons. The results for RMSE are also displayed in tabular form for the total of all autonomous factors in the table below. Here all RMSEs are shown relative to the RMSE of the model average, numbers below 1 indicate that a model outperforms the model average.

ARIMA	ETS	ETS (No Seas)	Reg. ARIMA	Seas. ARIMA	TBATS	Mod. Av.
1.035	0.966	0.98	1.013	1.029	1.047	1
1.018	1.025	0.977	1.02	1.04	1.048	1
1.047	0.984	0.989	1.182	1.027	1.125	1
1.023	1.064	1.048	1.028	1.052	1.083	1
1.081	1.116	1.069	0.925	1.088	1.06	1
1.091	1.051	1.099	0.981	1.077	1.046	1
1.168	1.23	1.22	0.821	0.984	1.043	1
1.079	1.244	1.249	1.006	0.905	0.978	1
1.047	1.241	1.189	0.928	1.192	0.811	1
1.027	1.266	1.2	0.911	1.19	0.837	1

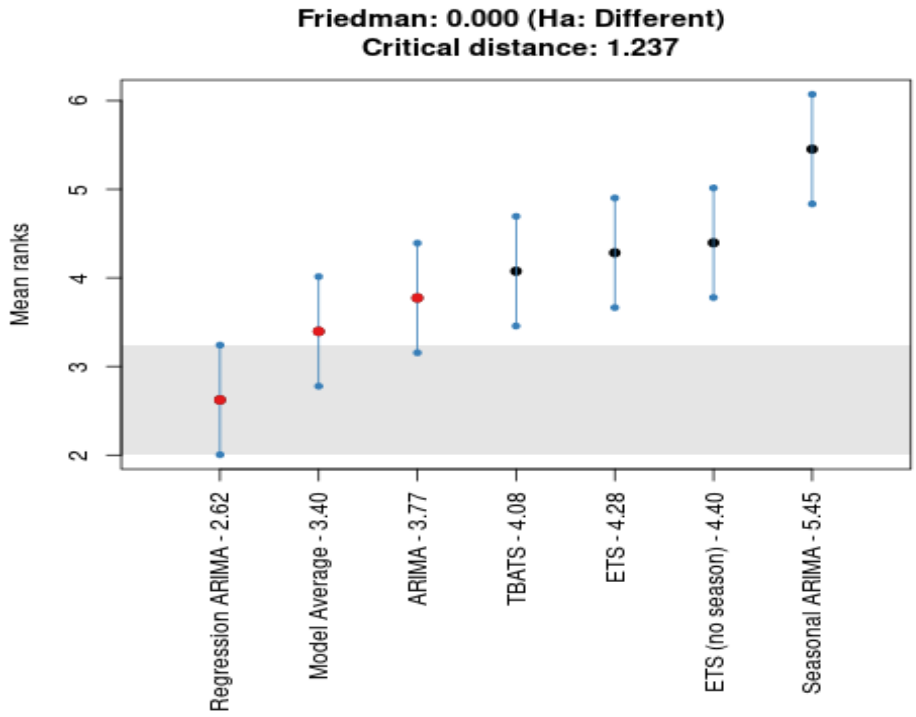
59. In general, model averaging is very robust at all horizons. Both ARIMA with regression and TBATS can outperform the model average, particularly at longer horizons. There are some instances where ETS models outperform the model average at short horizon. While these results are shown for the total above, similar conclusions can be drawn when looking at the results for CIC and SAB. It should be noted though that using the Nemenyi test for multiple comparisons indicate that even in instances where another model outperforms the model average, this is not statistically significant. To give an indication of this, the figure below summarize the results for one-day ahead forecasts of SAB and 14-day ahead forecasts of CIC respectively. Although an ETS model and ARIMA with regression model are the best models in these two specific cases, the superiority in forecasting performance is not significantly better than any other method whose corresponding interval lies within the grey band. In both cases the model average (as well as other models) lies in this band.

Figure 22. Nemenyi Plot for RMSE for One-Day Ahead Forecasts for SAB



Source: IMF staff

Figure 23. Nemenyi Plot For RMSE for 14-Day Ahead Forecasts for CiC



Source: IMF staff

Interval Forecast Comparisons

60. To evaluate interval forecasts, the IMF team considers two metrics. The first is the hit rate, defined as the proportion of times that the actual value of the forecast falls outside of the prediction interval. The second is the Winkler score defined above.

The hit for the 80 percent prediction interval for different series and methods are shown in the table below. Numbers close to 0.2 indicate a better calibrated interval.

h=1	h=2	h=3	h=6	h=7	h=8	h=9	h=10	h=13	h=14
0.08	0.09	0.25	0.09	0.19	0.21	0.21	0.21	0.17	0.17
0.02	0.13	0.19	0.13	0.17	0.17	0.21	0.17	0.19	0.15
0.02	0.08	0.11	0.04	0.06	0.11	0.15	0.09	0.08	0.06
0.06	0.09	0.21	0.06	0.11	0.15	0.19	0.17	0.15	0.13
0.08	0.15	0.26	0.13	0.15	0.17	0.19	0.21	0.15	0.19
0.08	0.09	0.32	0.08	0.21	0.19	0.26	0.25	0.15	0.21
0.08	0.17	0.26	0.26	0.23	0.26	0.34	0.42	0.4	0.47
0.19	0.3	0.28	0.13	0.23	0.21	0.21	0.26	0.26	0.23
0.21	0.3	0.25	0.15	0.21	0.21	0.21	0.29	0.26	0.23
0.19	0.28	0.26	0.13	0.25	0.25	0.28	0.37	0.23	0.26
0.21	0.32	0.25	0.11	0.23	0.23	0.23	0.32	0.26	0.23
0.13	0.21	0.19	0.21	0.23	0.21	0.19	0.19	0.21	0.17
0.08	0.15	0.08	0.08	0.11	0.08	0.08	0.06	0.02	0.02
0.08	0.11	0.08	0.06	0.09	0.08	0.06	0.04	0.02	0.02
0.09	0.17	0.13	0.08	0.09	0.06	0.06	0.06	0.04	0.04
0.13	0.21	0.15	0.17	0.15	0.15	0.13	0.11	0.09	0.09

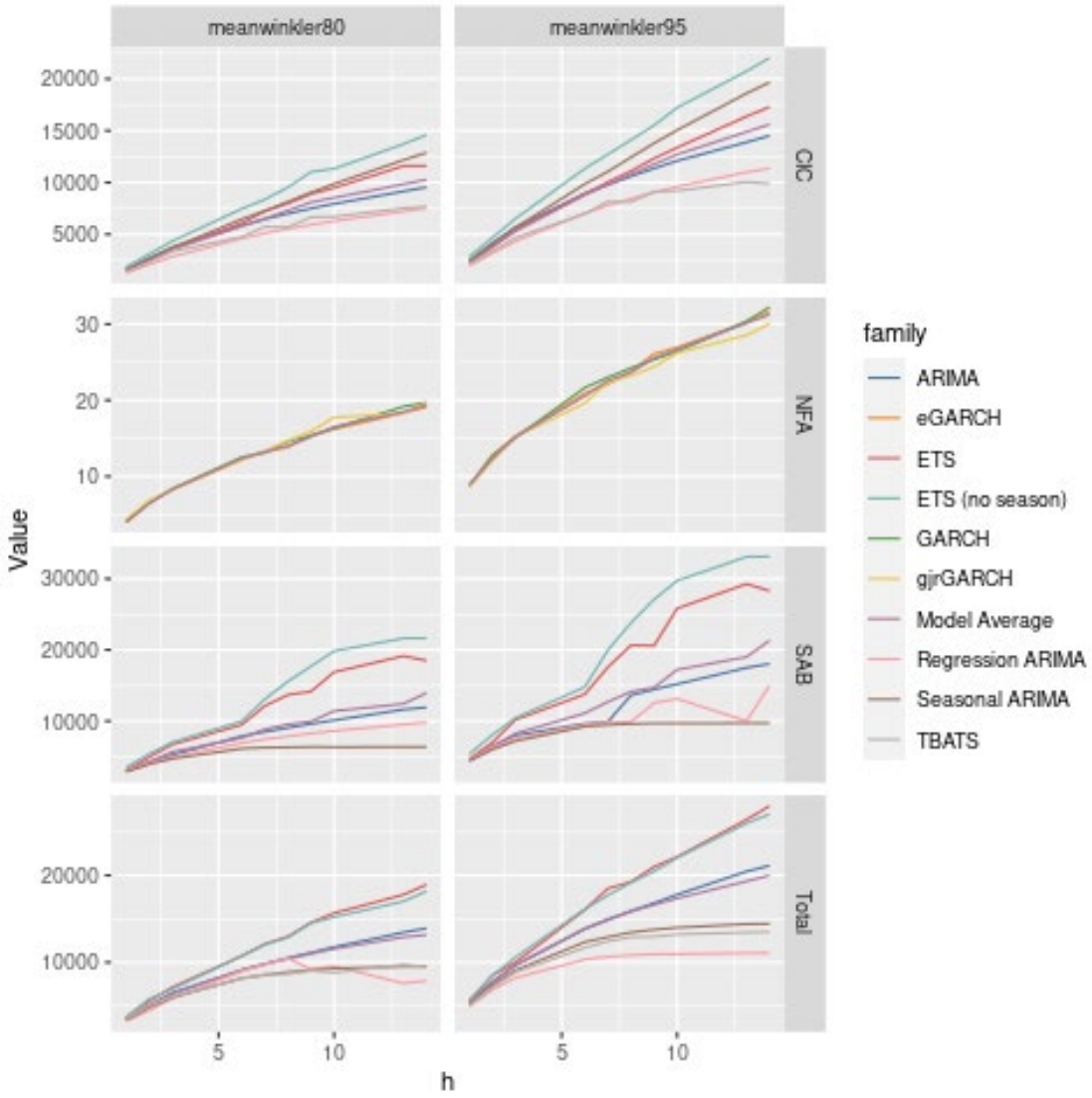
0.13	0.19	0.19	0.19	0.25	0.19	0.21	0.23	0.21	0.21
0.11	0.19	0.23	0.15	0.19	0.25	0.26	0.26	0.17	0.19
0.13	0.21	0.21	0.15	0.15	0.15	0.19	0.25	0.13	0.15
0.11	0.19	0.13	0.15	0.13	0.19	0.19	0.23	0.13	0.13
0.09	0.17	0.21	0.15	0.21	0.15	0.17	0.23	0.17	0.15
0.15	0.25	0.34	0.25	0.25	0.28	0.26	0.28	0.15	0.19
0.15	0.21	0.23	0.25	0.25	0.21	0.25	0.26	0.25	0.23
0.17	0.26	0.34	0.3	0.4	0.38	0.43	0.34	0.49	0.42

61. The results indicate that prediction intervals tend to be on the conservative side, particularly for very short-term forecasts. The TBATS model tends to lead to under-coverage. Similar conclusions can be made for the 95 percent prediction intervals.

The Winkler scores for the 80 percent prediction interval (left panels) and the 95 percent prediction interval (right panels) are shown from top to bottom for the CIC, NFA, SAB and Total.

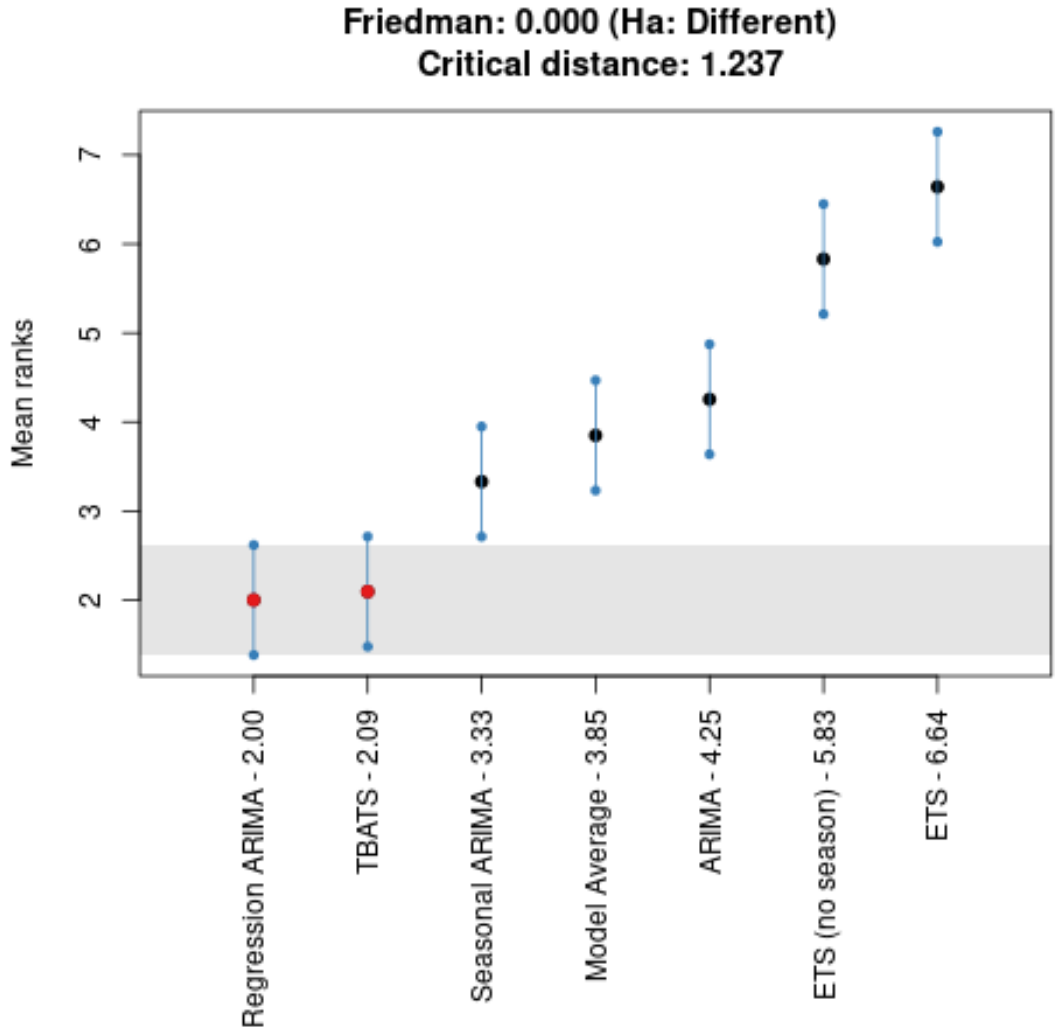
62. When considering the forecast intervals, the ARIMA with regression performs well, particularly at longer horizons, for CIC, SAB and the total sum. For the NFA, all GARCH specifications lead to similar performance. The model average does not perform as well as ARIMA with regression particularly at longer horizons and for the total. The Nemenyi plot for a 95 percent prediction interval for the total of all autonomous factors shows the superior performance of ARIMA with regression relative to the model average is statistically significant.

Figure 24. Winkler Scores for the 80 Percent Prediction Interval (Left) and the 95 Percent Prediction Interval (Right) and From Top to Bottom for the CIC, NFA, SAB, and Total (Each Plot Shows the Performance of Different Forecasting Methods Over All Horizons)



Source: IMF staff

Figure 25. Nemenyi Plot for Winkler Scores for the 95 Percent Prediction Interval and 14-Day Ahead Forecasts



Source: IMF staff

Forecast Reconciliation

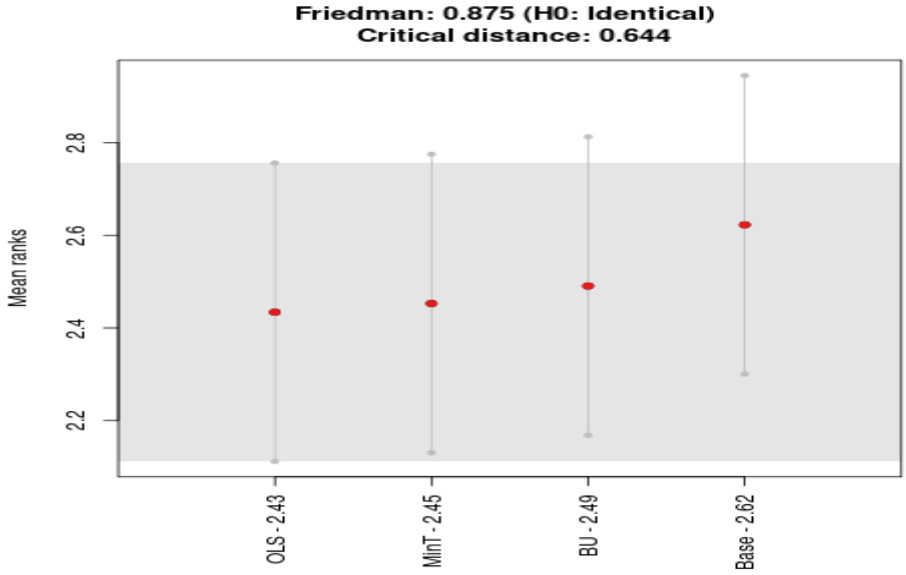
63. For the forecast reconciliation, ARIMA with regression is used for Total, CIC and SAB while the eGARCH was used for NFA. For brevity, results comparing different forecast reconciliation methods are presented for the total only.

64. The most robust and best performing reconciliation method is OLS with MinT also yielding similar results. For the point forecasts the difference in forecasting performance is not statistically significant between any of the methods, while for longer horizons the bottom up

method of simply adding up the forecasts of individual autonomous factors is significantly worse than all other alternative. This is shown in the figures below.

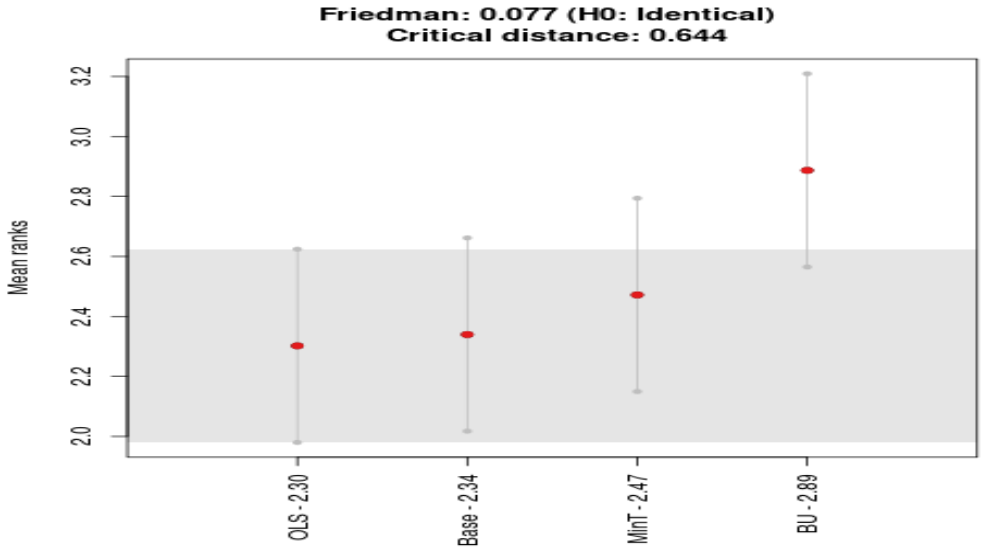
65. For the prediction intervals, OLS reconciliation significantly dominates all methods at short horizons and all methods bar MinT at longer horizons. This result is presented for the Winkler score for 80 percent prediction intervals.

Figure 26. Nemenyi Plot for RMSE of Different Reconciled and Unreconciled One-Day Ahead Forecasts of the Total



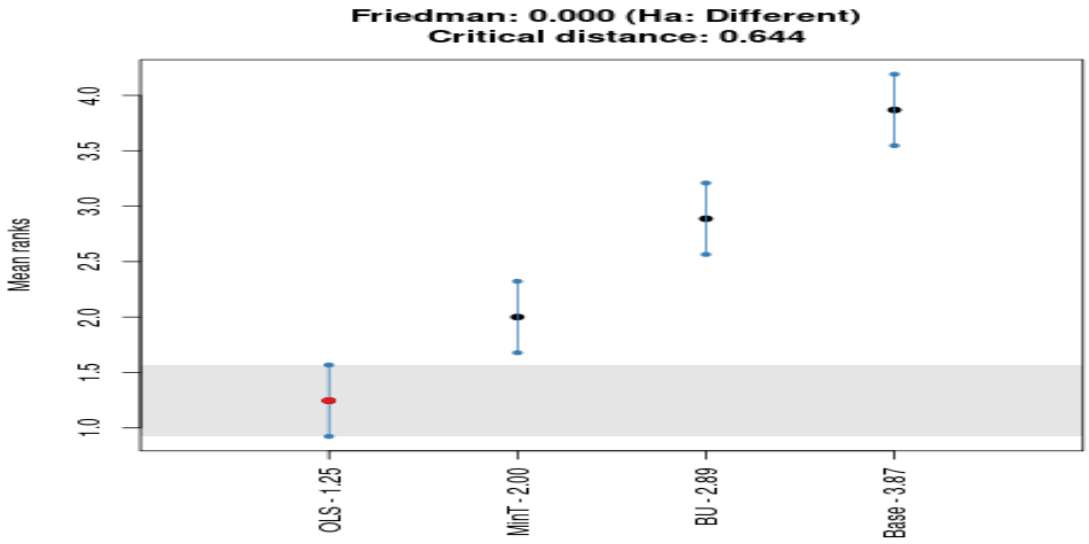
Source: IMF staff

Figure 27. Nemenyi Plot for RMSE of Different Reconciled and Unreconciled 14-Day Ahead Forecasts of the Total



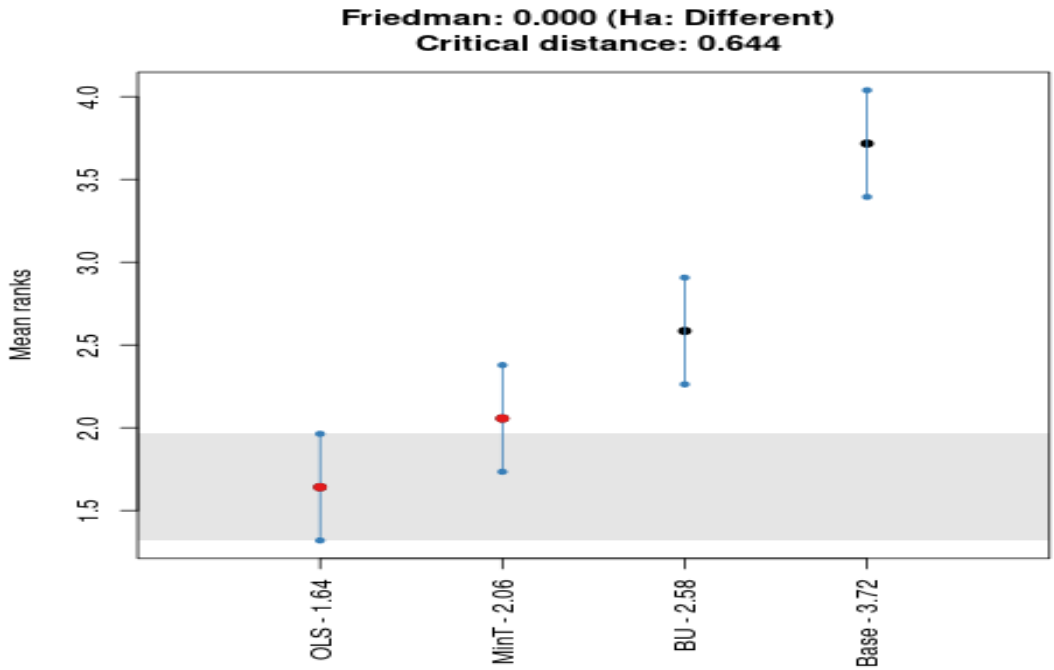
Source: IMF staff

Figure 28. Nemenyi Plot for Winkler Score of 80 Percent Prediction Interval of Different Reconciled and Unreconciled One-Day Ahead Forecasts of the Total



Source: IMF staff

Figure 29. Nemenyi Plot for Winkler Score of 80 Percent Prediction Interval of Different Reconciled and Unreconciled 14-Day Ahead Forecasts of the Total



Source: IMF staff

Conclusion

66. ARIMA models with regression leads to the best forecasting performance for SAB, CIC and the Total, with all GARCH specifications yielding similar results for the NFA. Model averaging improves point forecasts but not interval forecasts. Forecast reconciliation using the OLS method can lead to better point forecasts and better forecast intervals relative to a forecast of the total or a sum of forecasts of all three autonomous factors.

C. Recommendations

67. The CBUAE should forecast all the autonomous factors separately, as well as the net liquidity injection, using the forecasting framework designed by the IMF. Liquidity forecasting relies on projections for all the autonomous factors, and not only currency in circulation. Although NFA and SAB are often more complex to forecast, they can be modeled with the appropriate tools, which will still produce better forecasts than ignoring them or naively use past values.

68. The IMF team recommends using an ARIMA model with regression for forecasting CiC and SAB, and to use an EGARCH model for forecasting NFA. Out-of-sample performance evaluation show that these models dominate the alternatives for the horizon relevant for liquidity management.

69. Model dynamic selection and averaging should be used to improve the forecasting accuracy and reduce the modeling risk. The IMF software infrastructure allows to easily fit a wide range of models and select and average them on the fly while following the best standards in the forecasting literature. Although more complex than univariate forecast based on simple models, the team has shown that this approach offers superior accuracy and reduces the risk of misspecification.

70. The forecast reconciliation model designed by the IMF expert should be used to forecast the net liquidity injection and estimate the associated confidence interval. An important contribution of the IMF modeling framework is to use a forecast reconciliation approach to refine the forecast of the aggregate autonomous factors, instead of naively summing them. This approach also allows to estimate the confidence interval of the net liquidity injection, which can then be used to calibrate the required reserves.

71. The CBUAE could enhance the forecasts by incorporating further the expertise and granular knowledge of the CBUAE experts. This expertise can improve further the construction and selection of indicators for special events and policy events in the models. Furthermore, the IMF team has followed an agnostic approach, building on information that practitioners could extract solely from the data. Contextual data and expertise can further refine modeling choices to improve forecast further.

72. The CBUAE should publish the whole liquidity forecast and associated methodology to help anchoring market expectations and support liquidity management of market participants. The CBUAE has now the most extensive capacity in the market to provide the best forecasts of the UAE autonomous factors and changes in the overall liquidity conditions. Releasing these forecasts would help strengthening the liquidity management by market participants and help the market to form consistent expectations about short-term liquidity changes.

73. The CBUAE should staff a small team of econometricians to estimate and fine-tune the liquidity forecasting framework. Given the importance of liquidity forecasts for efficient liquidity management, and the increasing complexity of the UAE financial system, it is crucial that the CBUAE has in-house expertise in liquidity forecasting.

74. The CBUAE should sign a memorandum of understanding with the Treasury to share information about the Treasury future cash-flows. Forecasts from the Treasury about its expected cash-flows are crucial to support the projection of the state account balance.

75. The Treasury should operate a Treasury Single Account to consistently manage its cash flows and simplify the CBUAE's liquidity management. A Treasury Single Account at the central bank is considered as an international best practice for Treasury cash-flow management and central bank liquidity management.

IV. Calibration of the Monetary Operations

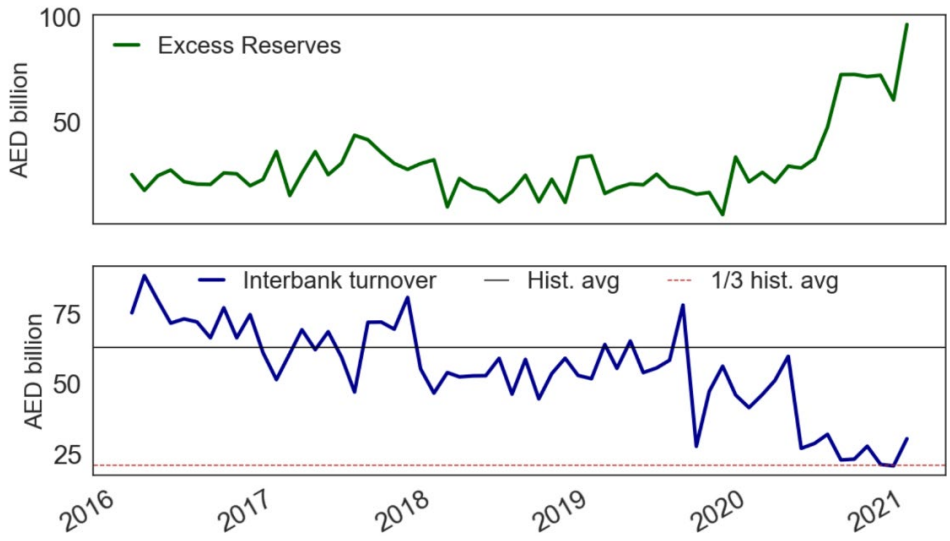
A. Conceptual Framework: Optimal Liquidity Surplus in a Floor

76. In a floor system, the central bank should maintain enough liquidity surplus to anchor the interbank rate at the policy rate, which is the overnight deposit rate. At a minimum, the central bank should maintain a liquidity surplus greater than the aggregate precautionary demand of reserves from commercial banks, so that banks are able to settle their payments. However, the aggregate precautionary demand from banks is not necessarily the optimal level of reserves, as the level of incompressible demand for reserves doesn't guarantee that the interbank rate will be anchored to the policy rate (i.e., the overnight deposit facility). To anchor the interbank rate at the policy rate, the central bank should supply enough reserves to stimulate the deposits of commercial banks at the overnight deposit facility, to stabilize the interbank rate at the floor and to avoid excessive volatility to occur.

77. The central bank faces a tradeoff between anchoring the interbank rate at the policy rate and supporting money market development and building the sovereign yield curve. While an excessive amount of structural liquidity generally anchors the interbank rate well, it has a detrimental impact on interbank money market trading. As banks are more and more uniformly excessively liquid, less and less banks need to borrow reserves on the market. Consequently, banks cannot place their excess reserves on the market and should either deposit them at the ODF or purchase central bank securities. This situation currently occurs in the UAE; as the

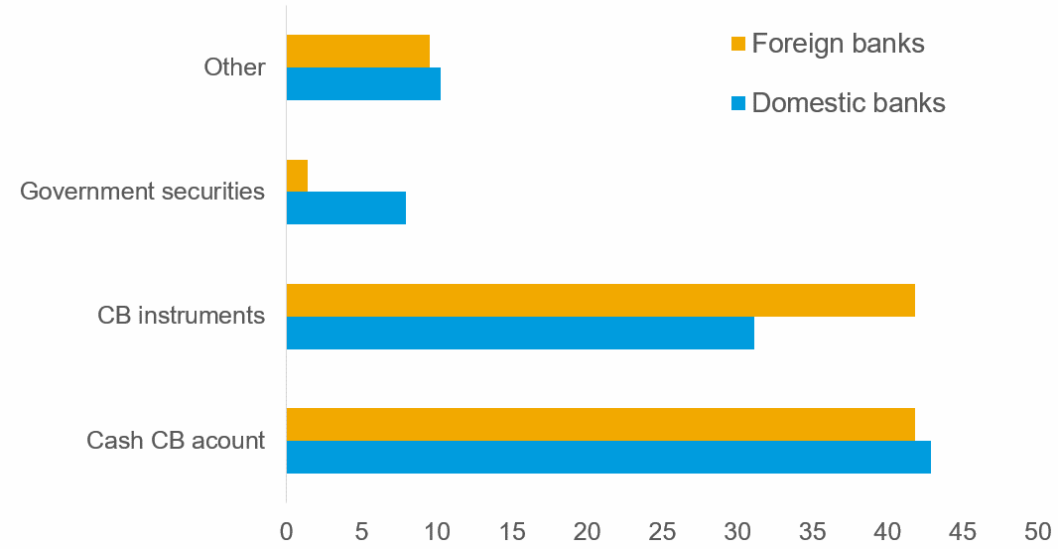
CBUAE has been operating with an increasing level of excess reserves, the interbank market turnover has shrunk over the last two years by around two thirds of the historical average. Also, sterilizing liquidity through the issuance of central bank securities is important in a country lacking Treasury instruments to build the sovereign yield curve. Therefore, the central bank should sterilize enough liquidity via securities to support capital market development and yield curve pricing.

Figure 30. Excess Reserves and Interbank Turnover (All Tenors)



Source: IMF staff and the CBUAE

Figure 31. UAE Survey: Placement of Banks' Liquidity



Source: IMF staff and the CBUAE

78. The market dynamic of the interbank rate spread with the policy rate and the objectives of the central bank should determine the optimal amount of liquidity surplus. The IMF team proposes a conceptual framework relying on: (i) a model of the demand and supply of central bank's reserves; and (ii) a formalization of the central bank monetary objectives. The conceptual framework serves as a basis for the empirical analysis presented below.

79. The model of precautionary demand for reserves is based on Poole (1968) and is customized to the specificities of the UAE, in particular, as an oil producing country. In Poole (1968), the demand for excess reserves is part of a bank's liquidity management decision. Banks want to hold excess reserves to avoid overdraft or reserve deficiency penalties on their account at the central bank when facing uncertain flows of funds. The model's predictions are twofold: (i) the quantity of excess reserves demanded varies inversely with the opportunity cost of holding reserves; and (ii) demand of excess reserves increases with uncertainty about reserves balances. It is usually assumed that uncertainty increases with payment activity (Furfine, 2000) and falls with the level of reserves requirements (Dow, 2000).

80. Building on this literature the behavior of excess reserves over a maintenance period of length $t = 1, \ldots, T$ days can be described as follows. Commercial banks demand central bank reserves ${E_t}^d$ for precautionary purposes, mostly to settle payments with other financial institutions, while arbitraging opportunities, domestically and internationally:

$$(1)\ {E_t}^d = a + f(i_t - \bar{\imath}) + g(r_t - \bar{\imath}) + h(\omega_t) + m\left(\sum_{j=1}^{t} R_j - \underline{R}\right)$$

Hence ${E_t}^d$ depends on:

- The money market interbank spread with the policy rate $(i_t - \bar{\imath})$. In the case of the UAE, the policy rate is equal to the US IOER.[17]
- A set of stochastic exogeneous factors ω_t such as oil prices, seasonal effects, etc.
- The fulfillment of statutory reserves $\underline{R}$ over the maintenance period, depending on the averaging strategy $m()$ used by the banks
- The spread between the US T-Bills and the policy rate$(r_t - \bar{\imath})$ capturing an alternative investment opportunity that banks have.

[17] The standard central bank monetary policy rule in a pegged regime reads:

$$\bar{\imath} = \bar{\imath}^* + \rho_t$$

where ρ_t is a risk premium and $\bar{\imath}^*$ the US target rate.

$E_t^d \geq E_t^i$ is the incompressible demand for reserves. The reserve requirement is met for the maintenance period if the cumulative sum of actual reserves on the last day of the maintenance period at least equals the sum of required reserves over the period $\sum_{t=1}^{T} R_t \geq T * \bar{R}$.

On each day of the maintenance period excess reserves are calculated as reserves account balances in excess of the required amount

$$E_t = R_t - \bar{R}$$

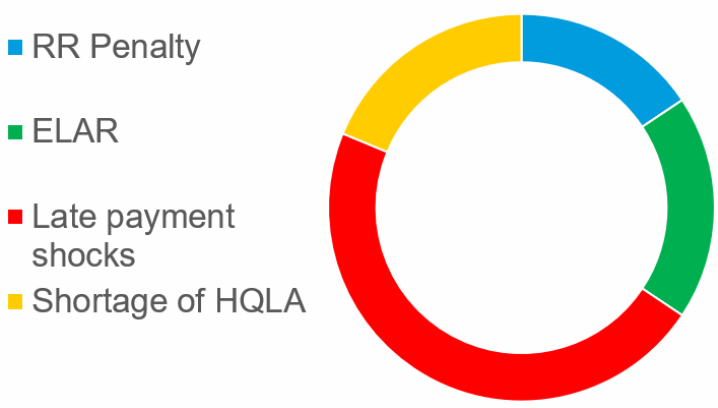
81. In line with specification (1), Furfine (2000) develops a model of bank reserves management that incorporates payment flows. In his model, payment flows are positively correlated with reserves balance uncertainty. Uncertainty generates a precautionary demand for reserves. As a result, interbank rates are higher on days characterized by higher payment flows. This result is empirically confirmed by Acharya and Merrouche (2012) in the United Kingdom context. In terms of specification (1), it implies that the spread should vary positively with ω_t.

82. As shown in Acharya and Merrouche (2012) any factor that causes banks to hoard liquidity for precautionary reasons would push rates and volatility upward. And any factor that pushes the *undesired* level of excess reserves upward, including a rise in capital inflows (AF) together with insufficient interventions by the central bank to absorb enough excess liquidity via the issuance of securities (B) is expected to cause rates to go down.

83. Further the model includes a full range of calendar effects. An extensive literature has documented that the interbank rate does not follow a martingale. Rates vary predictably on different days of the maintenance period (see Hamilton, 1996) and Bartolini et al. (2002). And volatility is higher at the end of the maintenance period. Whitesell (2006) shows that period-average requirements create incentives for banks to actively manage liquidity contributing to lower spreads and volatility, but this effect attenuates toward the end of the maintenance period. In a system with abundant liquidity, it is expected that these patterns in the interbank rate over the maintenance period are not observed and that the benefit of reserve averaging are not as strong unless reserves are unevenly distributed across banks.

84. The results of a banks' survey conducted by the CBUAE and the IMF mission confirm that excess reserves are held in priority to meet unpredictable payment flows. The penalty charged for shortfalls in reserves requirements is among the top four reasons for holding excess reserves (also ELAR). Another factor that leads banks to hold more reserves is that reserves count toward the fulfillment of liquidity requirements.

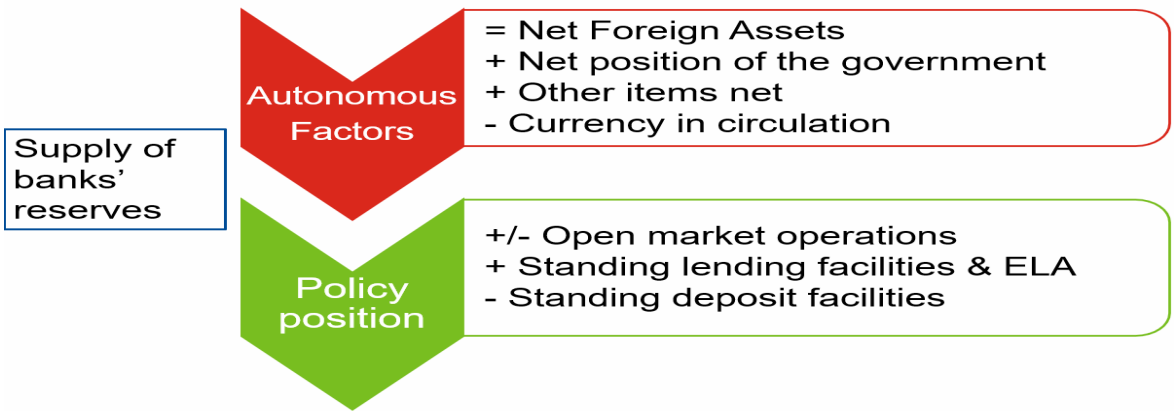
Figure 32. Survey Results: Reasons for Holding Excess Reserves



Source: IMF staff and the CBUAE

85. The supply of banks' reserves is determined by the autonomous factors and the policy position of the central bank. The net foreign assets, net position of the government, other items net inject liquidity while currency in circulation absorbs liquidity. Then, the central bank can adjust the structural liquidity by conducting open market operations, as well as operating standing facilities and ELA.

Figure 33. Supply of Banks' Reserves



Source: IMF staff

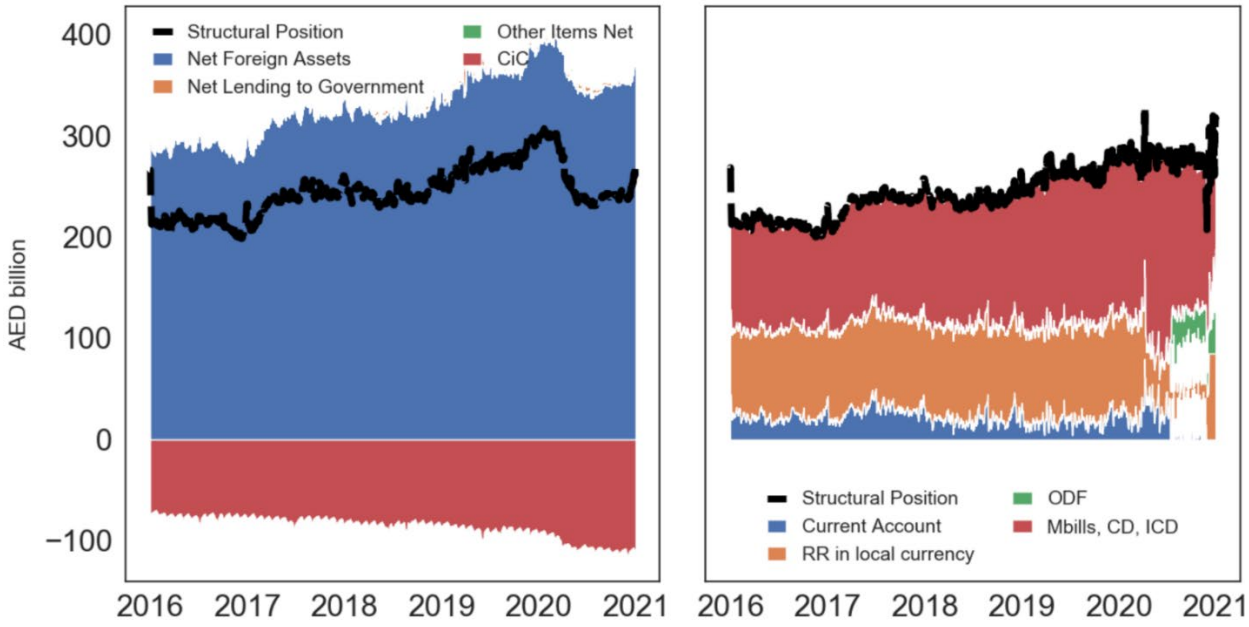
86. The IMF team formalizes the central bank supply of reserves by using the accounting equality of the central bank stylized balance sheet. On the central bank assets' side, NFA_t represents the net foreign assets, NLG_t the net lending to the government and $ONDA_t$ the other net domestic assets. On the liabilities side, the central bank has currency in circulation (CIC_t), bank's excess reserves ($E_t{}^s$), required reserves ($\underline{R}$) and securities (B_t).

$$(2)\ NFA_t + NLG_t + ONDA_t = CIC_t + E_t{}^s + \underline{R} + B_t$$

The notations are simplified and the autonomous factors are expressed as $AF_t = NFA_t + NLG_t + ONDA_t - CIC_t$. From the accounting equality, the supply of reserves can be expressed as the difference between the liquidity injected by the autonomous factors and the liquidity absorbed by the central bank:

$$(3)\ E_t^{\ s} = AF_t - \underline{R} - B_t$$

Figure 34. Structural Liquidity Position: Autonomous Factors and Banks' Reserves



Source: IMF staff and the CBUAE

87. The clearing market condition between demand and supply of reserves determines the interest spread dynamic. At the equilibrium, $E_t^{\ s} = E_t^{\ d}$, which implies:

$$(4)\ i_t - \bar{\imath} = f^{-1}\left(AF_t - B_t - M(\underline{R}) - a - g(r_t - \bar{\imath}) - h(\omega_t)\right)$$

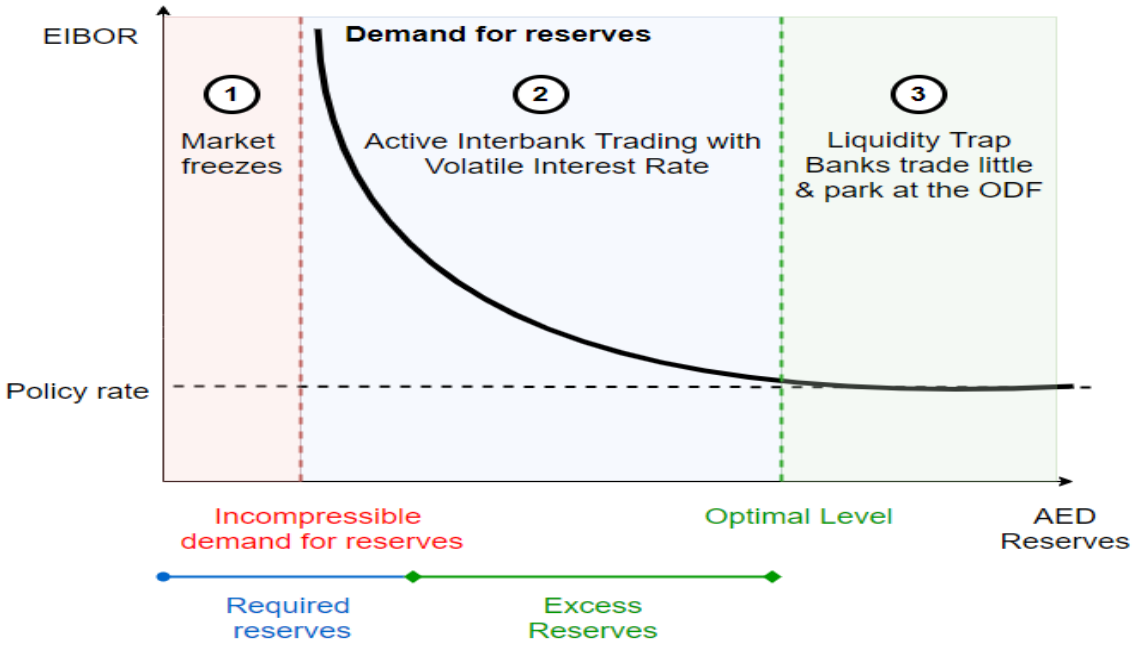
Where the notation is simplified: $M(\underline{R}) = m\left(\sum_{j=1}^{t} R_j - \underline{R}\right) - \underline{R}$

88. The structural functions f, g, h, m are potentially non-linear, difficult to estimate and to invert. Ideally, a structural model on banks' demand based on granular micro data should be used, but even with such data, the true demand of reserves from banks is confounded with other effects, in particular market microstructure. For these reasons, the IMF team has implemented a reduced-form approach (see below).

89. The IMF mission models the interest rate spread dynamic as a highly non-linear function articulated around three phases. f^{-1} reflects:

- The incompressible demand for reserves and the banks' settlement risk. When the reserves are below the incompressible demand, banks stop trading as they can't even settle trades.
- An active interbank trading market with volatile interest rate. Above the incompressible demand for reserves but below the optimal level, the relative scarcity of reserves is driving the rates above the policy rate.
- The liquidity trap when there is too much excess reserves. When reserves are in excessive amount, banks have little incentives to trade and park their liquidity at the ODF. The interbank market shrinks.

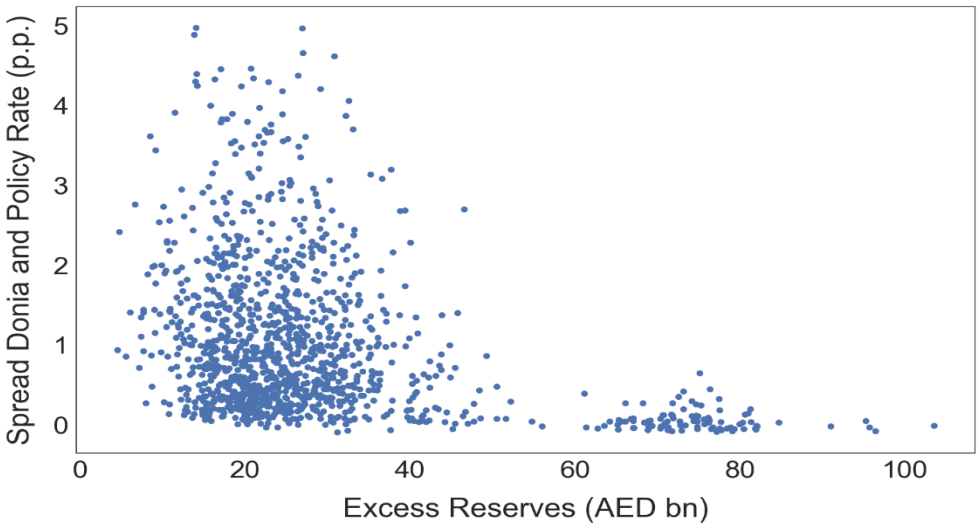
Figure 35. Theoretical Interest Rate Spread Dynamic



Source: IMF staff

90. The theoretical specification of the interest rate spread dynamic is consistent with the UAE data. Over the last five years of observations, there is indeed a strong, nonlinear relationship between the interbank spread and the level of excess reserves. When the level of excess reserves is below AED 25 bn, the DONIA spread surges quickly, and exponentially as the level of reserves approaches the level of incompressible demand.

Figure 36. Interbank Rate Spread with the Policy Rate and Excess Reserves



Source: IMF staff

91. The optimal level of liquidity surplus derives from the central bank objectives, which are twofold. The IMF team assumes that the central bank decides upon the volume of structural liquidity to:

- Maximize the monetary policy traction (i.e., to anchor the interbank rate at the policy rate).
- Support the interbank money market development and build a sovereign yield curve.

However, anchoring the interbank rate has the highest priority as a monetary objective. Therefore, the optimal amount of reserves should reflect this priority by first making sure that the interbank rate is anchored and only then to give the maximize room possible for market trading.

The optimal amount of reserves is the minimal amount of excess reserves for which the interest rate spread is, in absolute terms, minimal:

$$(7)\ E_t^* = \{\min E_t \mid \mathbb{E}\left[|i_t - \overline{\imath}|\right] = 0\}$$

92. Once the optimal liquidity surplus E_t^* is known, the optimal amount of liquidity absorption is the difference between the expected autonomous factors and E_t^*:

$$(8)\quad B_t^* + M\left(\underline{R}^*\right) = \mathbb{E}[AF_t] - E_t^*$$

Intuitively, the central bank should: (i) sterilize the expected liquidity injected by the autonomous factors; but (ii) leave enough liquidity to the banks to meet their incompressible demand for reserves and support market trading and limit interbank trading volatility.

B. Empirical Estimation of the Optimal Liquidity Surplus

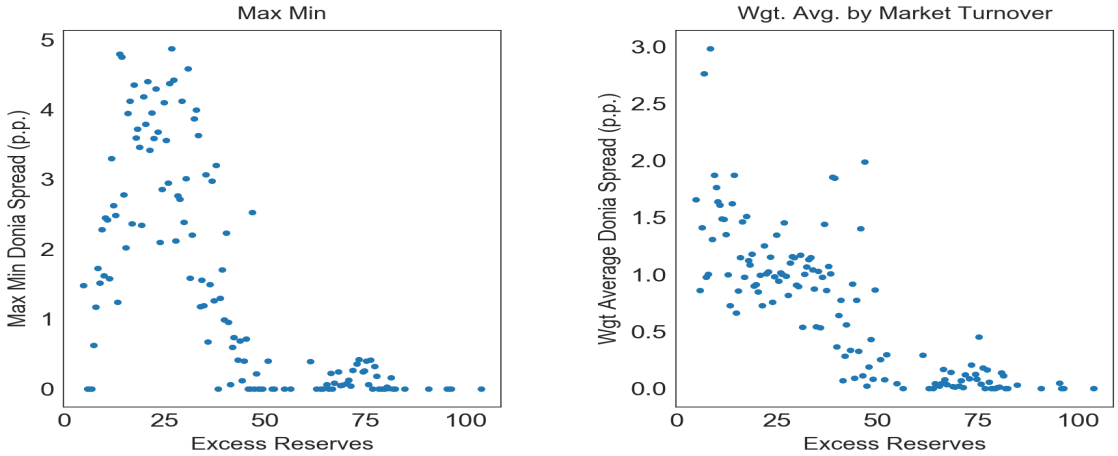
93. The empirical strategy aims at recovering the true relationship between excess reserves and the interbank rate. The conceptual framework and the descriptive statistics suggest that the functional relationship between the excess reserves and the interbank spread is highly non-linear, with a complex exponential decay shape. For that reason, it is not possible to use standard linear regressions. The IMF team presents two approaches, relying either on: (i) unconditional fit, via cubic splines or parametrized functional form; and (ii) a conditional fit, instrumented and cross-validated. The IMF experts have a preference for parametrized, even over-parametrized models, to guarantee parametric stability, which is crucial for operational purposes, as the CBUAE needs stable calibration of its operations. Once the functional relationship has been properly estimated, it is straightforward to recover the different phases.

94. The raw data exhibits a large mass point on the bottom left of the diagram, making necessary a data treatment. The mass point makes the direct fit, either conditional or unconditional, difficult and biased without treatment. It is possible to use a special estimator to tackle this issue (for instance, a rescaled Tobit model), or aggregate the data to flatten the distribution mass over the support. The IMF team prefers the latter, as it is a simple and robust way of operation. The IMF experts have implemented two types of data aggregation: (i) max-min dispersion of the policy rate spread for each level of reserves (discretized each half AED billion); and (ii) a weighted average of the DONIA spread for the same level of reserves, weighted by the market turnover on that day. The shape of the scatter plot under both approaches is broadly similar and allows for a balanced fit over the support of excess reserves.

95. The IMF team operationalizes the CBUAE objective into a practical, data-oriented condition. The conceptual framework defines the optimal level of excess reserves as the minimum level of excess reserves for which the interbank rate is anchored to the policy rate.

$$E_t^* = \{\min E_t \mid \mathbb{E}[|i_t - \bar{\imath}|] = 0\}$$

Figure 37. Data Aggregation by Max-Min Dispersion and Weighted Average



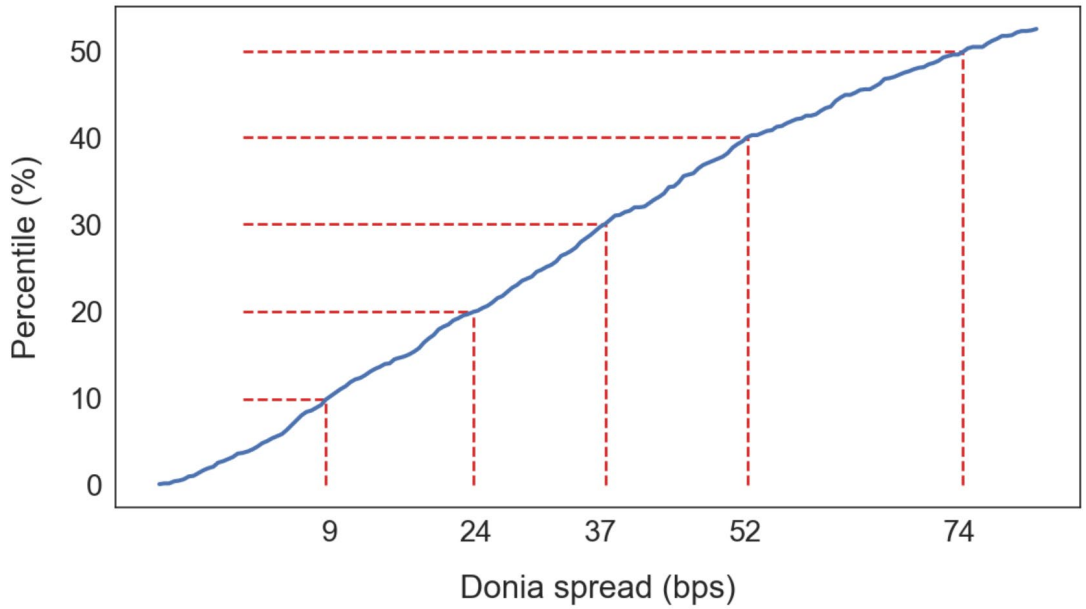
Source: IMF staff

96. In practice, the interbank rate can not be exactly at the policy rate, as there is a constant market noise. The market rate is technically hovering around the policy rate in a region delimited by a few basis points. The optimal length of the region is defined as the level for which the volatility of the interbank rate is contained within the tolerance zone for most observations (e.g., more than 90 percent). The determination of the market tolerance zone follows the empirical distribution function of the daily DONIA spread (raw data). The IMF team chooses 25 bps, which corresponds roughly to the lowest 20th percentile of the empirical cumulative distribution function.

97. The IMF team estimates an unconditional fit of the functional relationship between the excess reserves and the interbank spread, using two methods. The first method is a non-parametric fit via cubic splines. Cubic splines are very flexible, yet smooth enough to provide a reasonable fit. The second method is based on a parametrized fit via a decreasing double exponential functional form. A double exponential composes and exponential function and a power function. More precisely, the decreasing double exponential function is specified as:

$$f(x) = \alpha + \beta * e^{-\lambda^x}$$

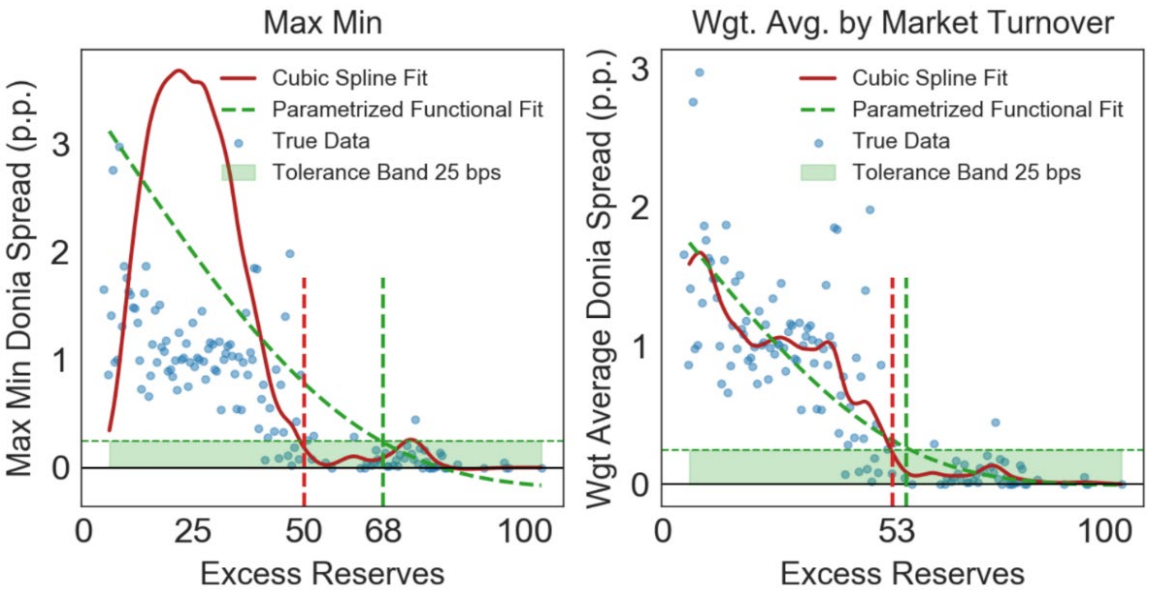
Figure 38. Empirical Distribution of the Interbank Spread on the Left Percentile



Source: IMF staff

98. The decreasing double exponential provides a very sharp decay rate and a quick stabilized shape. It is parametrized by three variables, the location α, the scale β and the decay rate λ, providing plenty of flexibility to accommodate different datasets. The estimation of the three parameters in the unconditional setup is carried out by non-linear least squares with the Levenberg-Marquardt algorithm, which is relatively robust to initial conditions and involves limited computation time compared to more intensive algorithms.

Figure 39. Calibration of the Optimal Liquidity Surplus via Unconditional Fit

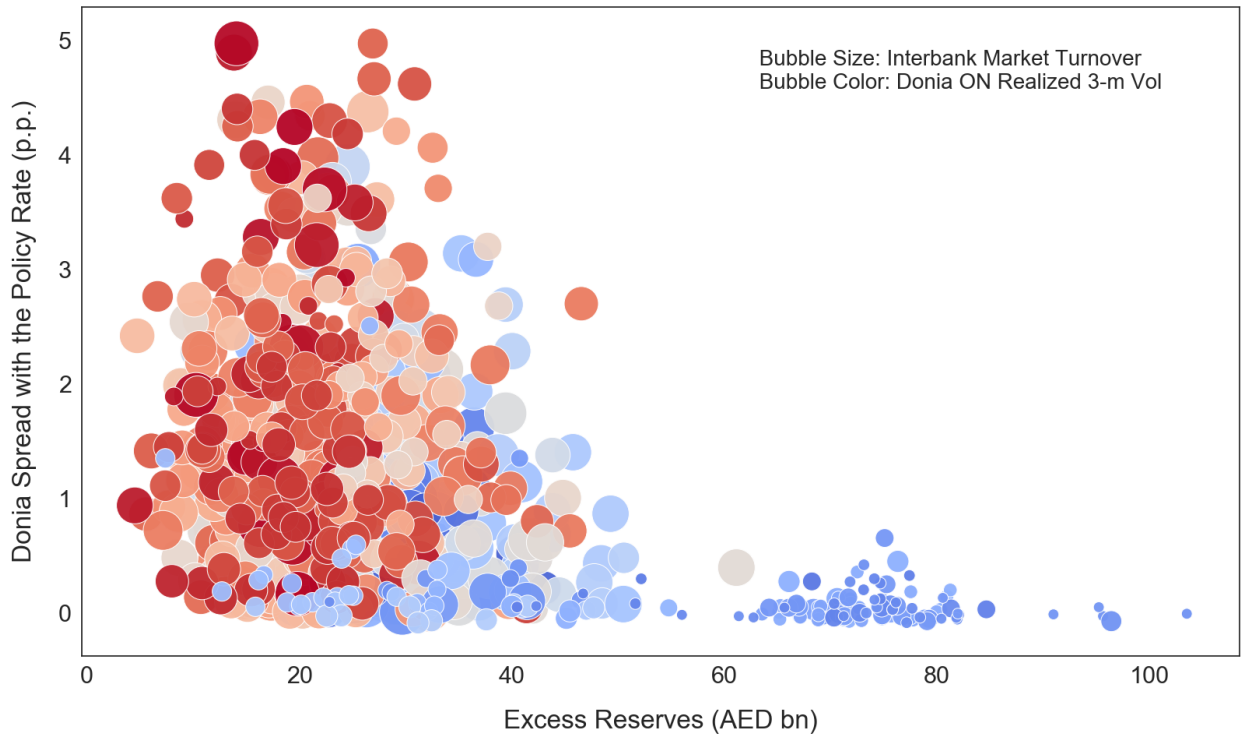


Source: IMF staff

99. Under both the unconditional non-parametric and the parametric approaches, the optimal liquidity surplus is estimated between AED 50–60 bn. The optimal liquidity surplus depends on the aggregation method as well as the fit algorithm chosen. While the cubic fit is poor on the max-min dispersion aggregation method, it works relatively well on the weighted average metric. After the AED 50–60 bn threshold, most of the observations exhibit an interbank spread within the tolerance band of 25 bps.

100. Important factors impact the reaction function of the interbank spread to the excess reserves, suggesting that the fit should be conditional instead of unconditional. The bubble plot presents the relationship between the two main variables—interbank spread and excess reserves—as well as prevailing interbank market turnover and the three-month realized volatility of the DONIA. The figure suggests that the very large amount of excess reserves is associated with tiny interbank market turnover and low volatility, reflecting low trading activity as explained above. On the contrary, the observations with the largest spreads have occurred both under large turnover and high volatility. These elements suggest that conditional fit is crucial to properly recover the true functional shape of the reaction of the interbank spread to the excess reserves.

Figure 40. Interbank Spread, Volatility, and Liquidity



Source: IMF staff

101. The price quantity relationship between the excess reserves and the DONIA spread is a typical example of endogeneity simultaneity and should be instrumented. Since the price (the interbank rate) partially determines the quantity (excess reserves available on the market) and vice-versa, the relationship is likely endogenous. Given the lack of natural experiment or experimental set-up, the only viable solution is to instrument the excess reserves by an exogeneous variable. The autonomous factors are natural candidates: the team uses both the level and the volatility of the sum of the autonomous factors, to design an over-identified regression set-up.

102. The IMF team estimates a conditional fit model, controlling for seasonal effects, market microstructure variables, uncovered interest parity and exogeneous risk sentiment variables. As suggested by the conceptual framework, these variables enter either the demand or the supply of reserves (or both), and therefore impact the determination of the interbank spread with the policy rate. Therefore, the mission has used the following variables as control variables:

- Seasonal factors: religious and secular holidays, regular calendar seasonality.
- Market turnover: capture market microstructure.
- Fed IOER: capture the uncovered interest parity and reflects international arbitrage.

- Oil prices (both in level and volatility): capture both the precautionary demand and the drivers of the autonomous factors.

- VIX to capture international risk sentiment.

- The Dubai stock market realized volatility and the Donia realized volatility to capture domestic risk sentiment.

103. The instrumented conditional fit estimation relies on an IV-2SLS algorithm with cross-validation.[18] A non-linear least-square set-up—as used for the conditional fit—would be very inconvenient in the context of a two-step instrumentation procedure. Instead, it is easier to impose the parametric form on the level of excess reserves directly, and to use a bijective transformation of the regressor instead of the regressor itself. The specification is therefore:

$$Donia\ Spread_t = \alpha + \beta * e^{-\lambda^{Excess\ Reserves(t)}} + \gamma \mathrm{X}_t + \epsilon_t$$

While most coefficients can be directly estimated via a standard IV-SLS procedure, the decay coefficient $\boldsymbol{\lambda}$ cannot. Hence, to circumvent this issue, the IMF team uses a cross-validation two-step approach:

1. Estimate via IV-2SLS $\boldsymbol{\alpha}$, $\boldsymbol{\beta}$, $\boldsymbol{\gamma}$ for a given level of the parametric decay rate $\boldsymbol{\lambda}$

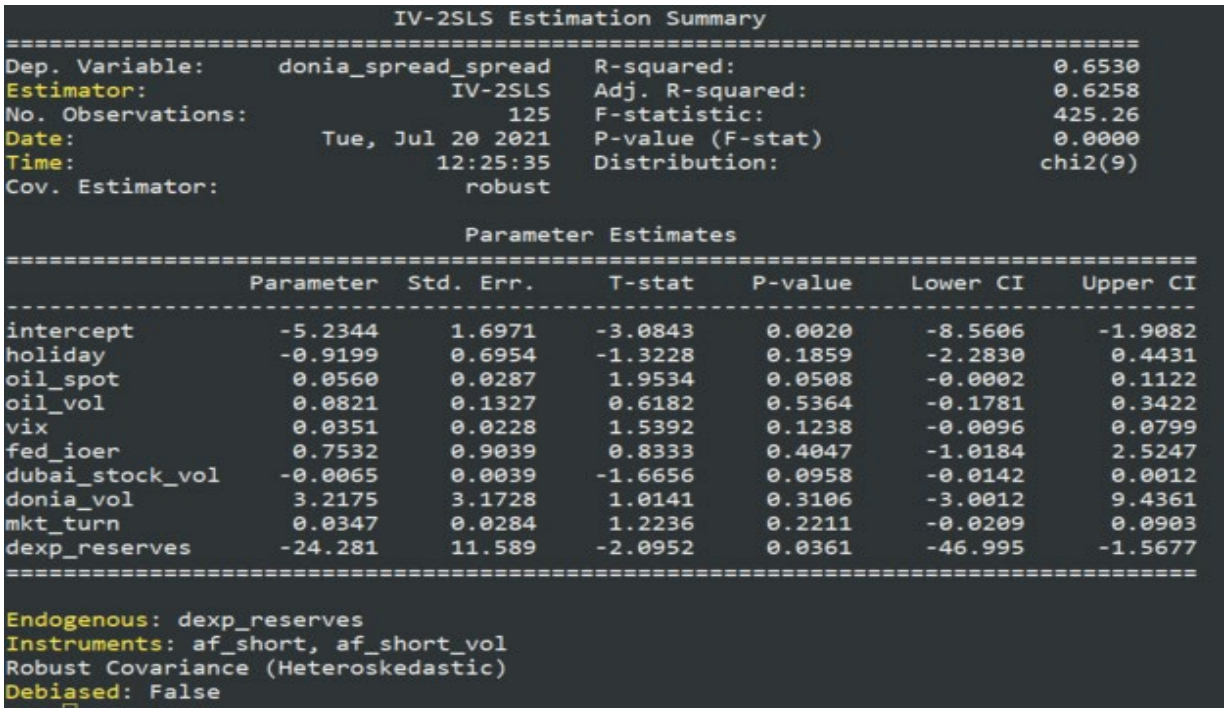
2. Repeat the process over a grid of potential $\boldsymbol{\lambda}$ and select the best one on maximizing an information criterion or minimizing the residuals sum of squares.

The cross-validation is key to be able to estimate a complex non-linear functional form with a standard linear IV-2SLS estimator.

104. The cross-validated IV-2SLS regressions exhibit very decent in-sample fit—with R2 between 65 and 78 percent for max-min dispersion and weighted average respectively, and a substantial the regressors are statistically significant at the 5th or at the 10th percentile threshold. Besides, the first stage of the IV-2SLS has an F-statistic near 10, suggesting a relatively decent fit on the first stage and adequate endogeneity control. The estimated results of the regressions are presented in the Python regression table below.

[18] The Python scripts to estimate this procedure are available on request, contact: https://romainlafarguette.github.io/.

Figure 41. Estimated Coefficients of the CV IV-2SLS for the Max-Min Spread Dispersion



IV-2SLS Estimation Summary

Dep. Variable:	donia_spread_spread	R-squared:	0.6530
Estimator:	IV-2SLS	Adj. R-squared:	0.6258
No. Observations:	125	F-statistic:	425.26
Date:	Tue, Jul 20 2021	P-value (F-stat)	0.0000
Time:	12:25:35	Distribution:	chi2(9)
Cov. Estimator:	robust		

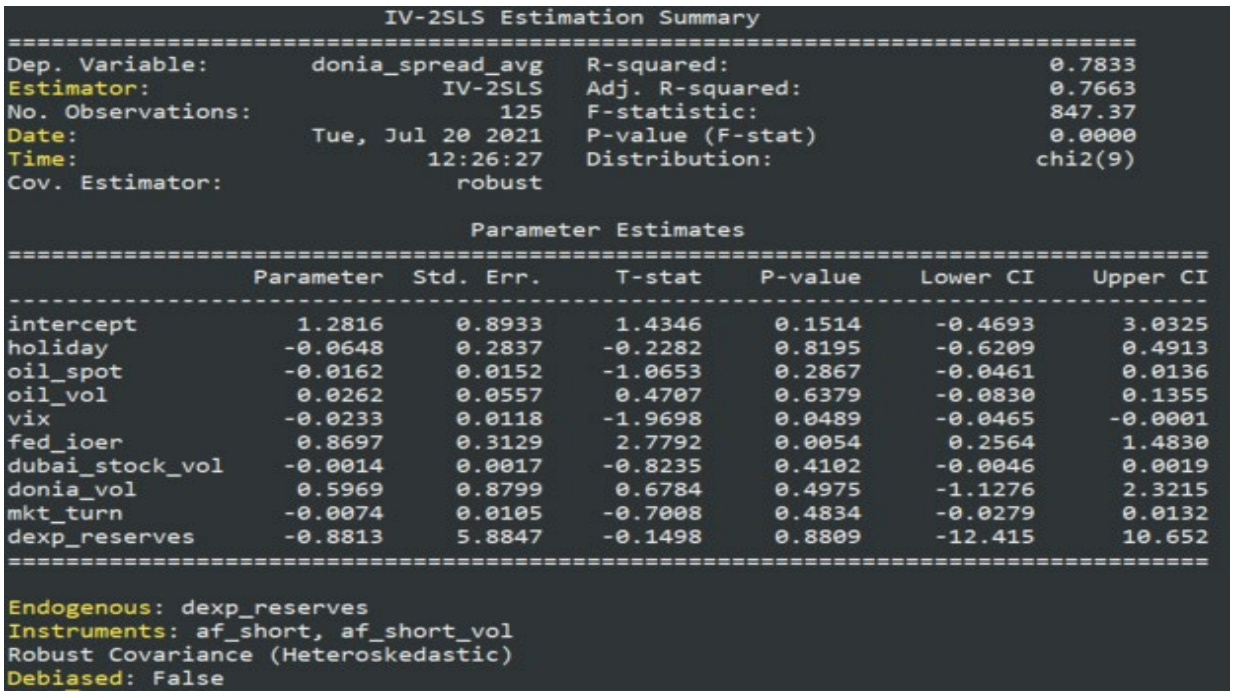
Parameter Estimates

	Parameter	Std. Err.	T-stat	P-value	Lower CI	Upper CI
intercept	-5.2344	1.6971	-3.0843	0.0020	-8.5606	-1.9082
holiday	-0.9199	0.6954	-1.3228	0.1859	-2.2830	0.4431
oil_spot	0.0560	0.0287	1.9534	0.0508	-0.0002	0.1122
oil_vol	0.0821	0.1327	0.6182	0.5364	-0.1781	0.3422
vix	0.0351	0.0228	1.5392	0.1238	-0.0096	0.0799
fed_ioer	0.7532	0.9039	0.8333	0.4047	-1.0184	2.5247
dubai_stock_vol	-0.0065	0.0039	-1.6656	0.0958	-0.0142	0.0012
donia_vol	3.2175	3.1728	1.0141	0.3106	-3.0012	9.4361
mkt_turn	0.0347	0.0284	1.2236	0.2211	-0.0209	0.0903
dexp_reserves	-24.281	11.589	-2.0952	0.0361	-46.995	-1.5677

Endogenous: dexp_reserves
Instruments: af_short, af_short_vol
Robust Covariance (Heteroskedastic)
Debiased: False

Source: IMF staff

Figure 42. Estimated Coefficients of the CV IV-2SLS for the Weighted Average Dispersion



IV-2SLS Estimation Summary

Dep. Variable:	donia_spread_avg	R-squared:	0.7833
Estimator:	IV-2SLS	Adj. R-squared:	0.7663
No. Observations:	125	F-statistic:	847.37
Date:	Tue, Jul 20 2021	P-value (F-stat)	0.0000
Time:	12:26:27	Distribution:	chi2(9)
Cov. Estimator:	robust		

Parameter Estimates

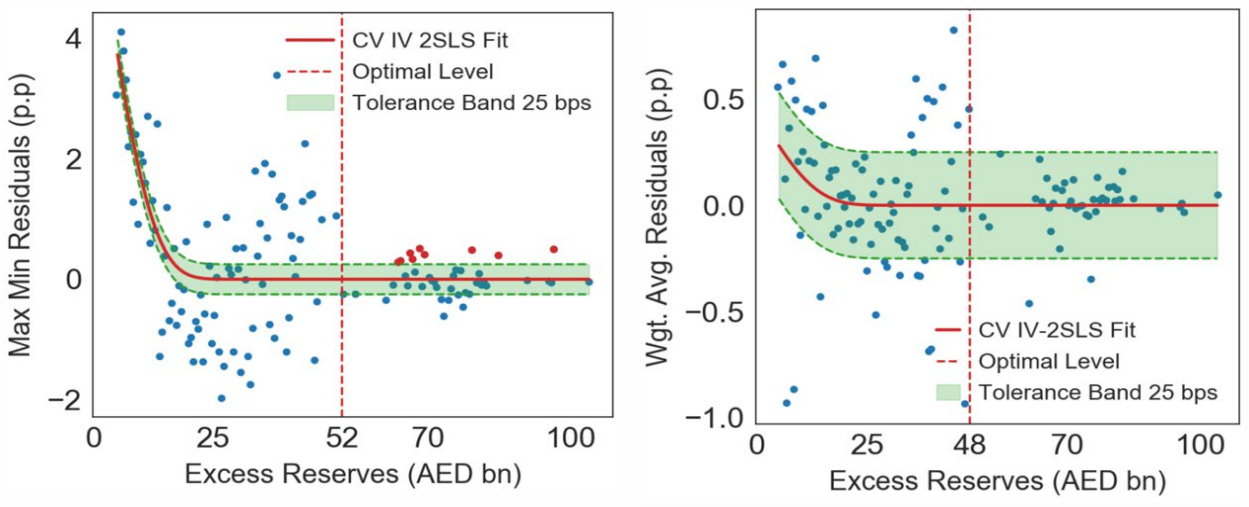
	Parameter	Std. Err.	T-stat	P-value	Lower CI	Upper CI
intercept	1.2816	0.8933	1.4346	0.1514	-0.4693	3.0325
holiday	-0.0648	0.2837	-0.2282	0.8195	-0.6209	0.4913
oil_spot	-0.0162	0.0152	-1.0653	0.2867	-0.0461	0.0136
oil_vol	0.0262	0.0557	0.4707	0.6379	-0.0830	0.1355
vix	-0.0233	0.0118	-1.9698	0.0489	-0.0465	-0.0001
fed_ioer	0.8697	0.3129	2.7792	0.0054	0.2564	1.4830
dubai_stock_vol	-0.0014	0.0017	-0.8235	0.4102	-0.0046	0.0019
donia_vol	0.5969	0.8799	0.6784	0.4975	-1.1276	2.3215
mkt_turn	-0.0074	0.0105	-0.7008	0.4834	-0.0279	0.0132
dexp_reserves	-0.8813	5.8847	-0.1498	0.8809	-12.415	10.652

Endogenous: dexp_reserves
Instruments: af_short, af_short_vol
Robust Covariance (Heteroskedastic)
Debiased: False

Source: IMF staff

105. The IMF team presents the conditional fit in a univariate set-up, using the estimated residuals of the DONIA spread on the exogeneous regressors instead of the raw level of the DONIA. Technically, while the optimal liquidity surplus can be estimated directly from the estimated coefficients of the cross-validated IV-2SLS regression, it is more intuitive to present the univariate non-linear fit of the excess reserves on the residuals of the dependent variable on the other regressors, so that the impact of excess reserves can be clearly represented. This is one potential application of the Frisch-Waugh theorem.[19] The approach is valid as the Frisch-Waugh theorem is a bijective mapping on the residual space, so that the optimal level of excess reserves in the two-step fit is the same as under the one-step approach.

Figure 43. Liquidity Calibration via Cross-Validated Instrumented Conditional Fit (for Max-Min Spread and Weighted Average Aggregation)



Source: IMF staff

106. Under both aggregation approaches, the optimal liquidity surplus estimated through the conditional cross-validated IV-2SLS fit is around AED 50 bn. The optimal liquidity surplus is slightly lower than the one estimated via the unconditional fit, reflecting the importance of omitted variables in the unconditional estimation. Both methods show that at AED 50 bn, the interbank rate is anchored to the policy rate with minimal interbank rate volatility. Above this level, there is no room to anchor further the interbank rate to the policy rate but leaving excessive liquidity on the market would be detrimental for market development and yield curve building.

107. Through unconditional and conditional fitting approaches, applied on two different data aggregation methods, the IMF experts have determined that the CBUAE should operate a parsimonious floor with excess liquidity in the magnitude of AED 50 bn. However, it is still unclear how the CBUAE should sterilize excess liquidity to reach a structural surplus of AED 50 bn. How should the CBUAE calibrate the mix between the different

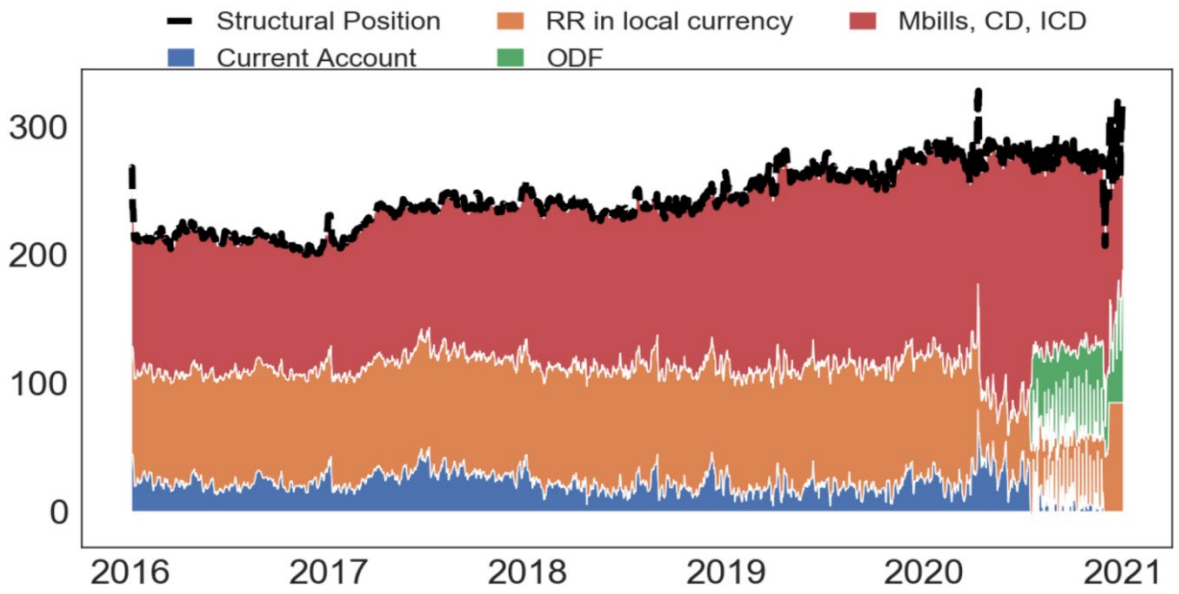
[19] For more details, please refer to Chipman (2011) *Advanced Econometric Theory.*

instruments—the required reserves, the issuance of long-term securities and the issuance of short-term securities? The IMF team has designed a conceptual and empirical framework to answer this question, detailed in the next section.

C. Optimal Operational Sterilization Mix

108. The CBUAE has different instruments to sterilize liquidity, each of them with specific features. It can use three instruments to sterilize liquidity: (i) the level of statutory reserves $\underline{R}$ with averaging gives the possibility to banks to smooth their liquidity across the reserves maintenance period, thereby reducing the interbank market volatility (see Bindseil 2014 for a discussion on the impact of reserves averaging on the interbank rate); (ii) long-term (up to one year) central bank securities B_t^{LT} are key to develop the capital markets and benchmark the yield curve, with regular issuance in sufficient amount; and (iii) short-term instruments B_t^{ST} should quickly reflect the evolution of liquidity conditions, with minimal duration risk. In practice, the CBUAE issues different types of instruments (M-Bills, Islamic CD) at different maturities and has a remaining stock of outstanding CDs which have been discontinued, but for the sake of simplicity, the IMF team only differentiates between long-term (structural) issuances and short-term issuances. By definition, the total level of CBUAE securities issued is equal to $B_t^{LT} + B_t^{ST} = B_t$.

Figure 44. Current UAE Structural Liquidity Position



Source: IMF staff and CBUAE

109. The optimal level of statutory reserves should depend on the volatility of the autonomous factors. In practice, the CBUAE decides its securities issuances based on its forecasts of the autonomous factors, and not on the realized (unknown at time t-5) autonomous factors. Hence, from the accounting equality, the optimal level of securities that the CBUAE will issue is equal to:

$$(9)\ B_t^* = \Im(AF_t) - E_t^* - \underline{R^*}$$

Where $\Im(AF_t)$ represents the forecasted autonomous factors. However, the optimal amount of liquidity absorption depends on the true expected values, and not the forecasted ones, potentially noisy. Hence, based on the clearing condition, where the interbank spread with the policy rate is 0 on average around the optimal liquidity surplus E_t^*:

$$(10)\quad B_t^* + m(\underline{R^*}) + \underline{R^*} = \mathbb{E}[AF_t] - E_t^*$$

Combining the CBUAE sterilization objective with the optimal sterilization level gives the optimal level of required reserves the central bank should impose on banks:

$$(11)\quad m(\underline{R^*}) = \mathbb{E}[\Im(AF_t) - AF_t]$$

Under reserves averaging *m()*, the optimal level of regulatory reserves should therefore be equal to the forecasting errors of the autonomous factors $\mathbb{E}[\Im(AF_t) - AF_t]$. The level of statutory reserves is stable, based on the average of past forecasting errors. Reserves averaging acts as a buffer to absorb forecasting noise.

110. The IMF team has provided the CBUAE with a probabilistic model for forecasting the autonomous factors (see above). With the data infrastructure provided, the forecasting errors are automatically generated by the IMF model. To add extra robustness, the CBUAE should calibrate the statutory reserves not based on the average past forecasting errors, but instead on the conditional forecasting errors at a given confidence level. Using probability confidence of interval instead of past forecasting errors has two main advantages:

1. **Forward-looking:** The forecasting model confidence interval evolves with structural breaks and other changes in the data generating process.

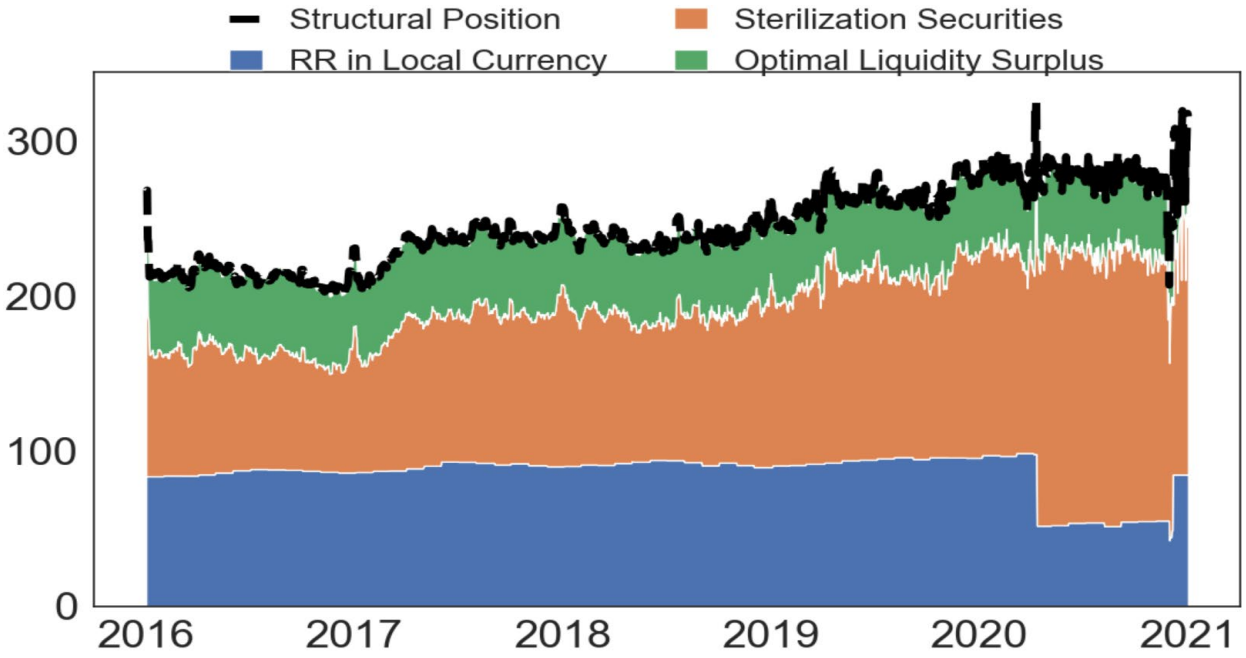
2. **Frequency-based:** The threshold of the confidence interval (e.g., 95 percent) allows to absorb the large majority of the shocks and implicitly determines the frequency of adjusting operations. However, there is a tradeoff for the CBUAE: the larger the statutory reserves, the more limited the room for structural operations.

111. Once the optimal level of required reserves is known, the CBUAE can directly infer its optimal level of securities. The optimal level of securities is the difference between the autonomous factors (liquidity injection), the optimal liquidity surplus and the required reserves (liquidity absorption).

$$B_t^{LT*} + B_t^{ST*} = \mathbb{E}(AF_t) - E_t^* - \underline{R^*}$$

Assuming that the optimal level of reserves is the historical one, it is straightforward to present the optimal securities amount.

Figure 45. Optimal Liquidity Surplus and Sterilization Instruments



Source: IMF staff

112. The CBUAE should be guided by two considerations to decide on how to split the issuances of securities between structural and fine-tuning operations:

- The structural operations are used to build the yield curve, and the issuances should be large over a few benchmark points to support capital market development.
- The short-tenor issuances should complement the structural operations to adjust liquidity and to allow risk-pricing to operate via short duration securities.

113. The IMF team recommends using standard time-series filter to deduct the split between structural operations and short-tenor issuances, conditional on a minimum benchmark size for each security issued. Using a simple HP filter,[20] with a high degree of smoothing (1600*20^24), the team has extracted the trend and the cycle of the optimal level of securities (both short and long maturities) to issue:

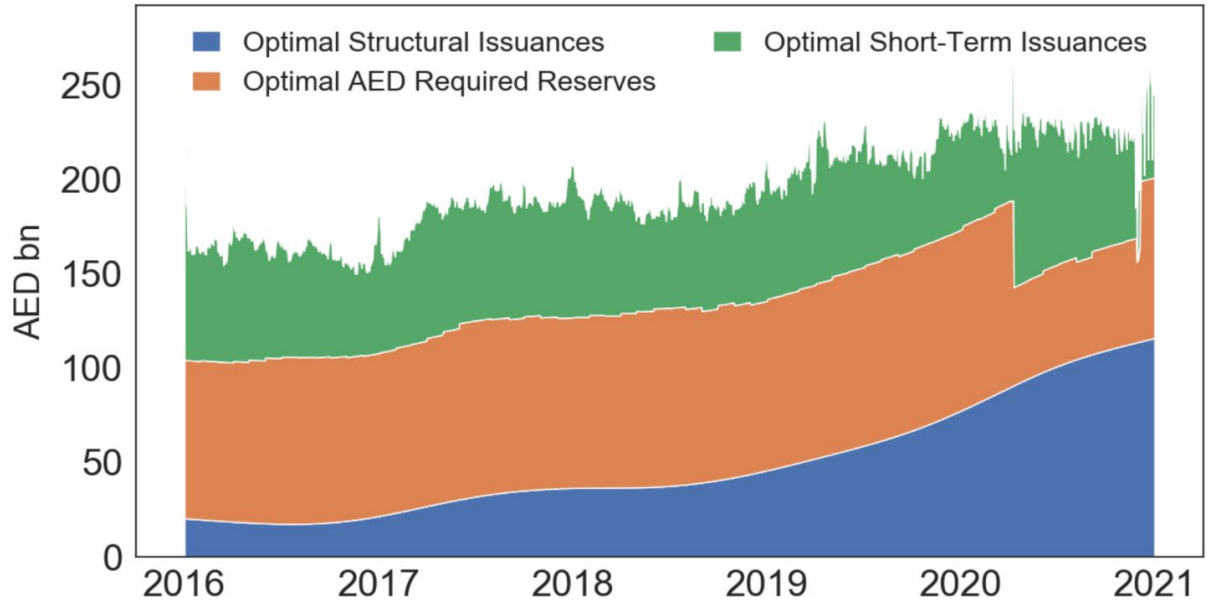
$$(13)\ B_t^{LT*} = Trend(\mathbb{E}(AF_t) - E_t^* - \underline{R^*})$$

The shorter-tenors issuances are the residual: $(14)\ B_t^{ST*} = \mathbb{E}(AF_t) - E_t^* - \underline{R^*} - B_t^{LT*}$

[20] The IMF experts have also tried the Hamilton (2017) filter, as well as the seasonally adjusted Baxter-King filters, which underperform the HP filter in the case of the UAE.

Using a very smooth filter guarantees the stability of the structural issuances over time. However, it might be the case that the CBUAE needs to adjust the trend level to make sure that each sterilization instrument issuance has enough volume to build a representative benchmark yield. The determination of the benchmark maturities and volumes should be guided by market development considerations and yield curve construction.

Figure 46. Optimal Split Between Structural and Short-Term Instruments

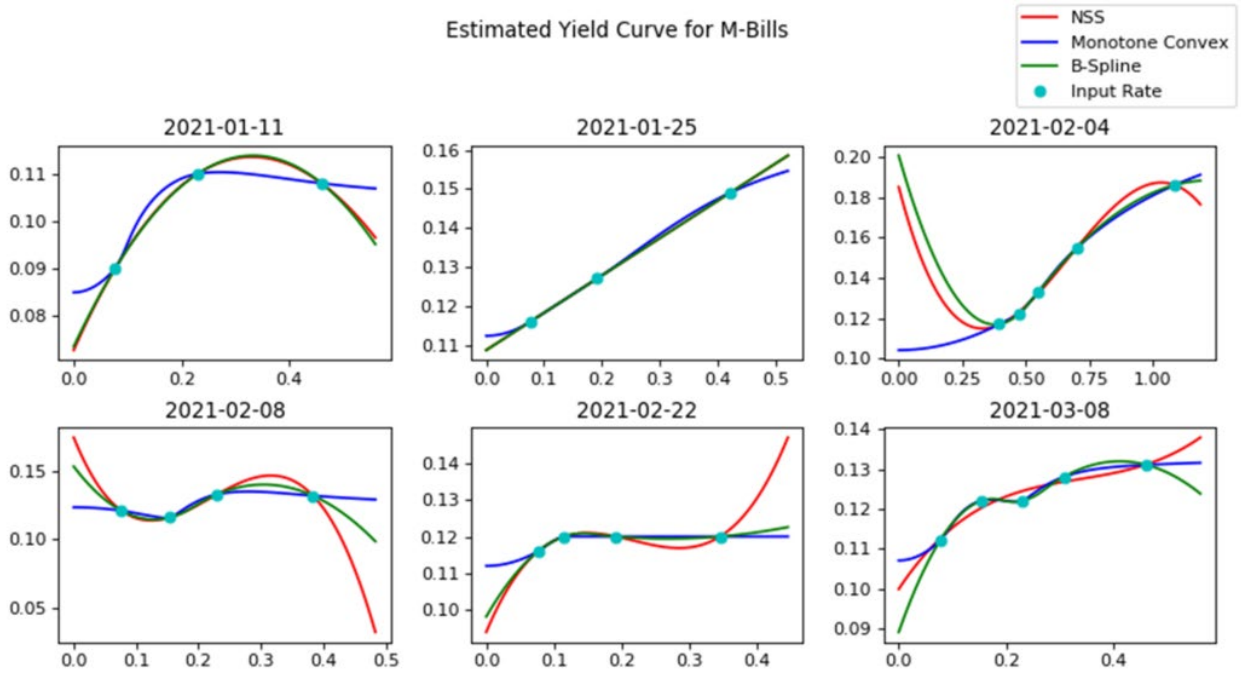


Source: IMF staff

114. The IMF team recommends using a monotone convex interpolator to estimate the sovereign yield curve in the UAE. Having a robust yield curve estimator is crucial to adequately issue securities along the curve and maintain an accurate risk-pricing. However, the UAE sovereign yield curve barely exists after one-year maturity, as the Treasury issues minimal amount of Treasury bonds. Therefore, most of the estimators commonly used in the industry are not appropriate for the UAE. For instance, the Nielson Siegel Svensson estimator assumes a full-fledged yield curve with a long end in order to fit the parameters. Besides, methods fit for advanced economies with deep markets tend to be not robust to short-sample estimation and are likely to be under-parametrized for countries with lower data quality. The IMF team suggests using an over-parametrized interpolator, monotone convex, as presented in Hagan and West (2010).[21] Over parametrization ensures parameter stability and allows for stable sampling. The team also tried basis splines, but this approach underperforms compared to the monotone convex interpolator.

[21] http://web.math.ku.dk/~rolf/HaganWest.pdf.

Figure 47. Yield Curve Estimation for the UAE Using Different Algorithms



Source: IMF staff

D. Recommendations

115. The IMF teams recommends operating under a liquidity surplus at around AED 50 bn. The AED 50 bn threshold is the result of the empirical estimation presented above but can be adjusted if market conditions and structural factors change.

116. The adjustment towards the optimal level should proceed gradually, with a close market monitoring and should be adjusted if necessary. A gradual approach is key to avoid market disruptions, to properly fix the expectations of market participants and anchor the policy rate.

117. The CBUAE should calibrate the required reserves to create a buffer to absorb its autonomous factors forecasting errors. The idea is to leverage on the averaging feature of the required reserves to limit market operations and to mitigate the interbank rate volatility.

118. The IMF team suggests calibrating the structural issuances based on a filtering approach to guarantee both stable and large enough issuances of securities. Stable issuance of long-term securities (up to one year) is key for supporting market development.

119. A follow-up IMF TA mission is needed to assess and project the monetary policy costs of the monetary framework. During this mission, the IMF team has focused on calibrating the optimal level of liquidity surplus to reach the CBUAE objectives. However, the level of liquidity surplus and the *operational modus operandi*—the mix between instruments and

their remuneration—have important consequences on the costs of monetary policy implementation and the income statement of the CBUAE. A thorough analysis of the monetary policy costs—also including different scenarios—is needed to adequately inform the policymakers and ensuring a financially sustainable operational framework.

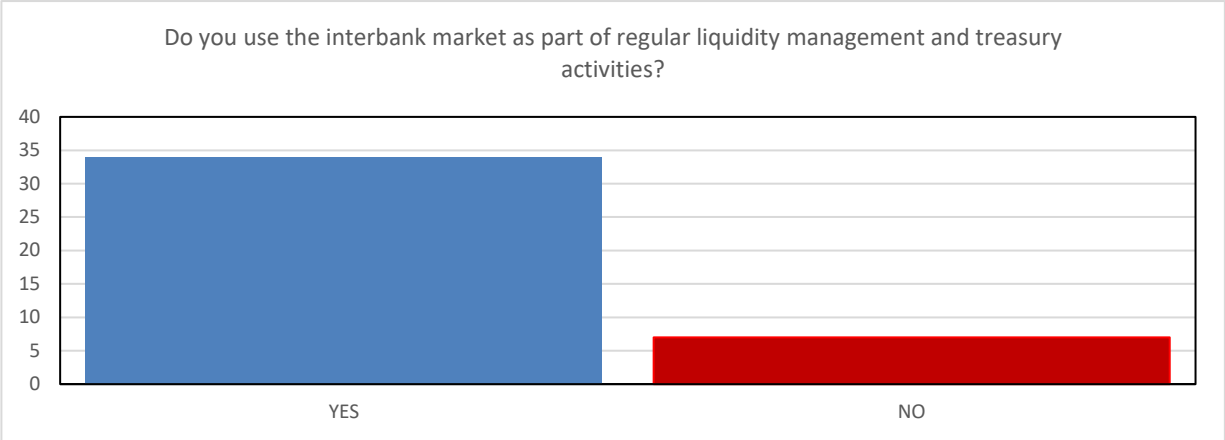
120. The authorities should closely monitor market developments, based on a solid data collection infrastructure and using the tools presented in this TA report, and staff the market surveillance team with quantitative researchers. Given the evolving complexity of the financial environment in the UAE and worldwide, it is crucial that the toolkit and CBUAE staff be adequate and well trained to provide appropriate guidance for policy makers. Also, it is important that the CBUAE operates a solid data collection infrastructure, to be able to analyze complex market developments in real time. Finally, the authorities should also establish a regular working group with market participants to exchange on recent market developments and potential issues the market participants might be facing.

V. Money Markets Development

A. Unsecured Interbank Market

121. Although market participants rely on the CBUAE as the main counterparty for liquidity management, the introduction of M-Bills and PDs are starting to develop a secondary market for M-Bills and an interbank repurchase market.

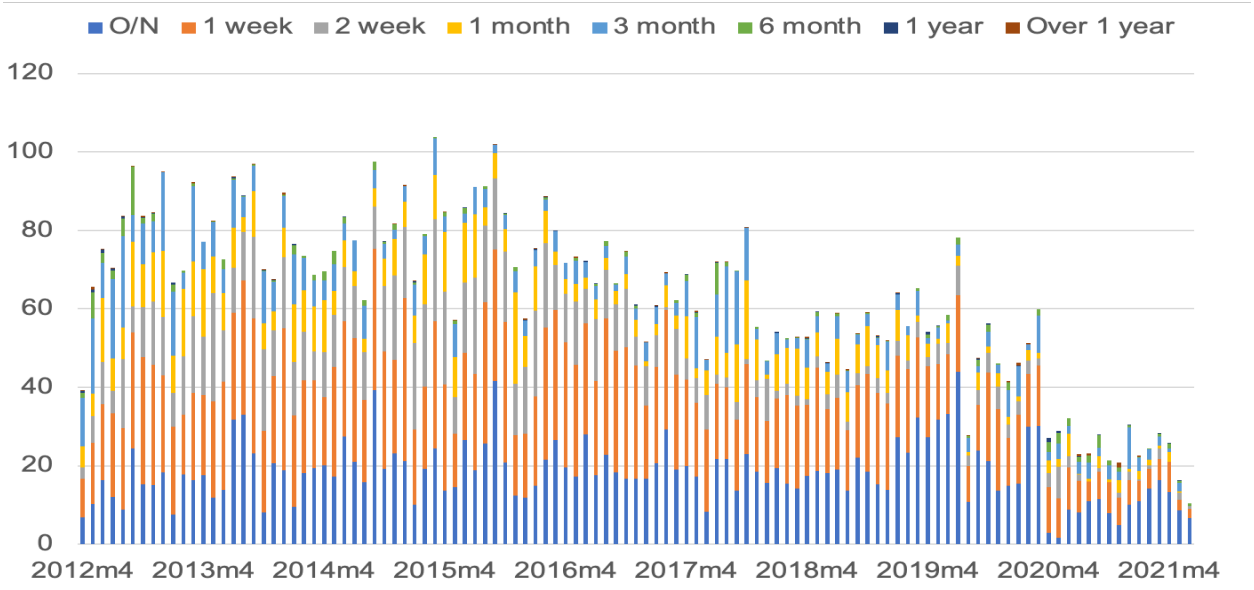
Figure 48. Usage of Interbank Market



Source: IMF's Banks Survey

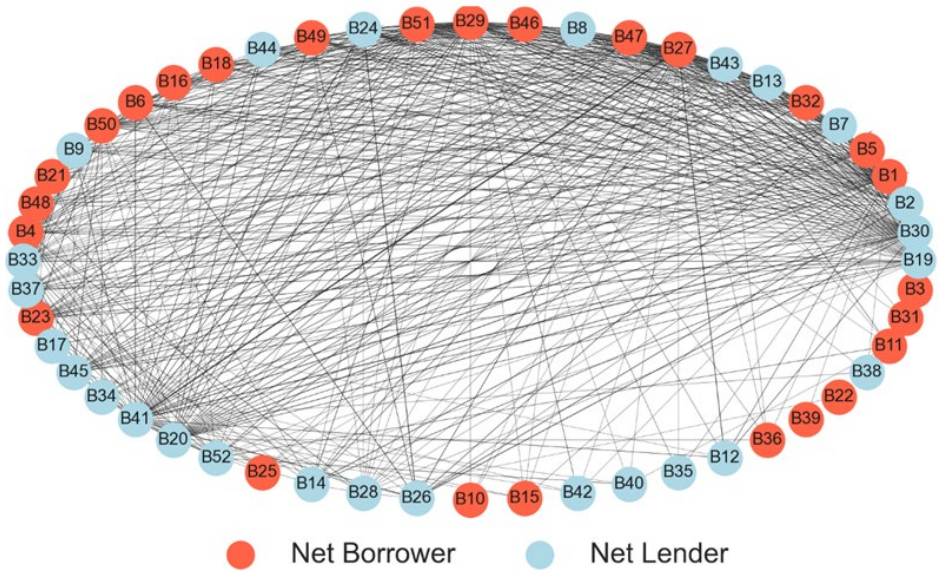
122. Unsecured interbank market activity in the UAE has plummeted since the outbreak of the COVID-19 crisis. This collapse has accelerated in Q1 and Q2 2020 following the implementation of the new monetary policy framework. The fall is most visible at short maturities. Along the fall in volumes, the network density of the market has declined significantly with the number of market participants reduced on average from 20 to 5 participants on both sides of the trade.

Figure 49. Unsecured Interbank Volume (in AED billions)



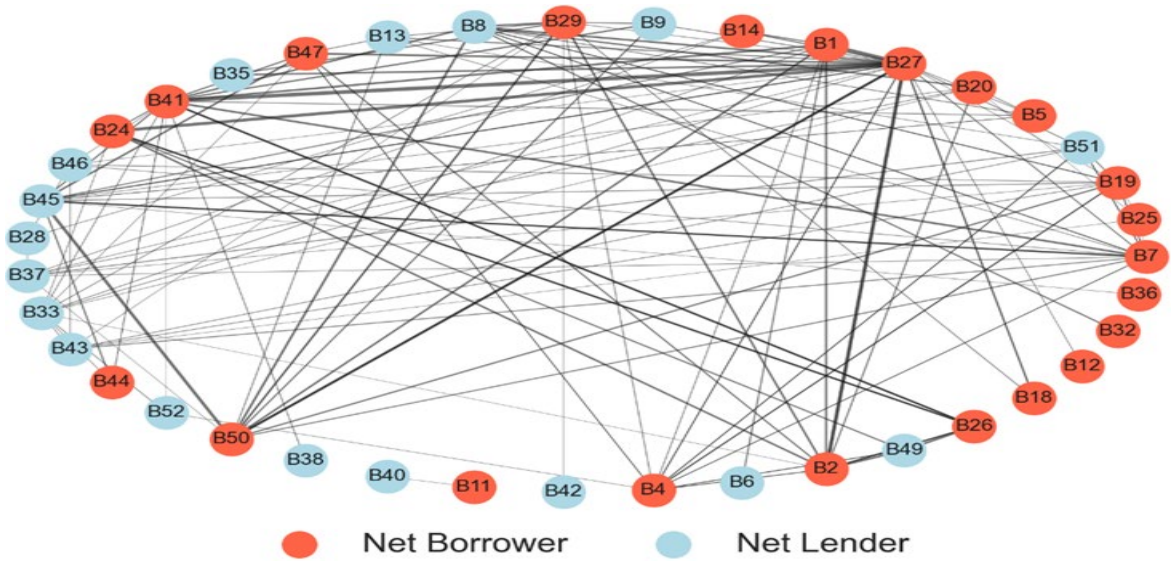
Source: CBUAE

Figure 50. Unsecured Interbank Network before July 12, 2020



Source: CBUAE and IMF staff, banks' data anonymization by IMF staff

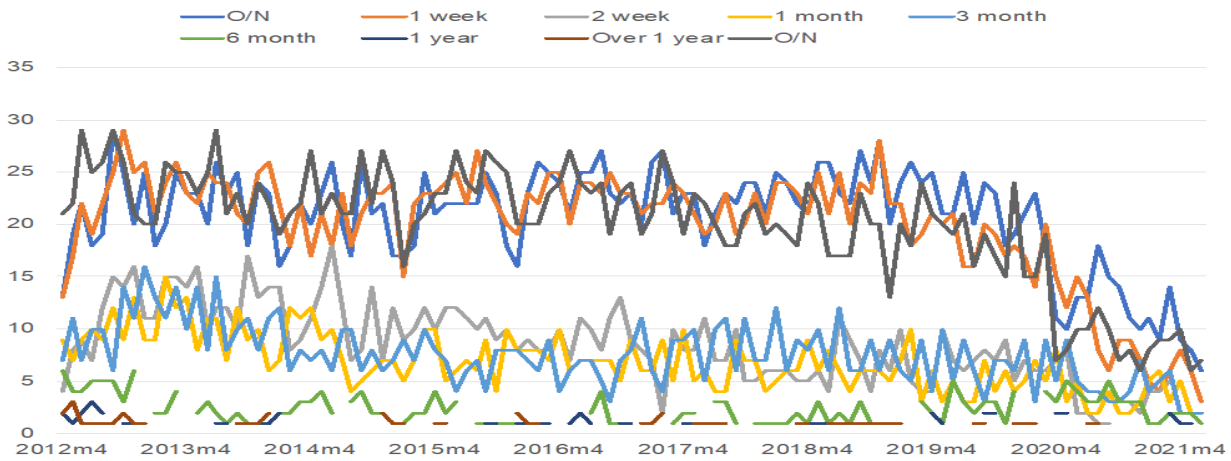
Figure 51. Unsecured Interbank Network after July 12, 2020



Source: CBUAE and IMF staff, banks' data anonymization by IMF staff

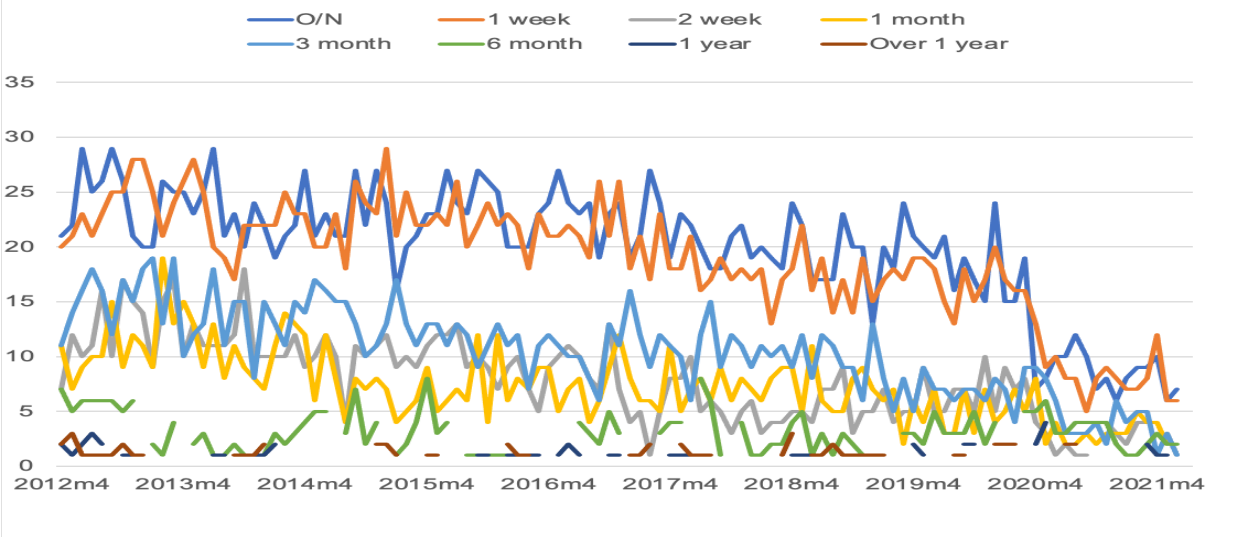
123. As a result, volumes have become highly concentrated at one or two lenders which increases the risk of an interbank market breakdown. At maturities longer than one-week the fall started earlier, in 2016, coincident with the adoption of stricter liquidity ratios causing banks to reprice the risk of term unsecured interbank lending. Lower volumes are not necessarily a sign of market tensions. Survey evidence indicate that the views of banks are equally split between those that consider counterparty risk to be a significant issue and those that do not. And counterparty limits remain mostly not binding varying from 65 million USD to 836 million USD, while over a full month the overnight volume stands at 10 billion AED on average according to survey evidence.

Figure 52. Participation in the Unsecured Interbank Market, Number of Lenders



Source: CBUAE

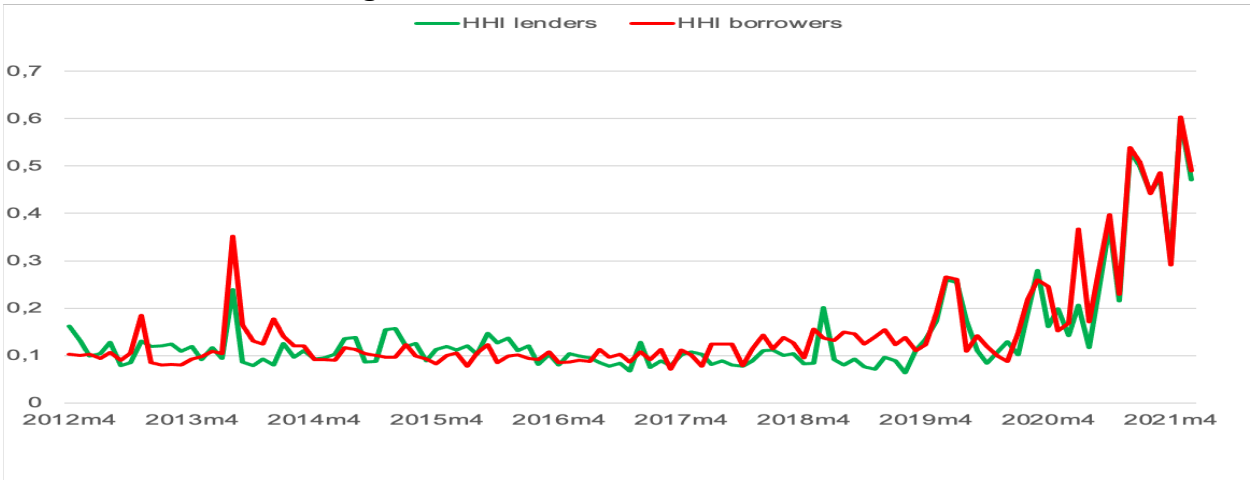
Figure 53. Participation in the Unsecured Interbank Market, Number of Borrowers



Source: CBUAE

124. Instead, the downward trend in volume is more likely the consequence of: (i) massive liquidity injection by the CBUAE; (ii) temporary and permanent adjustments to the monetary policy framework; and (iii) to the enforcement of Basel III liquidity regulations initiated in 2016. First, banks were provided with ample liquidity from the CBUAE in response to the COVID crisis reducing the need to tap the market for funding. Second, following the introduction of the ODF facility in July 2020, banks facing tight liquidity requirements prefer to park excess reserves at the ODF remunerated at 10 bps rather than increase their exposure to counterparty risk and earn barely more than 10 bps. Last, the reduction in reserves requirements in April 2020 from 14 percent to 7 percent has provided further leeway for banks to settle unexpected payment flows without much need to resort frequently to interbank loans. The permanent changes in liquidity regulation and adjustments to the monetary policy framework make it unlikely that market volumes will recover much in the future.

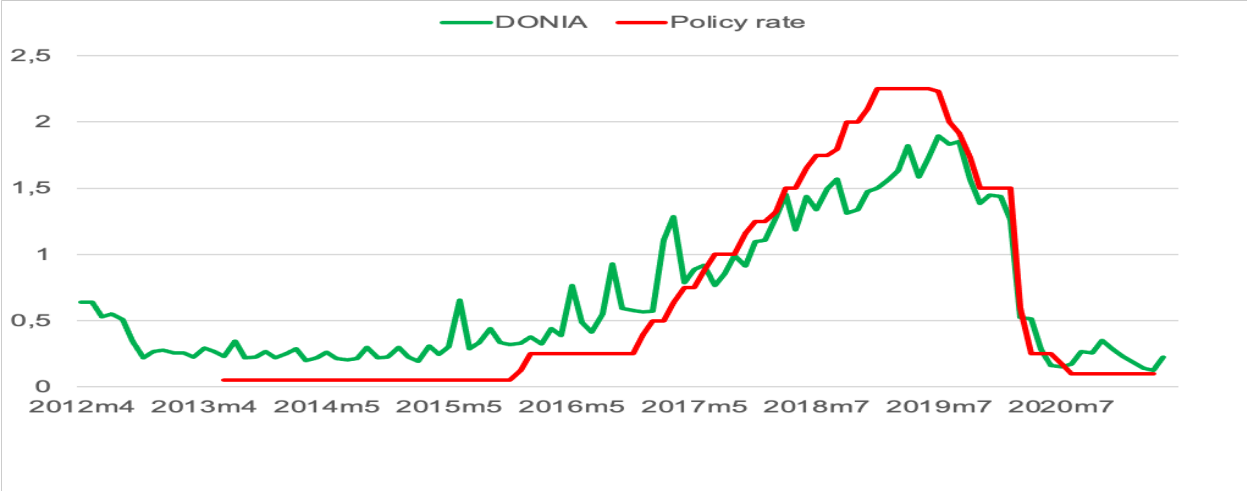
Figure 54. Herfindhal Index O/N Market



Source: CBUAE and IMF staff calculations

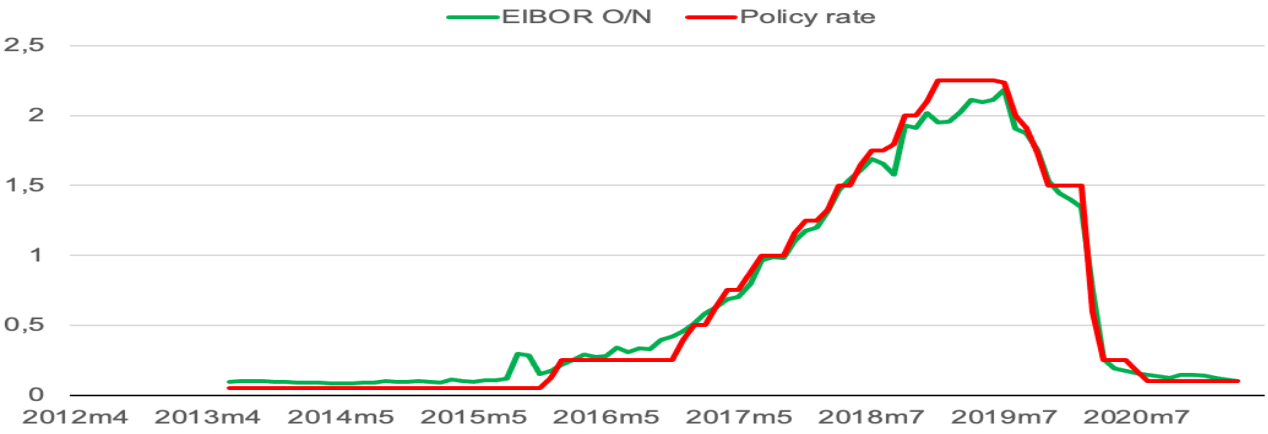
125. Interbank money market rates have displayed a negative spread to the policy rate for about 24 months from mid-2017 to mid-2019. Market rates falling below the policy rate probably result from domestic banks intermediating the CBUAE facilities for foreign banks and earning the small spread as witnessed in other countries since 2007. It may result also from a fall in the number of transactions hence causing EIBOR calculations to rely more on transactions with non-banks such as wholesale deposits with money market funds and investment funds. Non-banks typically have no access to the ODF explaining why EIBOR, which is partly integrating transaction with non-banks (DF2), exhibits a spread to the policy rate. In addition, differences in regulatory costs imply that the cost of bank borrowing from non-banks is somewhat lower than comparable interbank rates.

Figure 55. DONIA versus Policy Rate



Source: CBUAE and IMF staff calculations

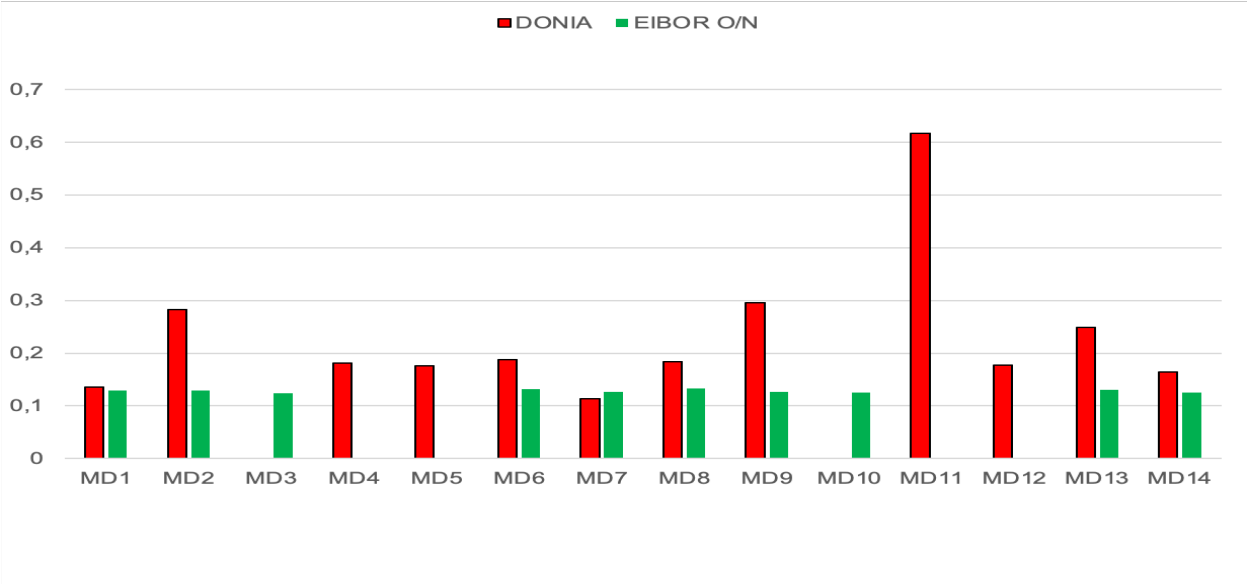
Figure 56. EIBOR versus Policy Rate



Source: CBUAE

126. Since 2019 market rates have remained stable and have oscillated close to the policy rate, in the context of ample excess reserves. This is true for the EIBOR based on quotations of a selected number of banks but also for the DONIA which is a volume-weighted average rate using actual overnight interbank transactions. Interestingly, on average within a maintenance period DONIA is more volatile than EIBOR toward the end of the maintenance period. DONIA is a better signal of market conditions; it better reflects variations in volume and changes in uncertainty that picks up typically at the end of a maintenance period. While EIBOR is remarkably stable throughout the maintenance period.[22] Equally puzzling about EIBOR is the significant narrowing of term premia since 2019 despite reduced volumes resulting from higher uncertainty, higher roll-over risk, and tighter regulation. EIBOR quotations beyond one week rely heavily on expert judgement which are highly dispersed at the higher end of the tenor distribution.

Figure 57. Rates over the Reserve Maintenance Period

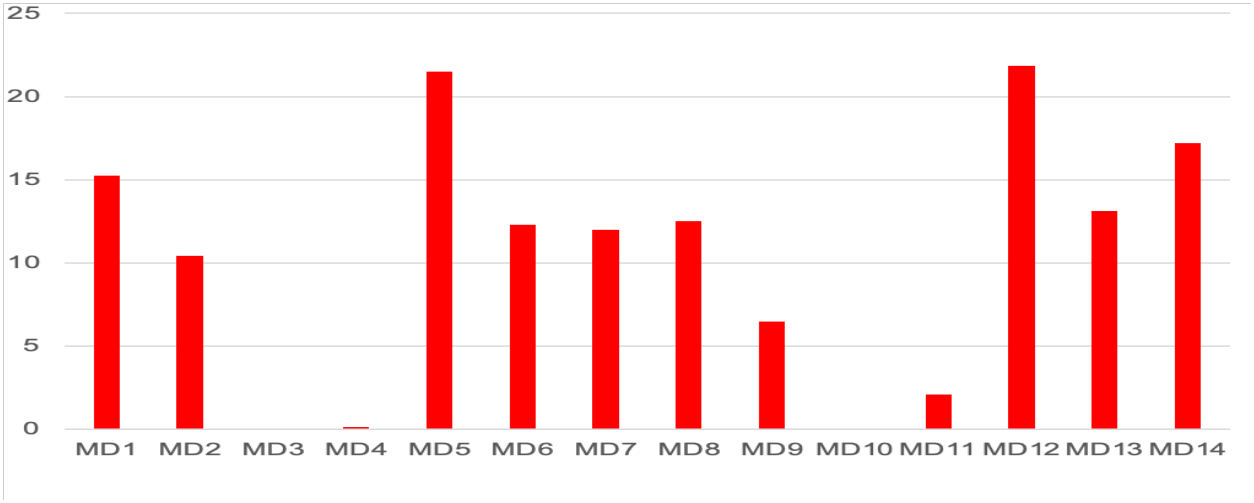


Source: CBUAE and IMF staff calculations

127. Transitioning away from EIBOR to DONIA is complicated by the decline in interbank activity. To overcome this issue the IMF team first recommends that the reform should focus on linking the new benchmark with actual transactions in the most liquid segment of the money market, chiefly the overnight market. The exercise is facilitated by the fact that the CBUAE has a ready access to detailed interbank transactions data through its payment system database. Further, as recommended in section IV the CBUAE should calibrate the liquidity surplus to boost market activity.

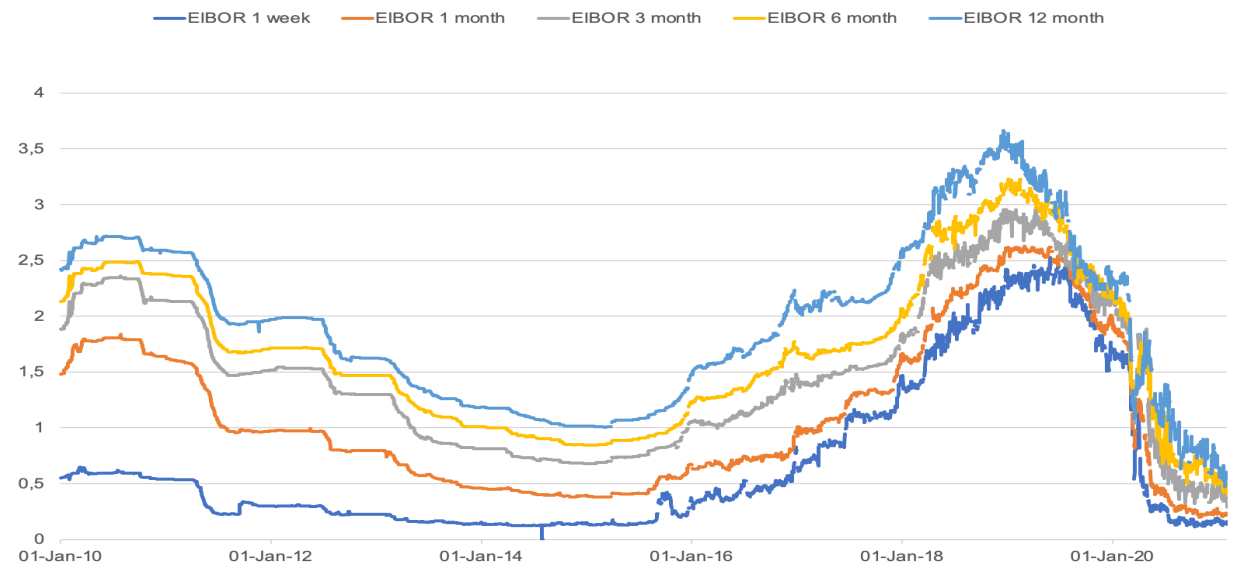
[22] It is probably the case that in absence of market trading, the EIBOR quotes are left unchanged for hours, even days. Quotes are often irrelevant in small markets as they are not updated soon to reflect potential new market conditions.

Figure 58. Unsecured Overnight Market Volume over the Maintenance Period (in AED billions)



Source: CBUAE

Figure 59. EIBOR by Tenor

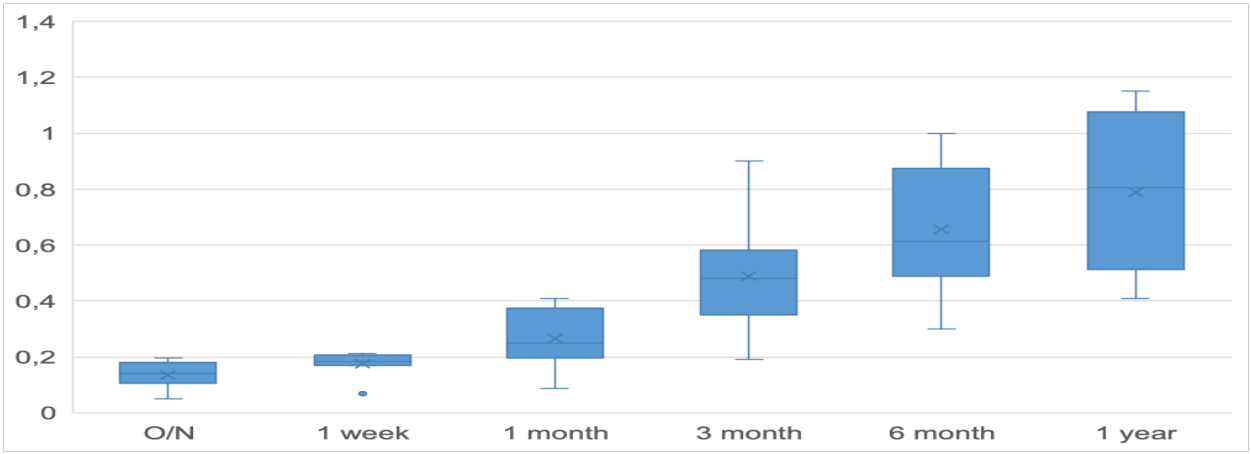


Source: CBUAE

128. Second, the IMF team recommends that the calculation of DONIA integrate bank borrowing from a wide range of non-bank wholesale counterparties (money market funds and investment funds). In the current context, it is to be expected that the bulk of the

transactions volume would come from wholesale deposit transactions with non-banks. [23] The CBUAE could collect these data from the entire banking system at time t-1 for the calculation of the rate at time *t*. The advantage of locating the calculation of the benchmark rate at the CBUAE is twofold. First, the rate would be based on transactions covering the entire banking system and not just from few selected banks. And second, *doing it yourself* rather than delegating means the CBUAE can carry out a serious quality check and cleaning of the row data before the calculation. Again this requires staffing the monetary policy directorate with economists with an expertise in econometric methods and experience analyzing large datasets.

Figure 60. Distribution of EIBOR Quotes by Tenor, October 1, 2020



Source: CBUAE

129. A more challenging area of the reform is the extension of the reference curve from overnight to term rates. The IMF team recommends that, in the short-run, markets be encouraged to use backward-looking term rates. For example, the one-month interest payment obligations would be calculated as the compounded O/N reference rate over the same one-month period. The advantages of this approach are that the calculation is simple, and the term rate can be calculated even if there are no transactions. The weakness of this approach is that the rate obtained does not integrate expectations of future interest rates and market conditions.

130. In the long-run, as derivative-markets linked to the new benchmark develop, forward-looking term rates could be constructed. Forward-rates are available at the beginning of the period to which they apply giving certainty to market participants. To this end, the CBUAE should publish the DONIA daily.

131. The IMF team recommends that the calculation of the term rates be delegated to the market under the oversight and following the guidelines of an expert group set up by the CBUAE. Market participants will have ready access to the required pricing data and the expertise and resources to execute the calculations.

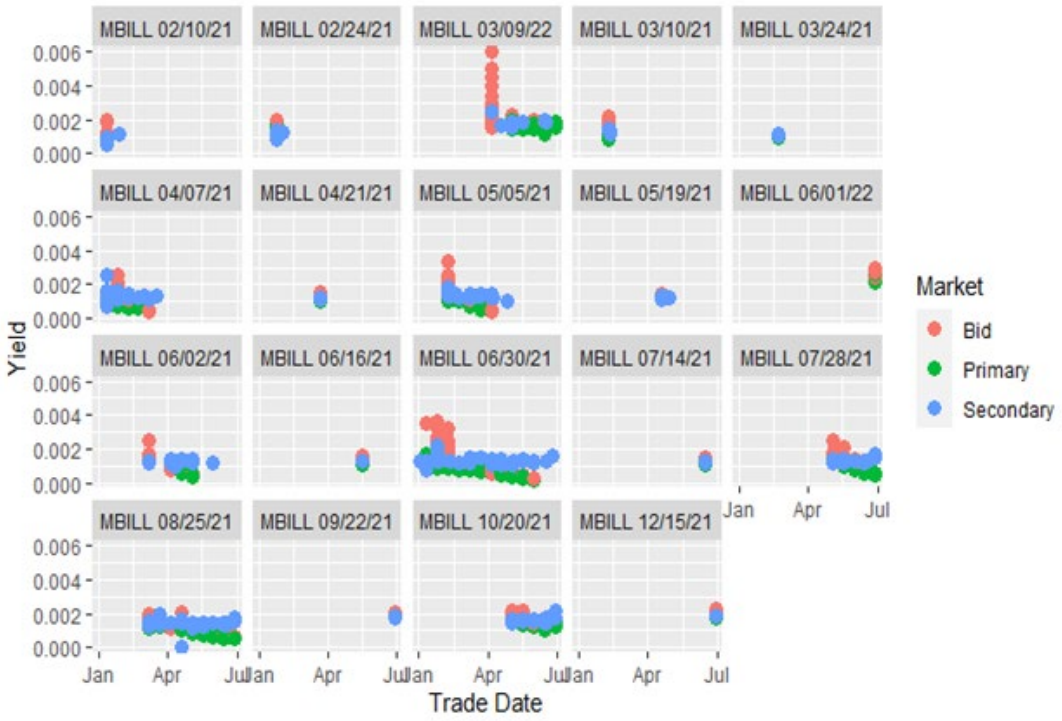
[23] As an example, wholesale deposit transactions with non-banks represent 70 percent of the volume of transactions used for the calculation of the SONIA rate by the Bank of England.

B. M-Bills Secondary Market

Assessment

132. The M-Bills secondary market has started to develop but still face problems of liquidity and deepness. A deep and liquid M-Bills secondary market is a cornerstone to the development of the Repo market as M-Bills are scarce marketable securities which can be used as an underlying collateral. The CBUAE may evaluate the possibility to increase the amount of issuance in long tenors to provide more securities to the market and improve liquidity. The CBUAE should consider that the demand for this M-Bills can absorb the new amount with low price impact. The dynamic observed in the M-Bill primary market reveals how the PDs bid by themselves and on behalf of their clients, sometimes above the secondary market prices but in general, the allotted bids are close to market prices. Furthermore, Figure 61 shows that the PDs have been trading in the secondary market close to the auction rates and in some cases even at lower rates.

Figure 61. M-Bills Bidding, Primary and Secondary Yields



Source: CBUAE

Recommendation

133. The PDs program can be further adapted to encourage a greater activity in the secondary market. The PD program, that was introduced in January 2020, is playing an

important role in the development of the M-Bills secondary market. However, market activity can be boosted through the relaxation of the cap on the maximum holdings for a single PDs in the primary auctions which is currently pushing banks to adopt a buy and hold approach. Moreover, the CBUAE should publish the ranking of the PDs and fine-tune the parameters of the program such as the bid-ask spread or the daily amount that the PDs should quote in the market since the average amount in the secondary market is 4.7 million. Also, the authorities may considerer different minimum quote size depending on the maturity of the M-Bill, currently the minimum size is 10 million.

C. FX Swap Market

Assessment

134. The USD-AED FX Swap market is the most developed money market in the UAE. According to the 2019 BIS triennial survey, it has a daily turnover of 30,769 million dollars and 84 percent of the volume has a maturity lower than 14 days. This volume is five times the daily spot volume reported in the survey. Due to its important volume and liquidity, it is the reference for other markets that use the implied rates in the swaps to quote other rates such as EIBOR or M-Bills.

Recommendations

135. The CBUAE needs to set market conventions for pricing of FX SWAP and track the implicit AED rate derived from FX SWAP points. The market convention is to trade swaps in terms of forward points considering the long leg operation to determine what is the relevant price bid or ask. The forward points are determined by the interest rate differential between the rates in AED and USD in the same tenor. In order to derive the implied AED rate from the forward points, one has to assume the rate on USD. According to the DTIs, it is possible to use the Libor as a proxy for the funding cost in order to get the implied AED.

$$Forward = \frac{spot(1 + r_{AED}t)}{1 + r_{USD}t}$$

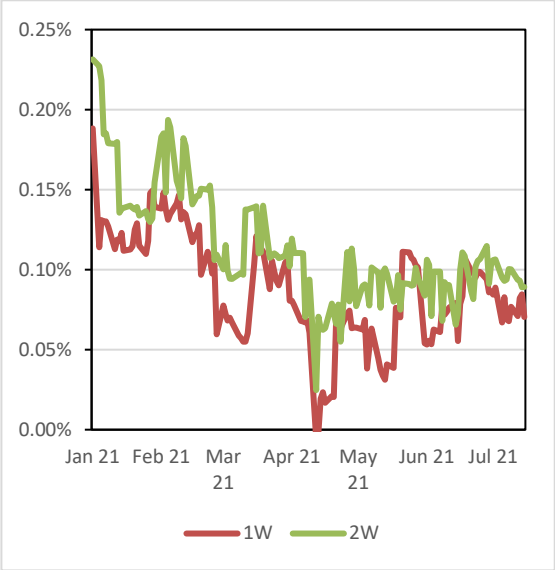
$$Forward\_points = Forward - Spot$$

$$r_{AED} = \left(\left(\frac{Forward_{points}}{Spot} + 1\right)(1 + r_{USD}t) - 1\right)\left(\frac{1}{t}\right)$$

Figure 62. Forward Points AED/USD

Source: Bloomberg

Figure 63. Implied AED ate in FX Swaps



Source: IMF Mission calculation
Note: Libor 1W is assumed to obtain the implied rate.

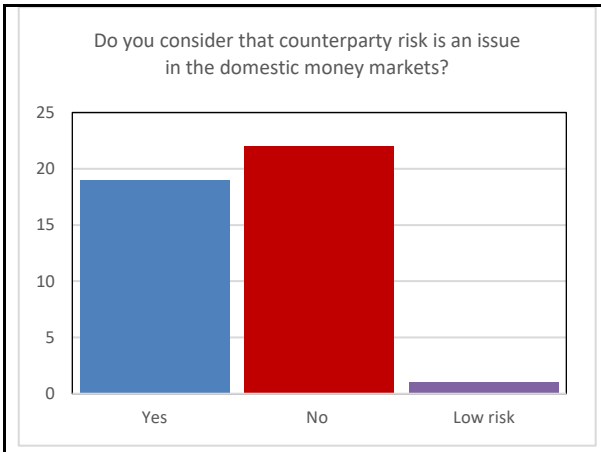
136. It could be useful to consider the adoption of the FX market global code of conduct as a good practice. The DTIs are already using ISDA especially for long-term transactions that could be up to ten years.

D. REPO Market

Assessment

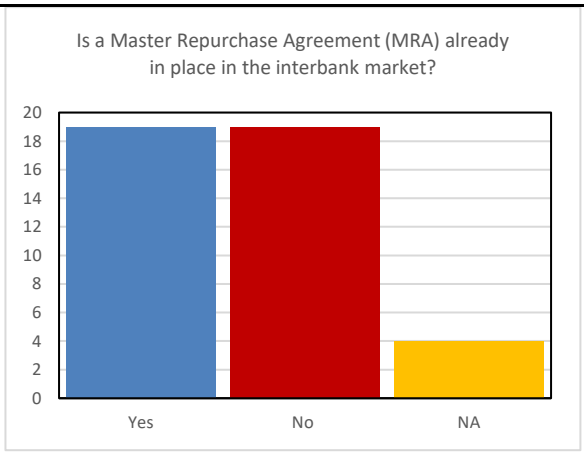
137. The onshore REPO market is at its infancy stage. The CBUAE should continue to support the development of the REPO market to reduce the counterparty risk perception among banks. Enforcement of the use of Master Repurchase Agreement (MRA) is key as half of the banks have not an MRA in place and some of them underline that a central counterparty for repurchase operation could help in the development of the REPO market.

Figure 64. Perception of Counterparty Risk



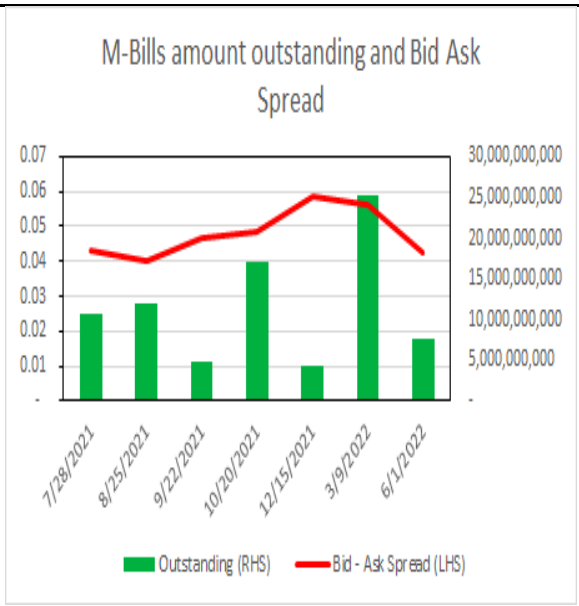
Source: Banks Survey

Figure 65. Usage of MRA



Source: Banks Survey

Source: Banks Survey



Source: IMF staff calculation

Recommendations

138. Liquidity in secondary market should be enhanced through allocation across tenors. The CBUAE should try to allocate higher amounts in the long terms M-Bills as well as re-tranch them to increase the amount outstanding that may promote more transaction in the secundary market. This increase should be according to the amounts determined in the liquidity projectos and when there is demand for this tenors. Currently some PDs maintain to maturity a significant percentage of the M-Bills allotted, with a higher amount the PDs could have more M-Bills available for sale or for trading.

139. DTIs highlighted the importance of continuing the development of a risk-free yield curve in AED jointly between the CBUAE and the DoF as a building block for the secondary market. In the absence of the UAE Federal government securities, the current risk-free curve is limited to the M-Bills instrument with a maturity up to 336 days. The DoF plans to issue a bond in AED by the end of the year. Some of the benefits of developing a UAE curve are:

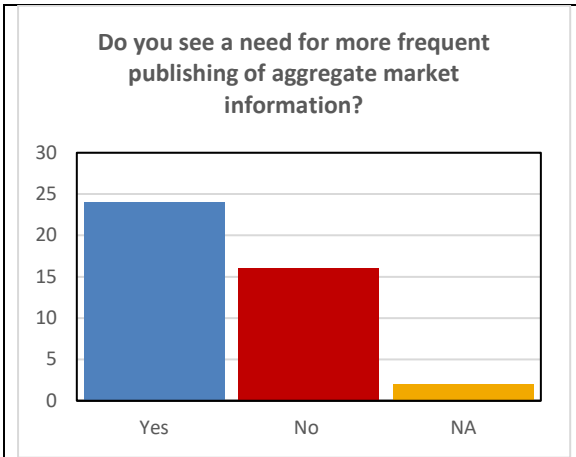
- Provision of a reference pricing across the term structure for other financial contracts.
- Support for the development of corporate bond markets.
- Provision of collateral for the repo market and the CBUAE's monetary operations.

140. More disclosures are needed to enhance the price discovery mechanism in the secondary market. DTIs have underscored the relevance of the actual trading volumes, rates, and weighted average yields across tenors in the interbank market as an element in their decision making. For the weighted average rates per tenor, the CBUAE should compile from the market all the transaction and compute the weighted average using the volume of the transaction for tenors such as one day, seven days, etc.

E. Communication Strategy

141. The CBUAE should continue improving the communication strategy with the market and create a website dedicated to its operations and market information. The CBUAE should develop a communication strategy that allow market participants to understand each of the pillars of the monetary framework and its OMO. It is important that the market clearly identifies which operations are regular and which are exceptional. Market participants highlighted that it would be useful to have more information to develop markets such as CBUAE auctions results, interbank repo rates, FX swap rates, volumes, collateral used, and active market participants.

Figure 66. Request of Market Disclosures



Source: IMF's Banks Survey

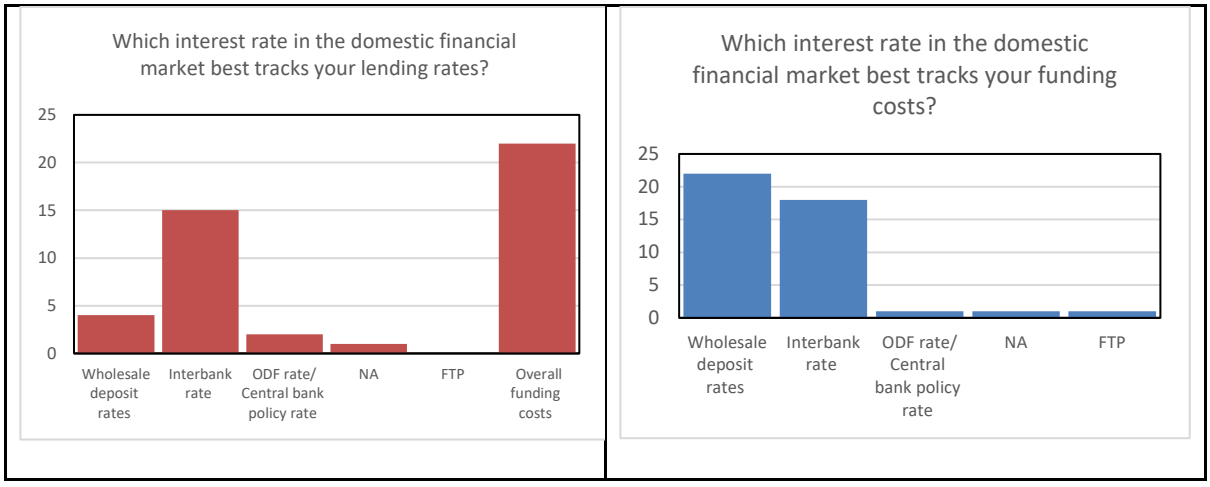
Word-cloud: Information wanted by DTI

Source: IMF's Banks Survey

VI. Monetary Policy Transmission

142. The market participants are still relying on the unsecure interbank interest rate (EIBOR) as a reference rate for their transactions and only few of them use the CBAUE base rate as a reference. As the EIBOR is discontinued, it is expected that the DONIA becomes the new benchmark. Other banks use their internal FTP models which include the base rate, RR and their retail and wholesale funding costs. The CBAUE should continue improving its communication framework to encourage the development of the secondary market and the interbank repo market thereby enhancing the transmission of the monetary policy. Interest rate pass-through provides a critical link between monetary policy decisions and their target variables. As the CBUAE operates at the lower end of the yield curve its policy decisions influence other overnight interbank market rates are transmitted to longer-term money market rates.

Figure 67. Reference Rates for Banks' Pricing



Source: IMF Banks' Survey

143. The CBUAE should collect the average monthly rates applied on various categories of deposits and loans on a bank-by-bank basis. It should compile a weighted average monthly rate for each category for all the banking system. Once long time series are available, the CBUAE should estimate the interest rate pass-through in UAE. Theory implies a positive relationship between market rates and retail lending and deposit rates, which can be formalized in the following markup pricing model:

$$iR = \alpha + \beta \cdot iM \qquad (1)$$

where i^R and i^M are retail (or longer term) and market rates (or shorter term) respectively; β is a long-run (LR) pass-through coefficient, and α is a markup. If markets are perfect (full information and perfect competition) and banks risk-neutral, β would equal 1, implying complete pass-through or a unit interest rate elasticity of demand for deposits and loans (Coricelli, Egert, and McDonald, 2006).

Empirical studies, however, suggest that in practice, pass-through is usually incomplete with β < 1, and varies widely by countries and markets. Equation (1) represents the long-run equilibrium relationship. The out-of-equilibrium adjustment can be described by the error-correction process:

$$\Delta i_t^R = \mu + \rho(i_{t-1}^R - \alpha - \beta i_{t-1}^M) + \gamma \Delta i_t^M + \varepsilon \qquad (2)$$

where ρ measures the speed of adjustment, and γ is a short-run (SR) pass-through coefficient.

Equation (2) can be further expanded with more short-run dynamics to arrive at the following autoregressive distributed lag form:

$$\Delta i_t^R = \mu + \rho(i_{t-1}^R - \alpha - \beta i_{t-1}^M) + \sum_{k=0}^{n} \gamma_k \Delta i_{t-k}^M + \sum_{k=1}^{n} \delta_k \Delta i_{t-k}^R + \varepsilon$$

or by substituting $\Delta i_t = i_t - i_{t-1}$ and grouping similar terms,

$$i_t^R = \theta + \sum_{k=0}^{n} \beta_k i_{t-k}^M + \sum_{k=1}^{n} \alpha_k i_{t-k}^R + \varepsilon \qquad (3)$$

In this equation, β_k's are short-run interaction elasticities, while α_k's reflects persistence of retail interest rates. By estimating equation (3), the long-run interest rate pass-through coefficient can be calculated as

$$\beta = (\sum_{k=0}^{n} \beta_k)/(1 - \sum_{k=1}^{n} \alpha_k) \qquad (4)$$

The mark-up pricing relationship between market and retail rates implies that β should be positive.

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APPENDIX I. CBUAE OPEN MARKET OPERATIONS

OMO	CATEGORY	COLLATERAL	LIQUIDITY PROVISION	LIQUIDITY ABSORPTION	TERM	FREQUENCY	PROCEDURE
M-Bills	Structural	Central Bank	M-Bill Repo	Issuance of M-Bill	Standard	Regular	Tender/ bilateral
Term Liquidity Facility	Fine-tuning	Fine-tuning Central Bank, government, corporates, foreign sovereigns	Repo	Reverse-Repo	Not standard	Non regular	Tender
Matched Transaction Facility	Fine-tuning	Central Bank and government	CBUAE buys securities in the market then sells back	CBUAE sells securities in the market then buys back	Not standard	Non regular	Tender/ bilateral
FX & FX Swap Facility	Fine-tuning	USD/AED	CBUAE buys USD vs. AED (near leg)	CBUAE sells USD vs. AED (near leg)	Not standard	Non regular	Tender/ Bilateral

Source: CBUAE

APPENDIX II. UPDATE ON STATUS OF PREVIOUS TA MISSION'S RECOMMENDATIONS[1]

Recommendations and Authority Responsible for Implementation	Status
Developing Monetary Policy Operational Framework	
Agree that the primary objective of the monetary policy implementation framework is to maintain short term interest rates in line with those consistent with maintaining the exchange rate peg, and that secondary objectives are to preserve financial stability and foster development of local markets.	Fully implemented.
Accelerate the development of liquidity forecasting by: • Complete the identification of key data sources. • Develop a liquidity reconciliation and forecasting template. • Staff the forecasting and reconciliation function and merge with the market operations function. • Develop an information sharing protocol with the Ministry of Finance (MOF) and DoF Abu Dhabi to obtain forward schedules of FX transactions and cash flows. • Begin analysis of forecasting errors.	Partially implemented as the identification has taken place and a draft MoU is already available. However, resources have not been yet allocated, and forecasting model is under development.
Reform the overnight deposit facility by: • Open the facility for the entire trading day. • Set the price equal to the Interest on Excess Reserves Rate (IOER) of the US Federal Reserve.	• The mission considers appropriate the current operational hours. The facility closes at 8:00 pm one hour before the payment systems. Few late operations takes place afterwards. • Implemented.

[1] For further explanation of the past recommendations, please refer to IMF MCM's TA report on "Developing Monetary Policy Operations and The Local Currency Government Bond Market."

Reconsider the proposed primary dealer system and implement the new liquidity management framework and allow access to all banks.	Due to the initial stage of the secondary market the mission considers appropriate to maintain for some time the primary dealer system to develop the market.
Settle all fine-tuning OMO instruments for value T+0.	Not implemented yet.
Discontinue practice to use bilaterally negotiated operations outside of overnight standing facilities.	Partially implemented.
Simplify implementation of the M-Bill auctions by removing the non-competitive bidding and re-offer options.	Partially implemented.
Adopt the reforms in the following sequence to reduce implementation risks: **1.** Introduce overnight standing facilities. **2.** Reform reserve requirements by expanding the use of averaging. **3.** Establish and communicate the regulatory treatment of the new M-Bills. **4.** Complete development of the liquidity forecasting function. **5.** Shift settlement of FX transactions with the CBUAE to T+2. **6.** Introduce the new M-Bill program while retaining the outstanding CD issues and price the associated early redemption option in line with new M-Bills. **7.** Review the costing exercise (the impact analysis on CBUAE's P&L) performed for the new monetary framework.	**1.** Implemented **2.** Implemented from 7-14 days. **3.** Implemented. **4.** Not implemented yet. **5.** Partially implemented. The settlement convention with financial institutions is T+2, while FX operations with the Abu Dhabi Department of Finance are settled at T+0. **6.** Implemented. **7.** Not implemented yet.

Source: 2018 and 2021 IMF Missions

APPENDIX III. EXAMPLES OF ANNOUNCEMENTS RELATED TO FINE-TUNING AUCTIONS

Example of announcement:

Central Bank's Intervention in the Money Market
July 8, 2021

Expected change in the total balance of the credit institutions' current accounts: 80,000.
Concept: Expected change in the total balance of the credit institutions' current accounts resulting from the maturity of previous operations, federal government transactions, and currency and coins' withdrawals or deposits.

Central Bank July 9, 2021, 9:00 AM Auctions:

Maturity	Amount	Settlement	Instrument	Operation
3	10,000	July 9, 2021	FX swap/Reverse Repo	Withdraw
5	15,000	July 9, 2021	FX swap/Reverse Repo	Withdraw
7	5,000	July 9, 2021	FX swap/Reverse Repo	Withdraw
10	25,000	July 9, 2021	FX swap	Withdraw
14	25,000	July 9, 2021	FX swap	Withdraw

Source: IMF Mission

Ex-post transparency example:

Central Bank Open Market operations Results
July 09, 2021

Operation: Withdraw
Total amount demanded: 100,000
Total amount allocated: 80,000
Number of participating institutions: 30
Number of participating institutions that received Allocation: 25

Auction 1 Allotted Bids:

FX Swap	Forward points	Tender	Allotted	Reverse Repo	Rate %	Tender	Allotted
7 days	0.02	2,000	2,000	7 days	.16	900	900
7 days	0.03	3,000	2,000	7 days	.17	500	100
7 days	0.05	5,000	0				

Auction 2 Allotted Bids:

FX Swap	Forward points	Tender	Allotted

Source: IMF Mission

APPENDIX IV. CBUAE'S FX SWAPS AND REPURCHASE TRANSACTIONS COMPARISON

OMO FX Swap	Australia	Switzerland	India	Singapore
Maturity	Up to 3 months	1 day—3 months	Discretionary	Up to 6 months
Frequency	Several times per month	As needed	Discretionary	Daily, as needed
Pricing Method	Bilateral with counter parties	N/A	Auction	Auction
Access Limited By/To	FX counterparty panel	N/A	Authorized dealer category-1 banks	Primary dealers
Function(s)	Liquidity injection & withdrawal	Liquidity management	Liquidity management	Liquidity injection & withdrawal
Hour				9:45 am

Source: BIS Markets Committee Compendium 2019

Repo/ Reverse Repo	Maturity	Frequency	Pricing Method	Access To	Function(s)
Australia	Up to 1 year; typically, around 1 month	At least daily	Auction	Most members of Reserve Bank's RTGS system	Liquidity injection and withdrawal
Brazil	Up to 6 months	As needed	Auction	Primary Dealers and Financial institutions	Reinforce target rate, Liquidity management
Canada	1 day	As needed	Single price auction	Primary Dealers, Government of Canada collateral	Reinforce target rate
Switzerland	1 week to 1 year	As needed	Auction (fixed rate tender)	All domestic banks with sight deposits at the SNB; Other domestic participants	Liquidity management

				in the financial market	
China	Generally, 7 days, other maturity up to 1 year, conducted discretion-arily	Daily	Auction	Primary Dealers	Liquidity injection and withdrawal
United Kingdom	6 months Any term, as determined by BoE	As needed	Uniform price auctions	Banks, building societies and broker-dealers	Liquidity insurance
India	(i) 1 day, but could be more than 1 day due to intermitt-ent holiday (ii) 14-day (iii) Varies	(i) 1 x day (ii) Twice a week (every Tuesday and Friday) (iii) As needed	(i) Fixed rate (ii) Auction (iii) Auction	Scheduled commercial banks, select Urban Cooperative Banks and primary dealers, select Scheduled State Cooperative banks	Liquidity management
Japan	(i) up to 1 year (ii) up to 6 months	As needed	Auction	Financial institutions	(i) Liquidity injection (ii) Liquidity withdrawal
Korea	(i) Mainly 7 days (ii) Varies	(i) Weekly (ii) As needed	Auction	Banks and investment & securities companies selected as eligible	(i) Liquidity management (ii) Liquidity management

				counter-parties	
Mexico	1 to 25 days in average	Daily, as needed	Auction: RP (Target rate floor), Deposits (Target rate ceiling)	Commercial and development banks only	Liquidity management, reinforce target rate
Singapore	Up to 6 months	Daily, as needed	Auction	Primary dealers	Liquidity injection and withdrawal
United States	(i) Up to 65 business days (ii) O/N	(i) Discre-tionary (ii) Daily	RP: Fixed-quantity multi-price auction; RRP: Fixed-price or fixed-quantity	RP: primary dealers; RRP: primary dealers plus some US government-sponsored enterprises, money market mutual funds, and depository institutions)	(i) Liquidity injection and withdrawal (ii) Reduces reserves, supports interest rate control as administered rate
Eurosystem	(i) 1 week and 3 months (ii) Varies	(i) Weekly for 1-week operations; monthly for 3-month operations (ii) As needed	(i) Fixed rate (ii) Varies, no quick tenders are conduct-ed currently	Monetary financial institutions fulfilling eligibility criteria	Basic refinancing (increased emphasis on intermediation) Fine tuning

Source: BIS Markets Committee Compendium 2019

APPENDIX V. PURPOSES OF THE RESERVE REQUIREMENTS IN THE UAE

As a *monetary policy tool*, the RR contributes to the defense of the fixed exchange rate arrangement. By creating a minimum demand for local currency reserve, the RR prevents a situation where very low demand for reserves could lead to important FX sales by the CBUAE. The capacity to impose regulatory demand for reserves is key in a fixed exchange rate arrangement without capital controls because the demand for local currency reserve could otherwise drop rapidly in response to expectations of a devaluation in the market. By supporting the demand for local currency reserves, the RR accelerates the increase of the domestic interest to reach a new equilibrium to stop outflows and defend the fixed exchange rate.

As a *macro-prudential tool,* the RR decreases systemic risks by: (i) increasing system-wide resilience against systemic liquidity shocks; and (ii) smoothing the credit cycle. A raise of the RR moderates credit growth and can be used to reduce the procyclicality of credit. However, although the RR can complement other macroprudential tools such as the debt-service-to-income, loan-to-value ratios, and counter cyclical buffers, it should only be used for macroprudential purposes if alternative instruments are not available or likely to be less effective. Changes in the RR also directly influence the monetary policy stance, may be circumvented by for example re-classification of liabilities, and are usually less targeted than other macroprudential tools available. Many central banks also use tighter RRs on FX liabilities to reduce dollarization, but the current regulatory stance in the UAE is neutral with no differentiation in RR ratios between local and foreign currency deposits.

As a *micro-prudential tool,* the RR ensures that banks hold a minimum amount of a specific HQLA as backing for deposits. This purpose is particularly relevant for the RR on USD liabilities since the CBUAE cannot play the lender of last resort role in USD. However, liquidity requirements such as the LCR and ELAR in the UAE have increasingly taken on that function in many financial systems.

As a *liquidity management* tool, the RR complements other tools for calibrating the appropriate level of system liquidity and has several advantages. Rather than relying exclusively on longer-term structural liquidity absorptions to steer the proper level of system liquidity, central banks can use a combination of RR and long-term structural liquidity absorptions. Compared to OMOs, RRs do not rely on banks' participation in auctions which reduces operational risk. By reducing the amount of liquidity to be absorbed by OMOs, the RR can facilitate OMO conduct and reduce operational risks, especially in small markets without strong competition between bidders. Moreover, reserve averaging provides an additional channel to limit interbank rate volatility. By giving banks more flexibility to adjust to high-frequency liquidity shocks, RR averaging allows the central bank to reduce the frequency of OMOs.

APPENDIX VI. EXAMPLE OF ANALYTICAL CENTRAL BANK BALANCE SHEET AND COMPILATION OF AUTONOMOUS FACTORS OF LIQUIDITY

Example of Analytical Central Bank Balance Sheet

Assets	Liabilities
1. Claims on nonresidents 1.1. Monetary gold and SDR holdings 1.2. Foreign currency 1.3. Deposits with nonresidents in foreign currency 1.4. Securities other than shares in foreign currency 1.5. Loans to nonresidents in foreign currency 1.6. Holdings of SDRs 1.7. Other foreign assets	6. Liabilities to nonresidents 6.1. Deposits from nonresidents in foreign currency 6.2. Securities other than shares in foreign currency 6.3. Loans from nonresidents in foreign currency 6.4. Use of IMF facilities 6.5. Other foreign debt
	7. Currency in circulation
2. Claims on the government 2.1. Securities 2.2. Loans and advances 2.3. Other	8. Securities issued by the central bank 9. Government deposits
3. Claims on deposit money banks 3.1. Loans through Lombard and overdrafts facilities 3.2. Rediscount and secured advances 3.3. Other loans (including repos) 3.4. Other	10. Liabilities to deposit money banks 10.1. Current accounts (required reserves and excess reserves) 10.2. Vault cash 10.3. Deposit facility/auctioned deposits
4. Claims on other sectors 4.1. Private sector 4.2. Nonfinancial public enterprises 4.3. Nonmonetary financial institutions 4.4. Other	11. Deposits by others sectors 11.1. Private sector 11.2. Nonfinancial public enterprises 11.3. Nonmonetary financial institutions 11.4. Other
5. Other assets	12. Revaluation accounts 13. Capital accounts 13.1. Capital 13.2. Reserves 14. Other liabilities

	Assets	Liabilities
	Net foreign assets (NFA=1.-6.)	Currency in circulation (C=7.)
NDA	Net position of the government (NPG=2.-9.)	Bank reserves (R=10.1.+10.2.)
NDA	Claims on deposit money banks (L=3.)	
NDA	Other items net (OIN=4.+5.-8.-10.3.-11.-12.-13.-14.)	
	= Monetary base (B)	= Monetary base (B)

Source: Andrea Schaeter, Implementation of Monetary Policy and the Central Bank's Balance Sheet, IMF WP/01/149

Compilation of Autonomous Factors of Liquidity

ASSETS	LIABILITIES
Net Foreign Assets (NFA) Claims on Government (CG)	Currency in Circulation (CiC) Government Deposits (GD)
Liquidity Provision Operations (LP)	Liquidity Absorption Operations (LA)
	Banks' Reserves (R)
	Other Factors Net (OFN)

TOTAL ASSETS = TOTAL LIABILITIES

NFA + CG + LP = CiC + GD + LA + R + OFN

R = NFA + CG + LP – CC – GD – LA – OFN

R = AF (NFA + CG – CC – GD – OFN) + CB Operations (LP – LA)

ΔR = ΔAF + ΔCBO

Source: IMF staff

APPENDIX VII. DATA AND IT INFRASTRUCTURE REQUIREMENTS

Liquidity forecasting is a crucial component of the operational framework of the CBUAE. It should rely on accurate, updated, and comprehensive data, as well as an adequate software and hardware infrastructure. Besides, as the UAE financial environment is complexifying, it is crucial that the modeling and technical capacities of the CBUAE are at par with industry standards and practices from central banks of other financial centers, such as the Hong Kong Monetary Authorities or the Singaporean Monetary Authorities. Implementing a complete and modern data and IT infrastructure will help the CBUAE scaling up its modeling capacity in the future. The importance of a solid data and modern IT infrastructure is crucial not only for liquidity forecasting but also for pricing CBUAE instruments, calibrating operations, managing collateral, monitoring market developments, implementing early-warning signals, etc. This annex reviews the data and IT infrastructure requirements for modern and efficient financial modeling.

Data Coverage: Liquidity forecasts are done on: (i) currency in circulation; (ii) state account at the central bank; and (iii) net foreign assets. Although these three items are available as central bank balance sheet items, their data must be updated daily and readily available to the monetary policy department for forecasting purposes. Granular data are essential for accurate and robust forecasting:

- *Currency in Circulation:* Daily data on currency issued by the central bank and currency deposited by commercial banks at the central bank. The decomposition by banknotes and coins denomination would help refine the forecasts by incorporating different denomination dynamics.

- *State Account:* The Treasury should share with the central bank its data on future expenditure and revenues items, in particular for large and exceptional items, to help the central bank anticipating significant liquidity disruptions (e.g., large flows). Also, more granular data on the revenues and expenditure of the government would allow the central bank to improve its forecast of the state account.

- *Net Foreign Assets:* The CBUAE should have access to FX settlement data, which are crucial to predict FX movements up to T+2. It should also receive information about large FX payments—particularly on oil and gas, which are the key drivers of the central bank's net foreign assets.

- *General Financial and Economic Data:* CBUAE staff, particularly research analysts and econometricians, should have access to a wide range of financial and economic data for their daily work, including liquidity forecasting and other topics. The most frequently cited databases are Bloomberg Market Data Feed™, Haver DLX™, EPFR Global Data™, Thomson Reuters Datastream™, and Refinitiv™. It is essential to access data from different providers—not only Bloomberg—to increase data coverage. For instance, Haver DLX™ and EPFR Global Data™ are helpful complements to Bloomberg on granular central banks data and daily capital flows information.

- *UAE-specific Market Developments:* The CBUAE should collect and automatize data-reporting about market indicators that are typically unavailable through commercial data sources (e.g., Bloomberg). For instance, about interbank market turnover, traded prices, secondary instruments trading, etc.

Database Management: The CBUAE should maintain a central database repository that the monetary policy department can access at any time, with adequately managed access rights to preserve data integrity. The dataset should follow the best industry standards regarding identifiers, data storage and accuracy, software access, and management (e.g., an Oracle SQL database). Notably, the monetary policy department should have direct access to the data to use modern statistical software (e.g., Python and R, see below) to directly query from the database. Direct data access allows for easy automation, data retrieval, cleaning, and management, to gain time and minimize operational risk.

Data Reporting: Data from external providers should be reported automatically and carefully checked to avoid inconsistencies and other issues. More generally, the statistics department should operate an automatic data control process to detect large movements in the data (for instance, more than one standard deviation) and raise a warning so that the CBUAE statisticians could check the input. Moreover, the monetary policy department should operate its own automatic routine check on the data it receives and communicate with the statistics department when needed.

Harmonization: Forecasting relies on time series. It is not enough that the dataset is recent and updated. The time series should also cover a sufficiently long period in the past to adequately fit the models. Given the evolving reporting standards and infrastructure, there is a need for statistical harmonization to ensure that the time series are consistent and comparable across time.

Software Requirements: Operating forecasting models and estimating financial models require a modern and complete statistical and programming toolkit. Given the strengths and weaknesses of the different available software, it is strongly recommended that the two most important of them, Python and R, are installed on CBUAE computers. They can be completed by other software such as Matlab or Eviews. While R is a specialized statistical language commonly used by academics, Python has a broader scope and is widely used in the financial industry, including central banks. R has a wide range of packages for forecasting, statistical inference, and Bayesian estimation. Python is the leading language used for data management, data visualization, simulated methods, machine learning, big data, kernel estimation, etc. The IMF TA mission, for instance, has used both R for the liquidity forecasts and Python for the calibration of the liquidity surplus. Packages such as reticulate or rpy2 allow for interoperability between the two languages.

Furthermore, it is crucial that the CBUAE staff can use an integrated development environment (IDE) for both Python and R to work in the best conditions. Therefore, installing the most updated RStudio and Python Anaconda complete distributions is strongly recommended, as both offer a full suite of tools for designing and implementing codes for scientific computing.

Finally, developing and collaborating on programming projects necessitate tracking changes and sharing the codes internally to reduce operational risks and foster collaboration among staff. Therefore, it is strongly recommended to use a versioning software such as git for this purpose, with an internal Github repository for the CBUAE. Archiving codes on Github tremendously reduces operational risks and helps programming teams to work together seamlessly. For instance, the IMF modelers use git internally for their programming projects.

Importantly, RStudio, Python Anaconda, and Git/Github are open-source software at the best international standards for data science and programming and are used by many financial institutions and large companies worldwide.

Hardware Requirements: Likewise, the CBUAE should be equipped with adequate IT hardware to operate the forecasting and modeling infrastructure. To reduce operational risk, increase computing power, guarantees continuous data backup, and facilitate cooperation among staff, the CBUAE should manage a high-performance computing server infrastructure. The computing servers should be accessible by the team from their CBUAE laptop—even remotely if possible—and offer substantial computing power (both CPU and GPU) and massive fast-access memory. The CBUAE should install Python Anaconda and RStudio on the servers and connect the servers to the CBUAE data repository to allow staff to run operations from the servers. Running monetary operations from the servers (e.g., liquidity forecasting, modeling, etc.) has many advantages. It reduces operational risks, fastens operations, saves staff time, and offers more flexibility to use time-intensive and memory-consuming algorithms. Finally, granting staff access to cloud computing allows them to scale up large and complex projects efficiently.

For instance, the IMF operates both physical and virtual servers accessible to all IMF staff:

- *On-premises, the IMF has several Intel Xeon 6246 3.30 GHz CPU with 24 cores physical, 48 cores hyperthreaded with 768 GB of RAM and 6TB Nvme SSD. Some of the servers have an Nvidia V-series GPU NVIDIA® Tesla™ V100 GPU Computing Accelerator—32GB HBM2—PCIe 3.0 x16 to allow for high-speed computing on GPU, which is helpful in algebraic computation (inverting large matrices, for instance).*

- *On the cloud, the IMF has granted access to its staff to Amazon AWS cloud computing platform and Microsoft Azure HPC. The cloud virtual machines are sized according to the computational needs of the projects.*

APPENDIX VIII. STATISTICAL FORECASTING MODELS

This appendix presents the specification of the statistical models used for forecasting the autonomous factors. Details about the treatment of structural breaks, choice of covariates, etc. are available in the main text.

ARIMA Models

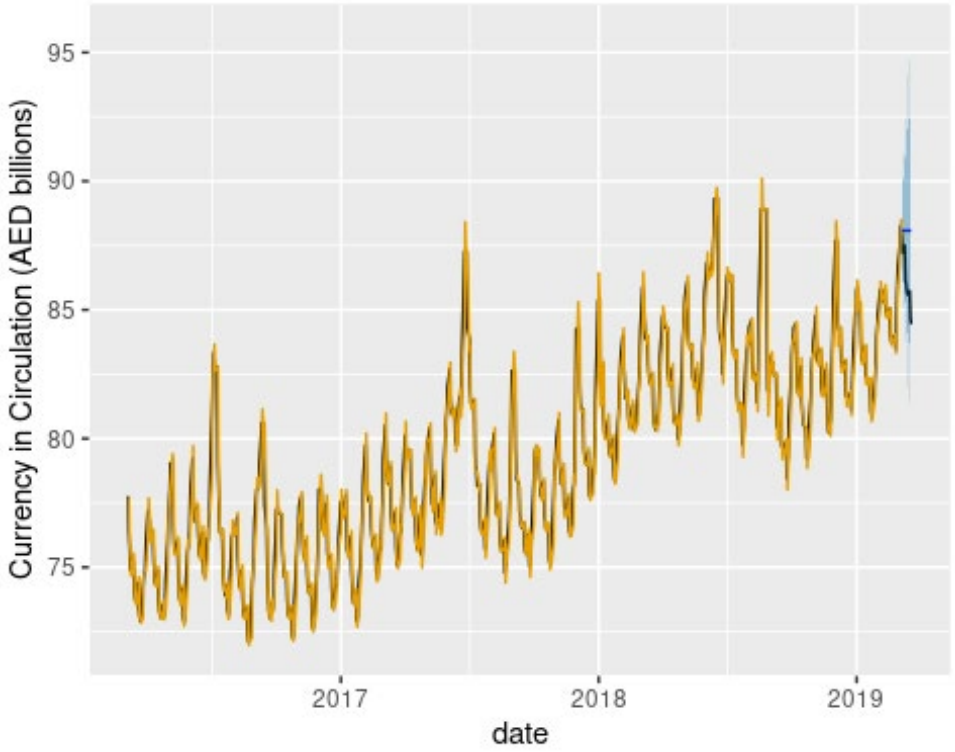
The Autoregressive Integrated Moving Average family of models is a flexible class of models used for time series forecasting in a wide range of settings. The existing expert forecast used by the CBUAE for forecasting Currency in Circulation is a form of ARIMA model. In general, the ARIMA model is defined as:

$$(1 - \phi(B))(1 - B)^d y_t = (1 + \theta(B))\epsilon_t$$

Here B is the backshift operator that lags a variable, i.e. $By_t = y_{t-1}$,$By_t = y_{t-2}$,etc. The order of differencing d is typically equal to 1 (or in rare cases 2) for nonstationary series and 0 for stationary series. The term $(1 - \phi(B)) = 1 - \phi_1 B - \phi_2 B^2 - \cdots - \phi_p B^p$ is known as the autoregressive (AR) polynomial or order p and the term $(1 + \theta(B)) = 1 + \theta_1 B + \theta_2 B^2 + \cdots + \theta_p B^p$ is known as the moving (MA) polynomial or order q. The term ϵ_t is a random 'noise' or 'innovation' term. The nomenclature ARIMA(p,d,q) is used to describe an ARIMA model, for example an ARIMA model with $p = 2$, $d = 1$ and $q = 2$ would be referred to as an ARIMA(2,1,2) model.

The figure below shows the forecasting results for an ARIMA(1,1,1) model using the period from March 6, 2016 to March 5, 2019, as training data and the period from March 6, 2019 to March 19, 2019, as the forecast period. The black line is actual data, the orange line, fitted values from the model and the blue line forecasts. Also shown in blue are prediction intervals in the form of a fan chart with the darker shading representing an 80 percent prediction interval and the lighter shading a 95 percent prediction interval. The prediction intervals are a critical forecasting output that should guide appropriate OMOs during the reserves maintenance period.

Figure 1. Forecasts, Fitted Values, and Prediction Intervals for ARIMA(1,1,1) Model



Source: IMF staff

Model Selection (ARIMA Order)

144. For all ARIMA models, choices of the orders p, d, q, P, D, Q must be made. The estimation is done using the stepwise algorithm of Hyndman and Kandakhar (2008):

1) Find d using KPSS test.

2) Estimating four initial models and choose the best of these four models.

3) Expand the candidate model set by considering models that have p or q differing from current best by 1.

4) Iterate until no improvement made.

The criterion for selection is the Akaike Information Criterion corrected for small sample size (AICc). The Algorithm implemented in auto.arima function within the forecast package in the R software environment. The same algorithms can be modified and applied to seasonal ARIMA and seasonal ARIMA with regression described below.

Seasonal ARIMA

An important extension to ARIMA models is seasonal ARIMAs (SARIMA), which allows for the modelling of patterns that repeat themselves every m observations. In general, SARIMA take the form:

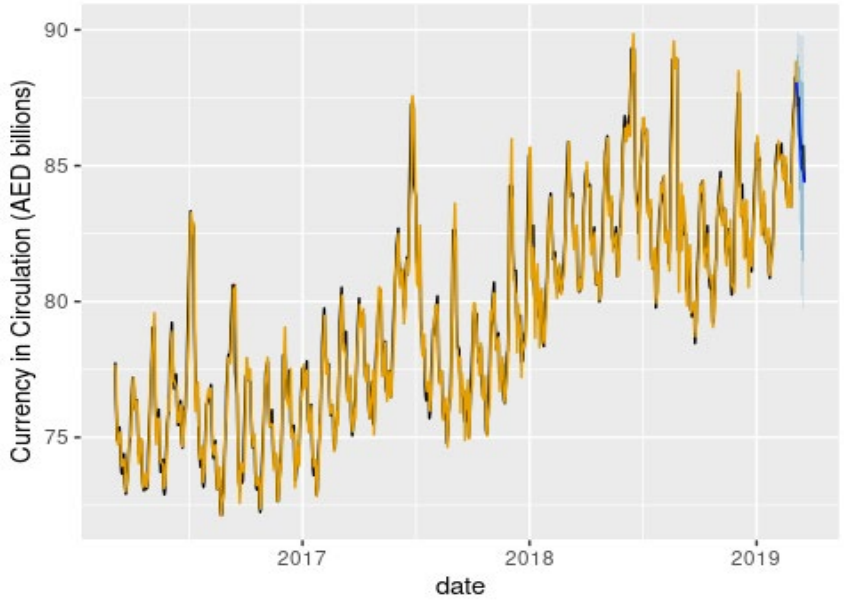
$$(1-\phi(B))(1-\Phi(B^m))(1-B)^d(1-B^m)^D y_t = (1+\theta(B))(1+\theta(B^m))\epsilon_t$$

where P, D and Q are the orders of the *seasonal* AR component, *seasonal* differencing and *seasonal* MA component. The nomenclature ARIMA(p,d,q)(P,D,Q)[m] is used to describe such models, for instance an ARIMA(1,0,0)(0,1,1)[5] model would be equivalent to

$$y_t = y_{t-5} + \phi(y_{t-1} - y_{t-6}) + \epsilon_t - \epsilon_{t-5}$$

The figure below shows the forecasts of currency in circulation from an ARIMA(4,1,1)(2,0,0)[5]. This seasonal ARIMA model can be seen to correctly forecast the decline in currency in circulation that took place during the evaluation period.

Figure 2. Forecasts of CiC from SARIMA(4,1,1)(2,0,0)[5] Model



Source: IMF staff

Seasonal ARIMA models of this form are only capable of explicitly capturing only one form of seasonality. In the Currency in Circulation data in particular (and possibly for the other autonomous factors), there are potentially multiple seasonalities. The candidate choices for m are shown in the table below.

m	Type
7	Weekly
30	Monthly
354	Yearly (Civic Calendar)
365	Yearly (Hijri Calendar)

Fortunately, since the ARIMA model is able to easily incorporate covariates, there are alternatives to capturing these multiple seasonalities.

Seasonal ARIMA with Regression

Dummy Variables

Seasonality can be modelled using dummy variables. This approach is particular well suited when the length of the seasonal pattern is short and when the pattern is not necessarily smooth. For example flexible day of week effects can be modelled using only four variables of the form

$$D_t^{(Mon)} = \begin{cases} 1 \text{ if Day t is a Monday,} \\ 1 \text{ otherwise.} \end{cases}$$

With similar dummies can be defined for Tue, Wed, Thur. These dummies are then included in a vector of covariates x'_t and the ARIMA model has the same specification as previously with y_t replaced by $y_t - x'_t\beta$. It is important to be clear that an ARIMA model with dummies (or other covariates) would be specified, in the example of an AR(1) as

$$y_t - x'_t\beta = \phi(y_{t-1} - x'_{t-1}\beta) + \epsilon_t$$

and not

$$y_t = x'_{t-1}\beta + \phi y_{t-1} + \epsilon_t$$

as is often the case. The first specification, which is the one that is used to allow for easier interpretation of the coefficients and avoids issues with using stationary predictors (such as dummies) as covariates for non-stationary data.

Fourier Terms

Where m is large, using dummies leads to an impractically large number of dummy variables. Instead as long as the seasonal pattern in smooth, Fourier terms can be used instead. For $j = 1, \dots, J$ these are defined as

$$s_t^{(j)} = \sin\left(\frac{2\pi jt}{m}\right)$$

and

$$c_t^{(j)} = \cos\left(\frac{2\pi jt}{m}\right)$$

The choice $J = 2$ is considered for monthly, and yearly effects with the length of year in both the civic and religious calendars considered.

ETS Models

The Error Trend Seasonality (ETS) class of forecasts is built up from simple exponential smoothing, as per the following:

$$\hat{y}_{T+1} = \alpha y_T + \alpha(1-\alpha)y_{T-1} + \alpha^2(1-\alpha)y_{T-2} + \cdots$$

where $\hat{y}_{T+1}$ is the forecast at time $T+1$ and α is a smoothing parameter. This can also be written in terms of latent components l_t via

$$\begin{aligned} \hat{y}_{T+1} &= l_t \\ l_t &= \alpha y_t + (1-\alpha)l_{t-1}, \end{aligned}$$

which is useful for extending the model to account for trend and seasonality. Trend can be incorporated via

$$\begin{aligned} \hat{y}_{T+h} &= l_t + hb_t \\ l_t &= \alpha y_t + (1-\alpha)(l_{t-1} + b_{t-1}) \\ b_t &= \beta^*(l_t - l_{t-1}) + (1-\beta^*)b_{t-1}, \end{aligned}$$

where h is the forecast horizon, b_t is the latent trend component and β^* a smoothing parameter. Alternatively, a damped trend can be modelled using a damping parameter ϕ as

$$\begin{aligned} \hat{y}_{T+h} &= l_t + (1+\phi+\phi^2+\cdots+\phi^h)b_t \\ l_t &= \alpha y_t + (1-\alpha)(l_{t-1} + \phi b_{t-1}) \\ b_t &= \beta^*(l_t - l_{t-1}) + (1-\beta^*)\phi b_{t-1}. \end{aligned}$$

Seasonality can be model in an additive fashion via

$$\begin{aligned} \hat{y}_{T+h} &= l_t + hb_t + s_{t+h-m(k+1)} \\ l_t &= \alpha(y_t - s_{t-m}) + (1-\alpha)(l_{t-1} + b_{t-1}) \\ b_t &= \beta^*(l_t - l_{t-1}) + (1-\beta^*)b_{t-1} \\ s_t &= \gamma(y_t - l_{t-1} - b_{t-1}) + (1-\gamma)s_{t-m}, \end{aligned}$$

where s_t is a latent seasonal term and γ is a smoothing parameter. Seasonality can be accounted for in a multiplicative fashion via

$$\begin{aligned}\hat{y}_{T+h} &= (l_t + hb_t)s_{t+h-m(k+1)} \\ l_t &= \alpha\frac{y_t}{s_{t-m}} + (1-\alpha)(l_{t-1} + b_{t-1}) \\ b_t &= \beta^*(l_t - l_{t-1}) + (1-\beta^*)b_{t-1} \\ s_t &= \gamma\frac{y_t}{l_{t-1} - b_{t-1}} + (1-\gamma)s_{t-m}.\end{aligned}$$

To make these forecasting models statistical models they can be rewritten with error terms. For example, simple exponential smoothing with additive errors is given by:

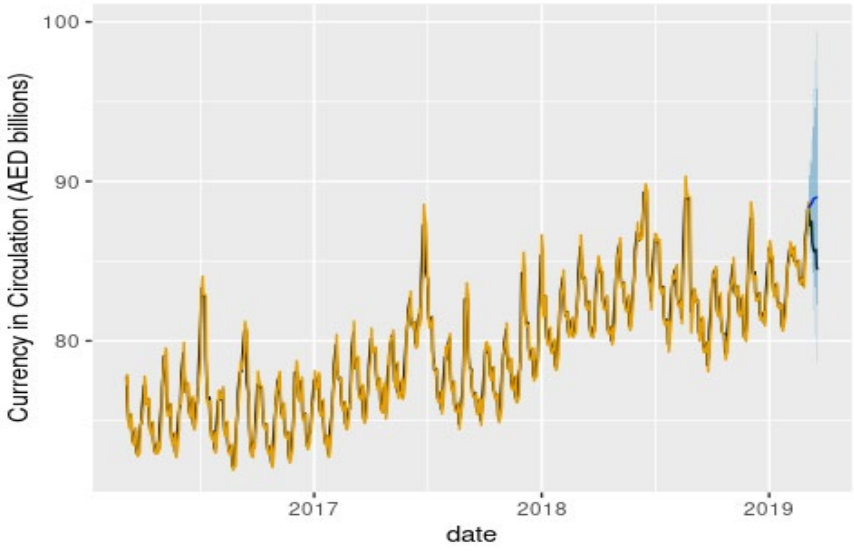
$$\begin{aligned}y_t &= l_{t-1} + \epsilon_t \\ l_t &= l_{t-1} + \alpha\epsilon_t\end{aligned}$$

Errors can also be incorporated multiplicatively. Different Error, Trend, Seasonal (ETS) models combine:

- Additive Error (A) or Multiplicative Error (M).
- No trend (N) Additive trend (A) or Additive damped trend (Ad).
- No seasonality (N) Additive seasonality (A) or Multiplicative seasonality (Ad).

The nomenclature ETS(.,.,.) is used, for example ETS(A,N,A) has additive errors, no trend and additive seasonality. Models can be selected via the AICc. Forecasts from an ETS(M,Ad,N) model are shown in the figure below.

Figure 3. Forecasts from an ETS Model



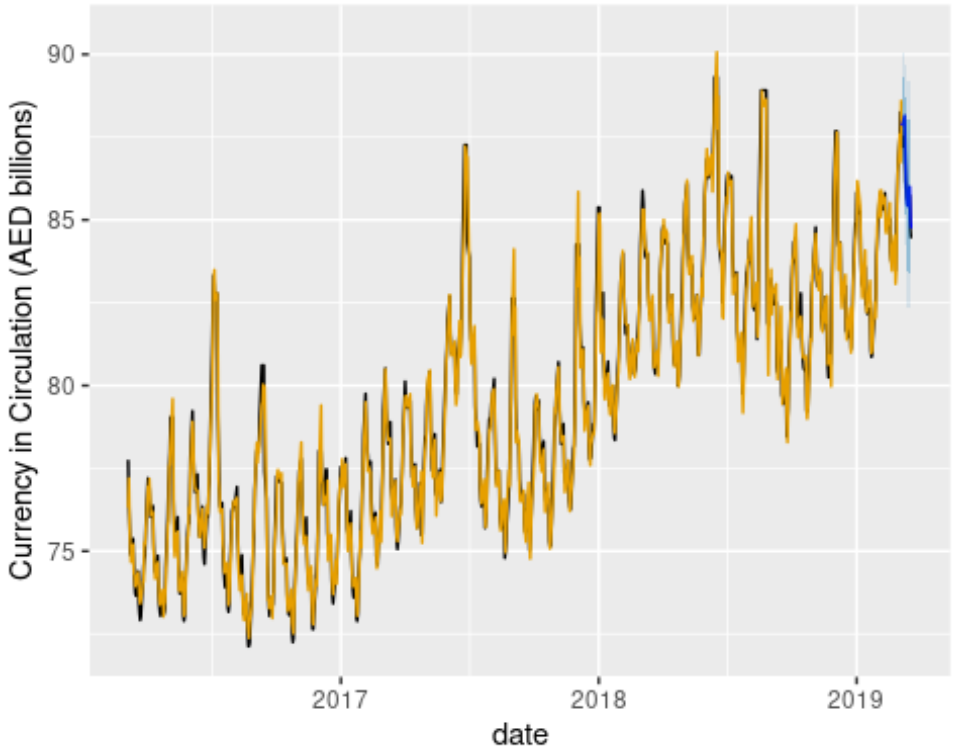
Source: IMF staff

A disadvantage of the ETS family of models is that covariates cannot be as easily incorporated into ETS models—as is the case for ARIMA models—making it difficult to control for structural breaks and holiday effects.

TBATS Model

The TBATS model incorporates many of the features of the models already introduced. Seasonality and trend are handled via exponential smoothing (using trigonometric terms for the former), a Box-Cox transformation is used and ARIMA innovations. This allows seasonality to change over time. A particularly attractive feature of the TBATS model is the ability to handle multiple calendars—it was initially proposed for modelling electricity demand in Turkey which is a time series also influences by both the civic Gregorian calendar and religious Hijri calendar. Forecasts from the TBATS model are shown in the figure below.

Figure 4. Forecasts from a TBATS Model



Source: IMF staff

Volatility Models

Volatility models are appropriate for forecasting the net foreign assets, given the highly volatile nature of the time series. Three classes of model are fitted.

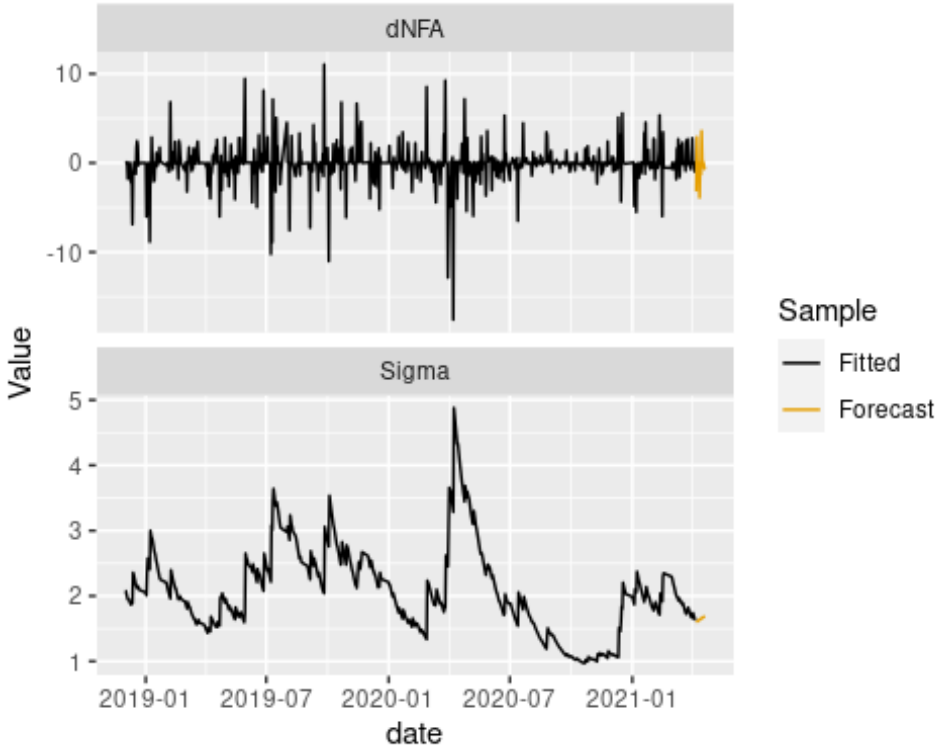
GARCH

The most popular family of conditional volatility models is the GARCH model. The variance is modelled as

$$\sigma_t^2 = \omega + \sum_{i=1}^{p} \beta_i \, \sigma_{t-i}^2 + \sum_{i=1}^{p} \alpha_i \, e_{t-i}^2.$$

A time series of net foreign assets residuals (top panels) and volatility estimates and forecasts are shown in the figure below.

Figure 5. Residuals of Net Foreign Assets (Top Panel) and Estimated and Forecast Volatility (Bottom Panel)



Source: IMF staff

EGARCH Model

The specification of the eGARCH model is given by

$$\log\sigma_t^2 = \omega + \sum_{i=1}^{p} \beta_i \log\sigma_{t-i}^2 + \sum_{i=1}^{q} \alpha_i \, g(\epsilon_{t-i}).$$

where $g(\epsilon_t) = \theta\epsilon_t + \lambda(|\epsilon_t| - E(|\epsilon_t|))$

An advantage of this specification is its asymmetry since the sign and magnitude of innovations have different effects on the variance.

GJR GARCH Model

The GJR-GARCH specification is given by

$$\sigma_t^2 = \omega + \delta\sigma_{t-1}^2 + \alpha\epsilon_{t-1}^2 + \phi\epsilon_{t-1}^2 I_{t-1}$$

where $I_{t-1} = 0$ if $\epsilon_{t-1} \geq 0$ and $I_{t-1} = 1$ if $\epsilon_{t-1} < 0$

Similar to eGARCH, this specification allows for asymmetric effects.

APPENDIX IX. SOFTWARE DOCUMENTATION

The documentation describes the R code used during the TA mission on forecasting the autonomous factors, what it aims to do, how to run it, and the underlying models and outputs.

Language

The code is written in the R language, and information is available at https://www.r-project.org/. R is an open-source language, meaning that all source code is available and is made of contributions by many people worldwide. It is also freely available, so the language and other libraries are also available to anybody with an internet connection free of charge.

The team chose the R language for this project because R has many statistical and forecasting packages that are easy to use "out-of-the-box". Abundant pre-coded packages allow implementation easily under R, such as ARIMA, exponential smoothing, and other models. R can also write out into familiar formats like csv and Excel and create visualizations that can be exported to PDF format, making the output readable to a large audience of non-specialists.

Environment

For most users of the R language, RStudio (https://www.rstudio.com/) is the de facto environment for reading, writing and executing R code. RStudio is also free.

and is used by statisticians, economists, and other professionals all over the world. To install RStudio, please visit https://www.rstudio.com/ and install the version corresponding to the operating system.

To run the code provided by the IMF team, it is recommended to use R version 3.6.3 so that the library version is the same. For a Windows environment, the IMF provides a folder containing the necessary libraries to run the code. The user should place this code in the same folder as the R source code, and this will ensure that the version of all libraries also matches.

Files

The IMF provides the following files:

- R scripts
- Config file
- Documentation (this file)

R scripts are files that have the extension .R, and contain commands that can be interpreted by the R language and be executed. These files contain all of the instructions to forecast currency in circulation and can be used for general forecasting of time series. All R scripts use a config file to

set up parameters for the instructions. These include input file names, days of the week that are weekends, models to run, output files, and others.

To execute an R script, it is easiest to open the file in RStudio, and execute either one line at a time or all at once. A separate session can be set up with the IMF to provide training on how to use RStudio and run R scripts.

Scripts

There are four R scripts provided:

- step_000_dataclean.R
- step_001_features.R
- step_002_model.R
- step_003_summary.R

These files should be run in order, as the output of each step is then used as the input for the next step. All of these files should read in the same config file, which is specified with the line

```
source("config.R")
```

The advantage of this approach is that by editing the config file, which is a reasonably easy-to-understand file, the user can have some flexibility when running the R code even if they are not too familiar with the R language.

The config file and R scripts have been heavily commented for clarity.

Step 0: Cleaning Data

The file step_000_dataclean.R does the following:

1. Read in the specified Excel or csv files from the `rawdatafile` parameter in the config file.
2. Set the start and end dates and remove bad dates based on the config file parameters.
3. Add a column `datatype` with values of data, holiday, and imputed.
4. Remove weekends based on the `exclude_days` parameter in the config file.
5. Linearly interpolate any dates that are missing in the data.
6. Save the output as specified by the `dataclean` parameter in the config file.
7. Create a plot of the target variable and save as PDF file.

This script should take only a few seconds to run. The original input file(s) should have dates in the first column, and the target variable column should be specified by the `targetcol` parameter in the config file. In the simplest case, the file will have two columns, one for the date and another for the target variable, with `targetcol` being 2.

Step 1: Adding Features

Once the original data is read in and cleaned, the next step is to add additional features for each date to help with the modeling. The file step_001_features.R does the following:

1. Read in the cleaned csv file from step 0.
2. Generate daily biases for each day of the week.
3. Generate trigonometric biases for each day of the month.
4. Generate trigonometric biases for each day of the year.
5. Add structural breaks based on the `structural_breaks` parameter in the config file.
6. Add bias terms around the 20th of each month.
7. Add bias terms for the quarter.
8. Combine all of the bias terms with the data and save as specified by the `dataFeat` parameter in the config file.
9. Plot all features and save as PDF files.

Each of the biases are background terms that are used to model different seasonalities. For example if the data showed a very strong tendency for Mondays to have higher values, the bias corresponding to Mondays would be modeled with a higher value to reflect this. In general if there are N weekdays that are used (typically with N=5), then there will be N-1 biases so that each weekday gets a unique bias.

Similar constructions are created to model how much within the month, quarter or year a particular date is in. In the case of CiC there can be structural breaks where the value changes rapidly for given dates, the `structural_breaks` parameter allows modeling of each structural break as different biases.

All of these biases are combined with the original data and saved as a csv file.

Step 2: Fitting the Model

The R script step_002_model.R does all of the modeling based on the output csv file from step 1. The script does the following:

1. Read in the csv output from step 1 containing the data and all features (biases).
2. Create a matrix of features.
3. Run the function `forecastLoop` that runs all models specified in the config file over a range of dates.
4. Save the forecasted results as an Excel file.

The function forecastLoop takes in a list of index values to run on, the data `Y`, the length of the validation set `testLength`, the forecast horizon `horizon`, the dates in the data `dates`, a matrix of features for each date `X`, and the models given by `modelLabels`. The function will iterate over the list of index values and for each one will generate a forecast for that date using all models given by `modelLabels`. The benefit of this approach is that each forecast date is treated independently. By editing the `modelLabels` parameter in the config file, the user can specify the needed models. The models available are:

Naïve: This model assumes a random walk with no parameters and forecasts future values with the most recent value. It can be considered a benchmark against which any model should perform better.

SNaive: Short for "Seasonal Naive", this model uses the base frequency of the data (typically five days per week) to forecast future values using the five most recent values repeatedly. If the data has a weekly periodicity, the expectation is that this model will perform better than the Naive model.

ETS: Short for "ExponenTial Smoothing", this model is an autoregression where the coefficients are weighted more heavily to recent dates. Typically one parameter will control how much recent dates are weighted compared to past dates.

ARIMA: The ARIMA model is a well-known model which allows autoregression of a time series. The auto.arima function used can select the best ARIMA model within the specified range of the parameters `max.d`, `max.p`, `max.q` which correspond to the usual d, p, q parameters of an ARIMA model.

ETSfeat: This is a model using externally specified features. In this case, the external features are the seasonal biases that were generated in step 1.

ARIMAfeat: This is the version of ARIMA models with external features, again using the seasonal biases from step 1.

ARIMAtrigB: An alternate version of ARIMAfeat, it uses the same external features, but uses a state-space ARIMA model.

TBATS: Based on the model initially developed by De Livera, Hyndman, and Snyder , this is an exponential smoothing state-space model with Box-Cox transformation to make the seasonal variation similar across the whole series.

TBATSfeat: A two-step approach that first uses an exponential smoothing model to fit the overall shape, then fits the residuals of the initial fit using a TBATS model.

Once all models are fit for all periods, the forecast results are saved as an Excel file.

Step 3: Summarizing the Results

The file step_003_summary.R will do the following:

1. Read in the Excel file of forecasts.
2. Calculate the errors between the true values and the forecasts.
3. Calculate the RMSE (root mean square error) for each model.
4. Calculate further models that either select the "best" models or the mean of several.
5. Write out the results of the RMSE calculation as a csv file.
6. Plot the RMSE values and save as PDF.
7. Plot the forecast values together with the original data.

Once the Excel file from step 2 for the forecast values is generated, these can be compared to the true values and errors can be calculated. Two further composite models are then introduced. One is to use the model with the best rolling error of each model for several dates leading up to the forecast date, and choosing the model with the smallest errors. Another is to take the mean of several models. Finally, these models are calculated and RMSE values are calculated for all models.

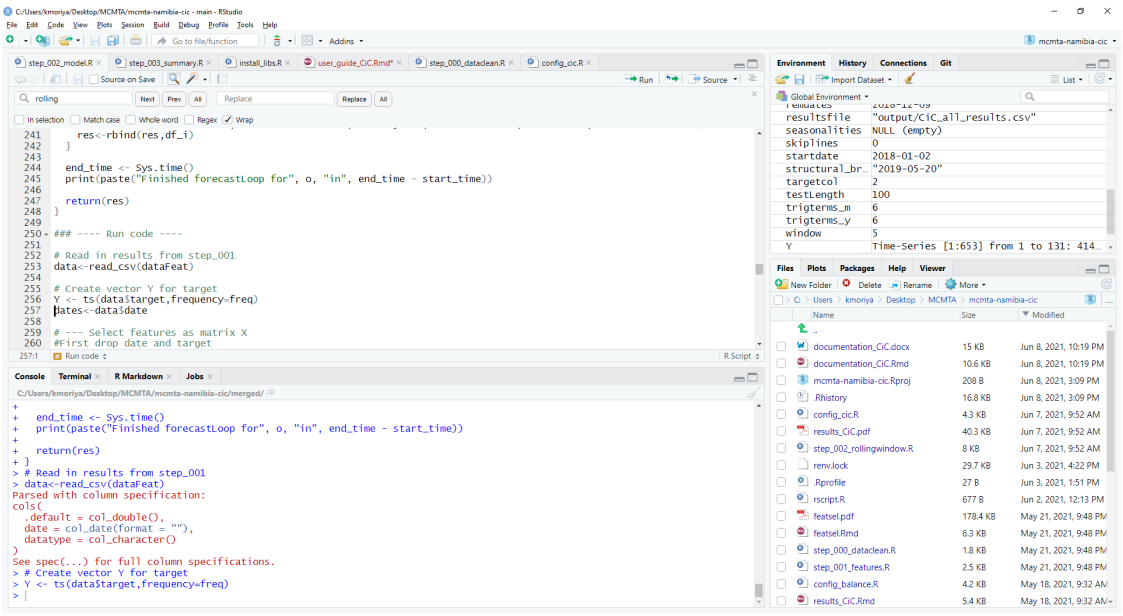
The forecast values and data plots are merged together to form one large PDF file, with each page showing different forecast origins. By flipping through these files, one can visually see what each model is doing and its comparison to the data.

For help with the code, please contact Kei Moriya (kmoriya@imf.org) and Romain Lafarguette (rlafarguette@imf.org).

APPENDIX X. USER R GUIDE

Using Rstudio

The code used for this project is in the R programming language, and it is easiest to use RStudio for reading, writing, and executing R code. Once RStudio is installed, the application should look like the following:



Source: IMF staff
Note: Screenshot of RStudio.

The upper left shows the source code, typically in the form of R scripts with extension .R. The lower left side shows the console, where R commands can be executed. The upper right panel shows available variables and additional useful information, while the bottom right panel shows files in the current folder, installed packages and other information.

More information on RStudio and how to use it is available at https://www.rstudio.com/ and other online resources, many of which are free.

Running the Code

To run the code, first open the R script of interest. The R code will have a line like

```
source('config.R')
```

so if necessary edit the config file. Details of the config file options are in the documentation file.

Once this is done, the user can execute each code line by moving the cursor to the line of interest and typing Ctrl + Enter. The line(s) run will be echoed in the console panel in the bottom left, and the console will show any output or errors as well.

The user can execute the entire R script either with Ctrl + A (select all) followed by Ctrl + Enter, or using the Source button at the top right of the source code panel.

As the code is executed, various outputs such as csv, Excel and PDF files will be generated, which will assist in understanding what the code is doing and how each model works.

For help with the code, please contact Kei Moriya (kmoriya@imf.org) and Romain Lafarguette (rlafarguette@imf.org).