September 7, 2018

An analysis of the recent dynamics in the federal funds market

Gara Afonso (FRB New York), Roc Armenter and Benjamin Lester (FRB Philadelphia)[1]

Rising rates in the repurchase (repo) market have been often cited as the driving factor behind the increase in rates and drop in volume in the fed funds market during the first half of the year.[2] As the Effective Federal Funds Rate (EFFR) came within 5 basis points (bps) of the top of the target range, a "small technical adjustment" was implemented on June 14, 2018, reducing the Interest On Reserves (IOR) to 5 bps below the top of the target range. Since then, the EFFR has settled at 1.91%, 9 bps below the top of the target range, with only a modest drop in fed funds volume.[3] Figure 1 plots the the IOR, the EFFR, and a measure of repo rates—the Secured Overnight Finance Rate (SOFR)—relative to the top of the target range, from the start of the year to the end of July, along with the evolution of trading volume in the fed funds market.[4]

Going forward, repo rates and other factors could exert additional upward pressure on fed funds rates, possibly requiring an additional technical adjustment to IOR. In this note, we analyze the recent changes in the fed funds market (up through July) through the lens of a structural model that captures the pass-through effects of repo rates. Using reasonable parameter values, the model reproduces closely the observed dynamics in the fed funds market, and hence provides an attractive framework for quantitative analysis.

We find that the effects of higher repo rates on the fed funds market were driven by the Federal Home Loan Banks (FHLBs) shifting their balances toward repo markets, and obtaining better rates from banks on those funds remaining in the fed funds market. Our analysis also illustrates how the lockstep movement in repo rates with the IOR was crucial to the success of the June technical adjustment. According to the model, further technical adjustments to the IOR would ensure that fed funds rates trade well within the target range even if repo rates soar, but interest-rate control may come at the cost of seriously inhibiting the fed funds trading.

The memo is organized as follows. In the first section, we highlight the key features of the model, with a more detailed description provided in the Appendix. In Section 2, we use the model to analyze the effects of the rising repo rates and the June technical adjustment. Section 3 discusses interest rate control going forward, with a focus on the effects of further technical adjustments in response to renewed pressure from repo rates. Section 4 concludes.

[1] We thank Ryan Bush, James Clouse, Elizabeth Klee, Jane Ihrig, Antoine Martin, Ed Nosal, Sam Schulhofer-Wohl, Julie Remache, William Riordan, Joseph Wang, and Jacqueline Yen for their continued help and feedback.

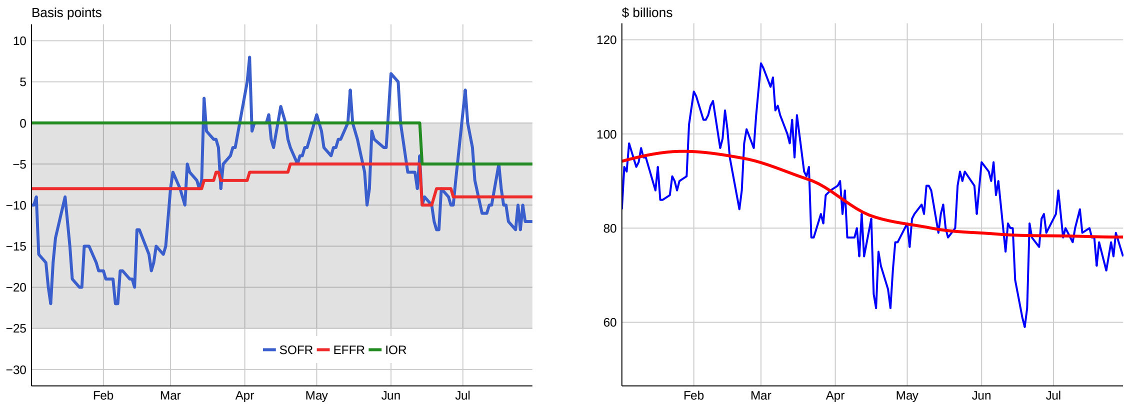
[2] Market participants often cited the large increase in Treasury bill supply as the main driver of the higher repo rates. See also the May Tealbook box "Recent Pressures in Money Markets" for additional discussion.

[3] The adjustment "has had exactly the intended effect on money market conditions," according to Potter (2018).

[4] All market rates are as reported by FRB New York and exclude month end dates. The Tri-Party General Collateral Rate (TGCR) showed similar dynamics, though it typically trades about 3 bps lower than the SOFR.

Figure 1: Key dynamics in the fed funds market in 2018

(a) Selected rates **(b) Fed funds volume**



Source: Federal Reserve Bank of New York

1 Brief description of the model

Our starting point is the structural model developed in Armenter and Lester (2017), designed to analyze fed funds trades between depository institutions that qualify for IOR (or "banks," for short) and FHLBs.[5] Banks are heterogeneous: Some have a net balance-sheet benefit from borrowing funds from a FHLB, perhaps due to Liquidity Coverage Ratio (LCR) considerations; while others face a net cost from borrowing due to, e.g., FDIC assessment fees. More precisely, the net return from borrowing fed funds for bank i at rate ρ_i is

$$\pi_i^b = \text{IOR} + x_i - \rho_i$$

where x_i is the balance-sheet net benefit, which can be positive or negative, and varies across banks according to a parametric distribution that we calibrate to match the observed dispersion in fed funds rates. We introduce search frictions to capture the over-the-counter nature of trades, and to generate several salient features of the fed funds market, including incomplete arbitrage, rate dispersion, and limited participation by banks.

We take repo rates to be exogenous, as conditions in the fed funds market do not seem to currently influence repo rates directly.[6] Focusing on the FHLBs' options and decisions, we assume that the transmission of repo rates into the fed funds market occurs through two channels:

- **Supply channel.** FHLBs split their balances between the fed funds and repo markets

[5]For further details on the model, data, and calibration see the Appendix. This is not the only structural model of the fed funds market post-2008; see Bech and Klee (2011), Chen et al. (2016), Schulhofer-Wohl and Clouse (2018), Kim et al. (2017), and Afonso et al. (2018), among others.

[6]Of course, there are common determinants of fed funds and repo rates—most importantly, the IOR, which we assume has full pass-through with repo rates in our model exercises. It is also likely that, as reserves become scarce, there will be additional linkages between the fed funds and repo markets, perhaps through the banks' liquidity decisions.

according to a linear function of the spread between the EFFR and SOFR,

$$\lambda = \lambda^* + \varepsilon\,(\text{EFFR} - \text{SOFR})\,,$$

where λ is the share of the FHLBs' balances allotted for lending in the fed funds market, λ^* is an intercept term, and $\varepsilon > 0$ captures the sensitivity of the FHLBs' liquidity portfolio to the spread.[7] This channel operates primarily through the supply of funds, but will also elicit a response in rates. For example, FHLBs will divert liquidity away from the fed funds market in response to higher repo rates, which in turn will lead banks to compete for the scarcer balances by bidding up fed funds rates.

- **Outside-option channel.** When seeking a counterparty in the fed funds market, FHLBs have an outside option for their balances, given by a weighted average of the repo rate and the prevailing rate at the Overnight Reverse Repurchase Agreement Facility (ONRRP),

$$r = (1-\alpha)\text{ONRRP} + \alpha \max\{\text{SOFR}, \text{ONRRP}\}\,,$$

where $\alpha \in [0,1]$ determines the sensitivity of the outside option to repo rates.[8] FHLBs will never accept a fed funds trade that offers a lower rate of return than this outside option, r. Hence, if $\alpha > 0$ and $SOFR > ONRRP$, an increase in the repo rate improves the outside option for FHLBs, who then demand better rates from banks in the fed funds market.

The "arbitrage surplus," defined as the spread between the IOR and the FHLBs' outside option $S = \text{IOR} - r$, is the key determinant of fed funds rates and volume in the model. For any given pair of counterparties, the gains from trade will be the sum of the arbitrage surplus and some idiosyncratic factors, like the FHLBs' preference for early return of funds and the bank's balance-sheet considerations. Whenever there is a change in arbitrage surplus, all bilateral trades in the market must adjust—and some may actually become unprofitable.

2 The fed funds market in 2018

For calibration and exposition purposes, we focus on the current year until July and split the data into three distinct episodes reported in Table 1, delimited by the evolution of repo rates and the technical adjustment to the IOR. We use the moniker "low repo" to denote the first period, from January 1 – March 9, 2018, when repo rates were relatively low. The second period, from April 23

[7] The FHLBs' liquidity requirements may imply a lower bound on the supply of fed funds, $\lambda \geq \bar{\lambda}$. We found no evidence in our calibration that fed funds lent by FHLBs are at a lower bound for the time being, and thus we have chosen to omit it. See Tikonoff and Wang (2017) for further discussion. Another possible concern with our specification is that FHLBs raise some of the funds lent through Discount Notes (DN), perhaps $10 bn. or more. This suggests that the spread between DN rates and the EFFR may be a relevant determinant of the FHLBs supply and its omission may lead us to overstate the FHLBs response to repo rates.

[8] The case $\alpha = 1$ corresponds to the specification in Schulhofer-Wohl and Clouse (2018). A possible structural interpretation of $\alpha < 1$ is that FHLBs have less bargaining power in the repo market late in the day.

– June 13, 2018, is labeled "high repo" for the obvious reasons. Finally, the "technical adjustment" period starts on June 14, 2018, when the IOR was reduced by 5 bps, and ends with the month of July.[9] Since the model does not encompass bank-to-bank trades, we focus on fed funds volume lent by FHLBs.[10]

Table 1: Key changes in spreads and fed funds volume

	Low repo period	**High repo period**		**Tech adjustment period**	
	Jan. 1 - Mar. 9	Apr. 23 - Jun. 13		Jun. 14 - Jul. 31	
	(I)	**(II)**	(II)-(I)	**(III)**	(III) - (II)
IOR	0	0	0	-5	-5
ONRRP rate	-25	-25	0	-25	0
SOFR	-15	-3	+12	-8	-5
EFFR	-8	-5	+3	-9	-4
FF Volume[a]					
Total	98	83.3	-14.7	76.6	-6.7
By FHLBs	96.8	81.2	-15.6	74.7	-6.5

All spreads in basis points relative to top of the FOMC's target range.
Source: Federal Reserve Bank of New York and FR2420.
[a] Volume is reported in $ bn.

In the Appendix, we show that the model can be calibrated to fit the data remarkably well: we match the EFFR and most of the distribution of fed funds rates within half a basis point in all three periods. The model also reproduces the changes in fed funds volume, though it is not capable of fully explaining the drop in volume since mid-June.[11] Importantly, the model's parameter values appear reasonable and close to alternative estimates, whenever they are available. Given the model's quantitative fit, we next deploy it to better understand the transmission of repo rates to the fed funds market, along with the effects of the technical adjustment to the IOR.

2.1 The effects of repo rates on the fed funds market

Our first exercise is to analyze the effects of the run-up in repo rates observed in the first half of the year.[12] We set the IOR and the ONRRP rate at 175 and 150 bps, respectively, matching the FOMC's target range between the March and June FOMC meetings. In the low repo period, we

[9]We discard the period March 10 to April 22 as one of transition. See the Appendix for futher discussion. The analysis does not include the recent uptick in the EFFR and drop in the fed funds volume.

[10]Ignoring bank-to-bank trades appears innocuous in the current environment, as Table 1 shows the vast majority of trades do involve a FHLB. Potter (2018) also shows that the share of trades above the IOR has remained low (Figure 9). However, the inter-bank segment of the market may regain traction over the medium term. See Afonso et al. (2018) for a model capable of generating such dynamics, as well as "Normalization scenarios in a structural model of the federal funds market," FOMC memo distributed June 1, 2017.

[11] One potential factor, that is not modeled here, is that there may have been a decrease in *aggregate* liquidity by FHLBs due to seasonal factors. See "Developments in the Federal Funds Market Following the Technical Adjustment to IOR," memo distributed on July 20, 2018.

[12]While market participants often cited the large increase in Treasury bill supply as the main driver of the higher repo rates, Baer et al. (2018) suggests other factors may have contributed to the increase in money market rates.

set the repo rate 15 bps below the IOR—the same spread observed for the first two months of the year. In the high repo period, we set the repo rate equal to the average SOFR recorded between the end of April and the June FOMC meeting, just 3 bps below the IOR. We solve the model for each scenario and report the predicted EFFR and volume in the last two columns of Table 2.[13]

Table 2: The effects of high repo rates

	Exogenous		**Model results**	
	IOR	Repo rate	EFFR	Volume ($bn.)
Low repo period	175	160[a]	167.4	96.8
High repo period	175	172[b]	170.4	81.2
Overall Change	0	+12	+3	-15.6
Decomposition:				
		Supply	+0.7	-10.8
		Outside option	+2.6	-7.7
		Interaction	-0.3	+2.9

All rates are in basis points. The ONRRP rate is constant at 150 bps.
[a] Based on 1/1/2018-3/9/2018 data for the SOFR rate.
[b] Based on 4/23/2018-6/13/2018 data for the SOFR rate.

In response to rising repo rates, FHLBs allocate fewer funds to the fed funds market and, with those funds remaining in the fed funds market, they negotiate better rates. To isolate the effect of the former—the supply channel—we calculate the model-implied fed funds rates and volume allowing the FHLBs' portfolios to change but holding constant the outside option, r. Similarly, to quantify the outside option channel, we fix FHLBs' portfolios and calculate the changes in rates and volume resulting only from the change in the outside option r. The contribution of each channel to rates and volume is reported in the lower right portion of Table 2, along with the interaction between the two channels.

Both channels are found to have an important quantitative role. The supply channel naturally has a large effect on volume. In addition, as FHLBs shift their portfolio away from the fed funds market, banks are forced to compete for scarcer funds, eliciting a mild increase in fed funds rates.

The outside-option channel has a larger effect on rates, explaining most of the change in the EFFR by itself. Our calibration implies that the 12 bps increase in the repo rate improved the FHLBs' outside option by 9 bps—a large effect. More surprisingly, the rise in the outside option also has a substantial effect on fed funds volume. The reason is that the increase in the repo rate reduces the arbitrage surplus between FHLBs and banks. As FHLBs demand (and obtain) higher rates, banks with sufficiently large balance-sheet costs choose not to participate in the fed funds market, which reduces the overall transaction volume. Finally, the interaction effect reflects the endogenous response of the FHLBs' supply to the higher fed funds rates caused by the increase in

[13] In other words, the low-repo and high-repo scenarios correspond to columns (I) and (II), respectively, in Table 1. Indeed, the model predictions track closely the observed averages between April 23 and June 13, 2018.

the outside option; restoring some of the fed funds volume and nudging rates downward.

Finally, we have observed some renewed upward pressure on fed funds rates in the last weeks of August, with the EFFR increasing by 1 bp and volume dropping by close to $ 10 bn. While this latest episode is too short—and the changes in rates too small—for us to re-evaluate our model at this time, the drop in fed funds rates appear roughly in line with the model's predicted response to a $3-4$ increase in repo rates. Fed funds volume would also be reduced in the model, though likely by a smaller amount than we observed.

2.2 The effects of the technical adjustment to the IOR

Next, we use our model to analyze the technical adjustment approved by the FOMC in mid June, whereby the IOR was set to 5 bps below the top of the target range. As Table 1 illustrates, this adjustment was effective in pushing down the EFFR, which settled at 1.91—only 4 bps below the IOR, but now safely away from the top of the target range of 2%.

A key observation is that repo rates moved in lockstep with the IOR, as shown in Figure 1. Using the model, we decompose the impact of the technical adjustment into the direct effect resulting from the decline in the IOR—keeping the repo rate constant—and the indirect effect following the subsequent drop in the repo rate.

Table 3 reports the results. The "no adjustment" scenario sets the IOR at 200 bps and the repo rate at 197 bps, based on the values observed in the month or so prior to the FOMC June meeting. The "adjustment" scenario sets the IOR and repo rates at 195 and 192 bps, respectively, and fits the data observed since the implementation of the technical adjustment quite well.[14]

Table 3: The effects of the technical adjustment

	Exogenous rates		**Model results**	
	IOR	Repo rate	EFFR	Volume ($bn.)
No adjustment	200	195[a]	195.4	81.2
Adjustment	195	192[b]	190.8	79.6
Overall Change	-5	-5	-4.6	-1.6
Decomposition:				
		Direct	-3.2	-12.6
		Indirect	-1.4	+11.0

All rates are in basis points. The ONRRP rate is constant at 175 bps.
[a] Based on 4/23/2018-6/13/2018 data for the SOFR rate.
[b] Based on 6/14/2018-7/31/2018 data for the SOFR rate.

We find that the lockstep movement of the repo rate and IOR is crucial to the overall success of the technical adjustment. As Table 3 illustrates, the direct effect of reducing IOR has a large impact on the EFFR—falling more than 3 bps—but also leads to a sharp reduction in fed funds

[14] In both scenarios the ONRRP rate is set at 175 bps. The model does overstate the fed funds volume after the technical adjustment, so the drop in volume in Table 3 is smaller than observed in the data.

volume. A cut in the IOR reduces the arbitrage surplus one for one and, as the pie shrinks, less guests show up at the party: FHLBs respond to the lower fed funds rates by diverting balances to the repo market, and banks with high balance sheet costs can no longer post a competitive rate. The combined effect is a large pass-through from the IOR to the EFFR, accompanied with a precipitous drop in volume.

The subsequent drop in repo rates—the indirect effect—pushes the EFFR further down but almost fully reverses the drop in fed funds volume. This is a consequence of both the supply and outside-option channels discussed earlier. First, the drop in the repo rate reduces FHLBs appetite for the repo market, causing balances to flow back to the fed funds market. Second, it reduces the FHLBs outside option and thus restores a large fraction of the arbitrage surplus that was lost by the drop in the IOR. Reversing the comparative statics discussed in the last section, the increase in the arbitrage surplus sustains trading and allows banks to remain active in the fed funds market.

3 Interest-rate control going forward

3.1 Higher repo rates and additional technical adjustments

We now use our model to explore the scope for further technical adjustments to IOR in response to renewed pressure from higher repo rates. Figure 2 reports the model-generated EFFR and fed funds volume for a range of repo rates given the current level of the IOR (teal line) and when it is set 5 bps lower (coral line). Under the current regime, fed funds rates are remarkably resilient, with the EFFR remaining more than 5 bps below the top of the target range for all repo rates below 2%. The relationship between the EFFR and the repo rate is nearly linear, with a pass-through of about 30%.[15] The effect on trading activity is more pronounced, as fed funds volume is cut in half when repo rates reach 2%, and drops even faster as repo rates rise further. According to the model, this sharp decline occurs because both FHLBs and banks retreat from the fed funds market as the arbitrage surplus shrinks, with the combined effect becoming stronger as the market becomes increasingly thinner.

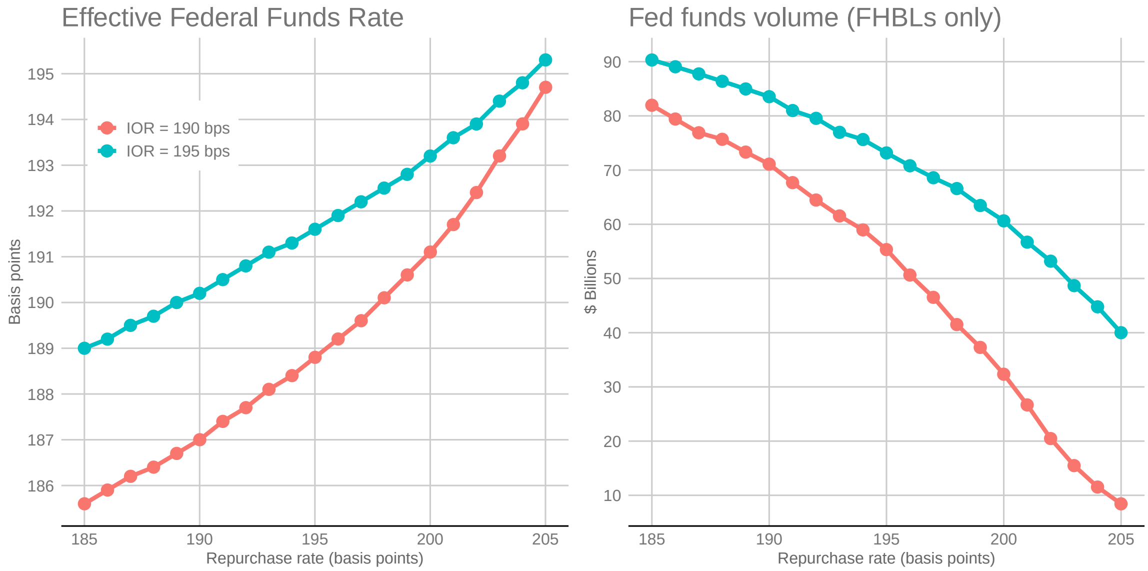
Figure 2 also displays the EFFR and volume across repo rates when IOR is set to 190 bps.[16] The lines (in coral) are noticeably steeper. The pass-through from repo to fed funds rate is substantially higher and volume drops precipitously to less than $20 bn for repo rates above 2%. This exercise illustrates that, as the arbitrage surplus shrinks, conditions in the fed funds market become more sensitive. Intuitively, a change of 1 bps in the repo rate is proportionally larger the narrower the margins are in the market in the first place.

This lesson could be particularly relevant if policymakers implement further reductions in the IOR; we find that, even though additional technical adjustments may be effective in ensuring interest-rate control in response to rising repo rates, they run the risk of thinning the fed funds

[15] That is, the EFFR increases by 3 bps for every 10 bps increase in the repo rate. This is essentially the same pass-through value as in Schulhofer-Wohl and Clouse (2018).

[16] Note that the values reported in Figure 2 do *not* reflect the overall effects of a technical adjustment, because in practice the repo rate moves in lockstep with the IOR.

Figure 2: Fed funds rates and volumes



market to the point of irrelevance. Table 4 reports the model's predictions for the EFFR and fed funds volume to various shocks to the repo rate under three different values of the IOR: when the IOR remains at its current level (195 bps), when it is reduced 5 bps below its current level, and when it is reduced 10 bps below its current level. For each calculation, we assume that repo rates move in lockstep with the IOR so that, after the technical adjustment to the IOR, the net change in the repo rate is less than the initial shock.[17]

Our results suggest that the EFFR would remain within the target range even if the repo rate increased by 15 bps, relative to its current level.[18] However, keeping a significant buffer between the EFFR and the top of the target range might require additional technical adjustments. In some cases a reduction in the IOR of 10 bps would be needed to restore the EFFR to the midpoint of the target range, but this would come at a steep cost, nearly wiping out all volume in the fed funds market in the worst case. As discussed earlier, the direct and indirect effects of a drop in IOR roughly cancel each other. However, in all but one scenario the net effect on the repo rate is positive, that is, the drop in IOR may have been sufficient to restore interest-rate control in the fed funds market but repo rates were left higher than before.

It is possible that our model overstates the drop in fed funds volume for some of the scenarios in Table 4. There are indeed good reasons to believe that FHLBs would not completely flee the fed funds market. For example, FHLBs need a minumum of early return liquidity between $30 and $40 bns., which is not available in tri-party repo transactions.[19] We explored this possibility

[17] Recall both the IOR and the repo rate are exogenous in our model, so the degree of pass-through from IOR to the repo rate is a premise of the scenario rather than a result.

[18] A sustained period with repo rates above 2% could incentivize banks to lend their excess reserves holdings in the repo market—perhaps even borrowing in the fed funds market for this purpose. This consideration is not present in our model, but could be an important force in driving up fed funds rates while possibly also reigning in repo rates.

[19] Delivery-Versus-Payments (DVP) repos do offer early return liquidity, but FHLBs appear limited in their capacity

Table 4: Upward repo pressure and IOR adjustments

Repo rate +8 bps

Exogenous rates		Model results	
IOR	Repo rate	EFFR	Volume[a]
195	200	193.2	61.5
190	195	188.8	56.0
185	190	184.5	50.3

Repo rate +10 bps

Exogenous rates		Model results	
IOR	Repo rate	EFFR	Volume[a]
195	202	194	53.8
190	197	189.6	48.4
185	192	185.4	40.1

Repo rate +12 bps

Exogenous rates		Model results	
IOR	Repo rate	EFFR	Volume[a]
195	204	194.9	45.0
190	199	190.6	38.7
185	194	186.6	28.2

Repo rate +15 bps

Exogenous rates		Model results	
IOR	Repo rate	EFFR	Volume[a]
195	207	196.3	30.8
190	202	192.4	21.0
185	197	188.7	12.9

The ONRRP rate is set at 175 bps and the baseline repo rate at 192 bps. All rates in basis points.
[a] In $ bn.

by imposing a lower bound on the FHLBs' fed funds holdings of $40 bn. in our specification for the supply channel. According to the model, a FHLBs' constraint mutes the negative effects from higher repo rates, with fed funds rates further away from the top of the target range and, of course, higher fed funds volume. Indeed, as the FHLBs' constraint effectively removes an important transmission channel, the pass-through from repo to fed funds rates is lower, albeit not zero since the outside-option channel remains active.

3.2 The effects of changes to the FDIC assessment fee

The removal of the large-institution surcharge, scheduled to take place before the end of this year, is often cited as an additional factor that may drive up fed funds rates. According to our model, a reduction in balance-sheet costs would increase fed funds rates and volume, but the magnitude of the effect depends on (i) the extent to which currently active banks benefit from the reduction, and (ii) whether currently inactive banks are encouraged to return to the fed funds market.[20] We compute an upper bound on the effect of removing the large-institution surcharge by reducing *all* banks' balance-sheet costs by 4.5 bps. According to the model, this leads the EFFR to increase by slightly less than 3 bps—a relatively modest amount that would not derail interest-rate control—while boosting fed funds volume. However, the surcharge removal leaves the fed funds market more

to expand their DVP repo activity past their current levels of about $10-15 bn per day. Of course, it is also possible that a large spread between repo and fed funds rate leads FHLBs to invest in their DVP repo capacity overall, bringing in a permanent shift in their liquidity portfolio. In addition, the Federal Housing Finance Authority (FHFA) may revise its liquidity regulations for the FHLBs, likely *increasing* the overall requirements but allowing the FHLBs more flexibility in their portfolio composition.

[20] Since our calibration is based on observed rates, there is considerable uncertainty around the distribution of balance-sheet costs for those banks that are currently inactive.

vulnerable to increases in repo rates: We find that repo rates at or above 2.10% would then push the EFFR above the top of the target range, absent any further adjustment to the IOR.

3.3 The effects of changes in FHLBs liquidity management

The FHFA has recently issued a revision to its liquidity regulations for FHLBs, to be phased in over the next year. The new regulations aim to increase the liquidity pools of FHLBs and broaden the pool of eligible assets to include, among other asset classes, Treasury securities.[21] While the overall effects of the new liquidity regulation are quite uncertain, it is possible that the net effect of the new regulations is to decrease the FHLBs' fed funds investment, perhaps sharply.

As a first pass to assess the possible impact of the new FHFA regulations, we conduct a simple counterfactual exercise in the model: Keeping rates at those observed in the technical adjustment period, we introduce a negative shock to the FHLBs' supply that drives their fed funds lending down to $40 and $30 bn. The result is an increase in the EFFR of 3 and 4 bps, respectively. Similarly to the effects of the removal of FDIC assessment fee, the regulations are not, by themselves, likely to threaten interest-rate control but do increase the risk associated with further repo increases.

4 Concluding remarks

Despite a number of simplifying assumptions, our model is able to match the recent dynamics in the fed funds market quite well. In particular, we have assumed that the transmission between the repo market and the fed funds market is a one-way street: Repo rates influence conditions in the fed funds market, but not vice versa. If this is, indeed, the case, then there may be cause for concern. The IOR would be essentially the sole policy lever, perhaps with the ONRRP rate providing minimal assistance, and the fed funds market would be no more than the proverbial canary in the coal mine—a warning system of changes in overall financing conditions, but a cog no more in the implementation of monetary policy. Such a situation could have serious drawbacks. Were the EFFR to drift out of the target range for reasons idiosyncratic to the fed funds market—perhaps due to a change in the liquidity management strategies of FHLBs—an adjustment to the IOR would effectively and, arguably, unduly influence a broad spectrum of money market rates.

Finally, we conducted our analysis within the strict confines of abundant reserves. As the normalization process unfolds and reserves become scarce, the inter-bank segment of the fed funds market may revive and drive the EFFR above the IOR.[22] The EFFR may also become more closely tied to the financing cost of banks, improving the resilience of the fed funds market and perhaps restoring some two-way linkages with other money markets. However, whether scarce reserves are a desirable goal remains unknown.

[21] More precisely, the FHFA determined to exclude Treasury securities when measuring the FHLB core mission achievement. For more details, see the FHFA advisory bulletin AB 2018-07, "Federal Home Loan Bank Liquidity Guidance," issued August 23, 2018.

[22] What exactly constitutes "scarce" reserves, and how scarcity will manifest, are open questions. See (Afonso et al., 2018) for an analysis of the transition from abundant to scarce reserves.

Appendices

A Model

A.1 Description

There are two agent types in the model: FHLBs, which lend their balances in either the fed funds or repo markets; and banks, which can borrow from the FHLBs in the fed funds market. The Fed sets the rate banks earn on their reserves as well as the offering rate at the ON RRP facility, denoted R and ONRRP, respectively. FHLBs do not qualify to earn interest on reserves, so their idle balances, if any, earn a zero net return. The prevailing rate in the repo market, p, is exogenous and taken as given by all agents.

Banks. Each bank i decides whether to be active in the fed funds market and, if so, it sets an interest rate, denoted ρ_i, that it will pay to borrow a fixed amount from a FHLB. If the bank obtains funds, it deposits them at the Fed and earns interest on reserves R overnight. Banks may also have have additional considerations associated with a fed funds transaction, denoted x_i, to be interpreted as the *net* balance sheet benefit. Balance-sheet considerations may include costs, like the FDIC fee on total assets, and benefits, like a favorable LCR treatment for borrowing funds from FHLBs.[23] The payoff from borrowing fed funds for bank i is then

$$\pi_i^b = R + x_i - \rho_i. \tag{1}$$

The distribution of x_i across banks is given by c.d.f. G over support $X \subset \Re$—including both positive and negative values. If a bank is not active or does not match, it earns zero payoff.

FHLBs. FHLBs split their balances between the fed funds market and the repo market. There are many considerations that go into this decision, including regulatory requirements, timing of the day, and, of course, prevailing rates. We assume that FHLBs allocate a share of their balances for lending at the fed funds according to

$$\lambda = \lambda^* + \varepsilon \left(\hat{\rho} - p\right) \tag{2}$$

where $\hat{\rho}$ denotes the EFFR, λ is the share of aggregate balances to be lent in the fed funds market, and $\lambda^*, \varepsilon > 0$ govern the level and elasticity of the supply of funds, respectively. This "supply" specification can be derived as an approximation to a simple model where fed funds and repo transactions are imperfect substitute instruments for the FHLBs' liquidity needs.

We assume balances lent in the repo market are simply expected to earn the net interest rate p. To lend in the fed funds market, though, FHLBs need to match with a bank.[24] To do so, FHLBs

[23] For further details on balance-sheet considerations see Wang and Bush (2018).

[24] A more accurate specification for (2) would then include both the expected rate if matched and the probability of matching—ideally, in both fed funds and repo markets. We have computed a version of the model with the expectation specification for the fed funds market and results are very similar.

seek to lend their balances at a particular rate ρ among those posted by the banks. If successfully matched, the FHLB obtains payoff

$$\pi^l(\rho) = \rho + \tau \tag{3}$$

where τ captures possible advantages that are specific of fed funds transactions for FHLBs, like early return of funds.[25] If unmatched in the fed funds market, FHLBs earn outside option r. We model the latter as a weighted average between the ON RRP rate and the repo,

$$r = (1 - \alpha)\text{ONRRP} + \alpha p, \tag{4}$$

where $\alpha \in [0, 1]$. One can interpret parameter α as the bargaining power of a FHLB late in the day in the repo market, or perhaps simply as the probability of finding a suitable counterparty then.[26] Either way, the parameter governs the pass-through coefficient of repo rates into the expected outside option in the fed funds market.

Matching frictions. We capture the over-the-counter nature of trading in the fed funds with search frictions. In particular, we use a "directed search" model, which assumes that there is enough transparency for FHLBs to target a particular rate, but not enough to guarantee that they would obtain it. For any given posted rate ρ_i, we define a queue q_j as the ratio of FHLB's balances seeking the rate to the measure of banks posting it. The matching function $\mu(q)$ then determines the probability a bank is matched, with $\nu(q) \equiv \mu(q)/q$ pinning down the probability that a FHLBs matches in the submarket for rate ρ_j.

A.2 Model solution

We briefly document how the model is solved.[27] The key decisions in the fed funds market occur in three different stages. First, banks have to decide whether or not to enter the fed funds market given their balance sheet considerations, x_i. Second, those banks that enter have to choose an interest rate, ρ_i. Finally, given the interest rates that have been posted, FHLBs have to choose which one to approach. In order to describe optimal behavior at each stage, we work backwards.

Search by FHLBs. Once interest rates have been posted, each FHLB seeks the rate that offers the maximum expected payoff, taking into account both the actual interest rate being offered *and* the probability of being matched. In particular, the expected payoff from a lender choosing a segment or submarket with interest rate ρ_i and queue length q_i is

$$\Pi^l(\rho_i, q_i) = \nu(q_i)\,(\rho_i + \tau) + (1 - \nu(q_i))r. \tag{5}$$

The first term captures the probability that the FHLB is matched, in which case it obtains the

[25] For a throughout discussion of the FHLBs liquidity needs and constraints, as well as timing considerations, see LeSeur (2014).

[26] See Schulhofer-Wohl and Clouse (2018) for a structural model where the repo rate determines the outside option of the fed funds market.

[27] See Armenter and Lester (2017) for a complete discussion of the model equilibrium and solution.

payoff (3), while the second term captures the probability that the FHLB fails to match, earning instead the outside option.

Let $\bar{\Pi}^l$ denote the maximum expected payoff that a FHLB can obtain in the fed funds, or "market utility." In equilibrium, then, any submarket with a positive queue $q_i > 0$ must satisfy

$$\Pi^l(\rho_i, q_i) = \bar{\Pi}^l. \tag{6}$$

That is, in equilibrium, any bank that is able to attract FHLBs must deliver an expected payoff equal to the market utility: For example, if a bank posts a relatively low interest rate, FHLBs must be compensated with a high probability of being matched (i.e., a short queue length), and vice versa. Using (5) to solve (6) yields a relationship between rates and queues:

$$\rho_i = r - \tau + \frac{\bar{\Pi}^l - r}{\nu(q_i)}. \tag{7}$$

Note that the search frictions allow different rates to co-exist in equilibrium.

Interest rate posting by banks. The FHLBs' indifference condition in equation (7) lays bare the trade-off facing banks: They can post a low interest rate and match with low probability but earn a large margin if they do so, or they can attract more GSEs by posting a higher interest rate, in which case they will match with higher probability but earn a narrower spread. Taking this trade-off as given, a bank with balance sheet consideration x_i solves the following profit maximization problem:

$$\begin{aligned} \max_{\rho,q} \quad & \mu(q)(R + x_i - \rho) \\ \text{subject to} \quad & \rho = r - \tau + \frac{\bar{\Pi}^l - r}{\nu(q)}, \end{aligned}$$

where the market utility $\bar{\Pi}^l$ is taken as given. From the objective function, it's clear that a bank's expected profits are equal to the product of the probability of being matched, $\mu(q_i)$, and the revenue from accepting a deposit, $R + x_i - \rho_i$. The necessary and sufficient first-order condition associated with the problem is

$$\mu'(q_i) = \frac{\bar{\Pi}^l - r}{R + x_i + \tau - r}. \tag{8}$$

Together with the indifference condition (7), we obtain the optimal queue and rate as a function of the balance-sheet considerations, $q(x_i)$, and $\rho(x_i)$. Thus search frictions endow the banks with some market power, while rates remain responsive to aggregate conditions.

Bank entry decision. A bank enters the fed funds market if, and only if, its expected profits from doing so are nonnegative. One can easily show that a bank's profits are increasing in x_i, so that the optimal entry decision is determined by a cutoff rule: There exists a unique $\bar{x} > 0$ such that profits are nonnegative if, and only if, $x_i \geq \bar{x}$. From (1) is quite immediate that if bank i posts $\rho_i = R + x_i$ it then obtains zero profits. Optimality (8) also requires that the bank cannot obtain positive profits by varying the rate. Together with (7), this implies

$$\bar{x} = \bar{\Pi}^l - \tau - R. \tag{9}$$

Fed funds market aggregate consistency. The fed funds market must "clear," in the sense that the queues q_i must be consistent with the FHLB's supply of aggregate balances:

$$\int_{\bar{x}}^{\infty} q(x_i) dG(x_i) = \lambda. \tag{10}$$

Conditions (9) and (10) are used to pin down the threshold and market utility in equilibrium. We can then compute the volume in the fed funds market as the number of matches realized,

$$V = \int_{\bar{x}}^{\infty} \mu(q(x_i)) dG(x_i)$$

and the volume-weighted distribution over traded rates is given by p.d.f.

$$f(\rho_i) = \frac{\mu(q(x_i)) dG(x_i)}{V}$$

if $q_i > 0$, zero otherwise. We can then readily compute the EFFR $\hat{\rho}$—as well as any moment of interest of the volume-weighted distribution of fed funds rates.[28]

Equilibrium. To close the model, the supply of funds λ must be consistent with (2). More formally, an equilibrium consists of a supply of funds λ, a threshold $\bar{x}$, and a joint distribution of queues and rates $q(x_i), \rho(x_i)$ such that equations (2) to (10) are satisfied.

B Calibration

B.1 Data and time periods

We work with public and confidential data for the present year to date. The model is not suited to day-to-day variation, so we split the data into three data episodes and work with the average values over the period, after removing the last business day of each calendar month.[29] The data episodes are:

1. January 1st to March 9th, when the EFFR stayed constant at 8 basis points below IOR, repo rates were generally well below the EFFR, and volume in the fed funds market averaged close to \$100 bn.

2. April 23th to June 13th, when the EFFR traded just 5 basis points below interest on reserves, repo rates were systematically above the EFFR, and fed funds volume dropped to \$80 bn.

[28] Because of the search frictions, fed funds volume is always less than the total balances supplied by the FHLBs: We assume that the difference is lent in the repo market, later in the day.

[29] Non quarter-end month-end movements have become minimal in the second quarter of 2018, but for comparison purposes we remove them for the whole time sample. For more detail see Tikonoff and Wang (2018).

3. June 14th to July 31st, from the time the technical adjustment to the IOR was effective to the latest date of our analysis.

We discard the time period between March 10th to April 22nd as one of transition. Dates were chosen such that policy rates—interest on reserves and ONRRP rate, as well as the target range by the FOMC—were constant within each data episode.

We use public data for the fed funds rate distribution as released by the Federal Reserve Bank of New York. We equate the repo rate to the SOFR, relying again on public data from the Federal Reserve Bank of New York.[30] For volume data, we use fed funds transactions by FHLB.[31] Table 5 reports the summary statistics for the variables of interest. For each time episode we work with the average over the period, though we keep an eye on the median as well to avoid any particular value to be driven by outliers.

Payoffs and quantities in the model are scale free, so we choose to normalize the measure of banks to one, express volume in billions of dollars, and rates in basis points. The data also follow this choice of units.

B.2 Specifications

For the distribution of balance-sheet considerations we use a fine grid over support $[-15, 10]$ and approximate $G(x)$ with a Gamma distribution with two parameters, shape and scale.[32] For exposition purposes, we use the (unconditional) mean μ_x and standard deviation σ_x, which can be expressed in basis points.

The matching function is given by $\mu(q) = 1 - \exp(-q)$, which is commonly used in direct search models for its tractability. In any case, we do not have data to fine tune a more flexible specification.

B.3 Parameter choices

The model parameters to calibrate are six: λ^*, ε from the supply function (2); μ_x, σ_x for the distribution of balance-sheet considerations; τ, the FHLBs' special valuation of fed funds; and the weight α from the outside option (4). All these parameters are kept constant across data episodes. Policy and repo rates are set to their observed values in each data episode, as reported in Table 5.

We target the fed funds volume due to FHLBs and EFFR in each data episode, as well as the 25th and 75th percentiles in the dollar-weighted distribution of fed funds rates. We ignore the FFR 99th Percentile, which is typically set by a bank-to-bank funds transaction that the model is not set to capture. The fed funds volume in the first data episode is matched exactly by choice of

[30] Using the TGCR requires a slight re-calibration of the model, since the TGCR is typically below the SOFR. The main results, though, are essentially unchanged.

[31] We thank Joseph Wang for his help. Results are very similar if we use instead total fed funds volume.

[32] The choice of parametric distribution is mainly for convenience, remaining parsimonious while being quite flexible. The support was chosen such that results were invariant to the particular bounds.

Table 5: Summary Data

1/1/2018 - 3/9/2018

	Mean	Median	Max.	Min.
Effective FFR	142	142	142	142
FFR 1st Percentile	139.4	140	140	130
FFR 25th Percentile	141.8	142	142	141
FFR 75th Percentile	143	143	144	142
FFR 99th Percentile	152	150	165	148
Fed funds volume (total)	98	97	115	84
Fed funds volume (by FHLB)	96.8	96.2	114	81.9
SOFR	134.9	134	145	128

Memo: IOR = 150 bps, ONRRP rate = 125 bps.

4/23/2018 - 6/13/2018

	Mean	Median	Max.	Min.
Effective FFR	170	170	170	170
FFR 1st Percentile	165.8	166	166	165
FFR 25th Percentile	169.1	169	170	169
FFR 75th Percentile	171.2	171	172	170
FFR 99th Percentile	181.5	181	187	180
Volume	83.3	83	94	63
VolumeFHLB	81.2	81.1	91.3	60.8
SOFR	172.4	172	181	165

Memo: IOR = 175 bps, ONRRP rate = 150 bps.

6/14/2018 - 7/31/2018

	Mean	Median	Max.	Min.
Effective FFR	191	191	192	190
FFR 1st Percentile	189.2	190	190	188
FFR 25th Percentile	190.5	191	191	189
FFR 75th Percentile	191.8	192	194	191
FFR 99th Percentile	205.4	206	206	200
Volume	76.6	78	88	59
VolumeFHLB	74.7	75.7	85.3	56.7
SOFR	191.6	190	204	187

Memo: IOR = 195 bps, ONRRP rate = 175 bps.

All rates in basis points. Volume in $ billions. Month ends excluded.

units. We are hence left with 11 targeted moments and 6 free parameters, so arguably the system is over-identified.

Table 6 reports the model fit. All targeted rates are matched within half a basis point—a rounding error for all purposes. In addition, the model matches the 1st percentile of the fed funds rate distribution for two out of three episodes, the exception being the period 4/23-7/18 when some fed funds rates were agreed 4 basis points below the EFFR. In the model as well as in the data, more than 80% of total traded volume is within plus/minus one basis point of the EFFR. Fed funds volume in the model is very close to the data, though it overstates somewhat the volume in the more recent episode—perhaps due to a decrease in *aggregate* liquidity by FHLBs.[33]

Table 6: Model fit

	1/1 - 3/9		**4/23 - 6/13**		**6/14 - 7/31**	
	Data	Model	Data	Model	Data	Model
Effective FFR	142	142.4	170	170.4	191	190.8
FFR Percentile 1st	139.4	139.9	165.8	168.6	189.2	189.1
FFR Percentile 25th	141.8	141.6	169.1	169.5	190.5	190.2
FFR Percentile 75th	143	143.2	171.2	171.1	191.8	191.4
FFR Percentile 99th	152	145.2	181.5	172.5	205.4	192.7
Fed funds Volume[a]	96.8	96.8	81.2	81.2	74.7	79.6

All rates in basis points. Data are period means, excluding month ends.
[a] Volume in $ bn., excluding bank-to-bank transactions.

The parameter values are reported in Table 7. The elasticity of the supply function is quite low, with an increase in the spread between the EFFR and the repo rate of one basis points shifting $1.6 bn—less than 2% of the FHLBs average liquidity—into the fed funds market. The level is within estimates of total liquidity balances by FHLBs.[34] The distribution of balance sheet considerations is quite disperse and points to balance sheet *costs* as retaining an important role in the market—yet the calibration points to smaller costs than the estimates of the marginal cost of the FDIC fee by Banegas and Tase (2016).[35] Banks with zero or positive balance sheet considerations play an important role in our results. These banks post moderately higher rates and constitute a growing fraction of the market according to the model—up to a fourth of all active banks, and an even larger fraction of fed funds trade.[36]

We are not aware of any current study to contrast our last two parameter values, the value of early return money for FHLBs and the repo-rate pass-through to the outside option.[37] We instead

[33]We did find that total FHLBs' overnight loans decreased in the last month or so. See also "Developments in the Federal Funds Market Following the Technical Adjustment to IOR," memo distributed on July 20, 2018.

[34]The FHLB's office of finance reports a total liquidity portfolio of $133 bn. in April 2018 (`www.fhlb-of.com`). The estimate, though, includes cash balances with commercial banks as pass-through reserves. See also Tikonoff and Wang (2017).

[35]Since we are basing our calibration on traded rates, the model is actually silent about the balance-sheet considerations of banks that stayed inactive thorough the sample period.

[36]These facts line up with banks that were termed "non-IOER arbitrage borrowers" in Wang and Bush (2018).

[37]That said, 3 basis points appears a reasonable estimate for the marginal value of early return money for FHLBs.

Supply function	
Level λ^*	119 \$bn.
Elasticity ε	1.6 \$bn./bp
Distribution $G(x)$	
Mean μ_x	-3 bps
Std.Desv. σ_x	4 bps
FHLBs preferences	
Early funds return τ	3 bps
Outside option	
Repo pass-through α	.75

Table 7: Parameter values

briefly discuss how the calibration pins down the parameters τ and α. A key feature of the model is that no agreed-upon rate can be valued below the outside option of the FHLBs. By either giving an additional value for fed funds—a higher τ—or by weighing down the repo rate—a lower value of α—the calibration can reconcile the large fraction of trades with rates below the repo rate in the last two episodes. Parameter α also effectively governs the strength of the outside-option channel for repo rates: If $\alpha = 0$, repo rates would impact the fed funds market only through the supply channel.

References

Afonso, Gara, Roc Armenter, and Benjamin Lester, "A Model of the Federal Funds MArket: Yesterday, Today, and Tomorrow," February 2018. Federal Reserve Bank of Philadelphia WP 18-10.

Armenter, Roc and Benjamin Lester, "Excess Reserves and Monetary Policy Implementation," *Review of Economic Dynamics*, 2017, *23*, 212–235.

Baer, Tony, Ari Morse, and Tony Rodrigues, "Quantifying Stock and Flow Effects of Treasury-Bill Issuance on Money Market Rates ," MarketSource, Federal Reserve Bank of New York August 2018.

Banegas, Ayelen and Manjola Tase, "Reserve Balances, the Federal Funds Market and Arbitrage in the New Regulatory Framework," Finance and Economics Discussion Series 2016-079, Board of Governors of the Federal Reserve System (U.S.) September 2016.

Bech, Morten L. and Elizabeth Klee, "The Mechanics of a Graceful Exit: Interest on Reserves and Segmentation in the Federal Funds Market," *Journal of Monetary Economics*, 2011, *58* (5), 415–431.

Chen, Han, Jim Clouse, Jane Ihrig, and Elizabeth Klee, "The Federal Reserve's Tools for Policy Normalization in a Preferred Habitat Model of Financial Markets," *Journal of Money, Credit and Banking*, 2016, *48* (5), 921–955.

Kim, Kyungmin, Antoine Martin, and Ed Nosal, "Can the US interbank market be revived?," June 2017. Federal Reserve Bank of Chicago.

LeSeur, Eric, "Primer: FHLB Liquidity Management and its Impact on the Fed Funds Market," MarketSource, Federal Reserve Bank of New York October 2014.

Potter, Simon, "Confidence in the Implementation of U.S. Monetary Policy Normalization," August 2018. Speech, Remarks at the 23rd EMEAP Governors' Meeting, Manila, Philippines.

Schulhofer-Wohl, Sam and James A. Clouse, "A Sequential Bargaining Model of the Fed Funds Market with Excess Reserves," Working Paper Series WP-2018-8, Federal Reserve Bank of Chicago 2018.

Tikonoff, Anna and Joseph Wang, "Money Markets: Fed Funds Volumes Trended Higher in First Half of 2017 as FHLBs Increased Debt Issuance," MarketSource, Federal Reserve Bank of New York July 2017.

_ and _ , "Why do Overnight Unsecured Funding Rates Decline on Non Quarter-end Month-ends?," MarketSource, Federal Reserve Bank of New York July 2018.

Wang, Joseph and Ryan Bush, "Fed Funds: Beyond IOER Arbitrage," MarketSource, Federal Reserve Bank of New York June 2018.