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Effectiveness of Central Bank Swap Lines in Alleviating the Mispricing of FX Swaps at the Start of the COVID-19 Pandemic

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At the start of the COVID-19 pandemic the increased market volatility and risk aversion led to a deterioration of U.S. Dollar funding conditions in the Euro Area. The swap line interventions by the ECB and Federal Reserve on March 15, 2020 aimed to alleviate the mispricing of EUR/USD FX swaps. We find that these swap line interventions were effective since they alleviated part of the mispricing. The announcement effect of the interventions is however limited; the impact of the swap line interventions is larger and more significant closer to the implementation date. This study provides insight into the effectiveness of central bank interventions in the FX swap market during turbulent periods.

Keywords: Central Bank Policy, FX Swaps, Financial Markets, Covid-19
JEL classification: E58, G2, G15, H12

1. Introduction

Around March 2020, financial markets started to react to the COVID-19 pandemic. The increased market volatility and risk aversion also disrupted both the demand and supply of U.S. Dollar funding in the Euro Area (Avdjiev et al., 2020). As a result, the premium to borrow U.S. Dollars in the EUR/USD FX swap market rose sharply in the first weeks of the COVID-19 pandemic. Given the deteriorating U.S. Dollar funding conditions worldwide, the Federal Reserve and ECB intervened in the market by reducing the swap line rate for borrowing Dollars by 25 basis points and introducing 84-day swap operations (Persi, 2020). Following the interventions on March 15, the value of the Federal Reserve liquidity swaps rose more than 7500 fold from approximately 58 million Dollars on March 11 to approximately 440 billion Dollars around May 6.[1]

This study aims to estimate the effectiveness of central bank swap lines in solving price deviations in the foreign exchange (FX) swap market at the start of the COVID-19 pandemic. Since the global financial crisis in 2008, the price of FX swaps deviates from the no-arbitrage price implied by the Covered Interest Rate Parity (CIP) condition. Studies

[1] Source: FRED (series: Central Bank Liquidity Swaps Week Average). Retrieved via https://fred.stlouisfed.org/series/WCBLSA.

on the CIP deviation around those crisis years attribute a role to differences in counterparty risk, but also found that the introduction of swap lines had a stabilising impact on the FX swap market by lowering the volatility of deviations from CIP (Baba & Packer, 2009a; 2009b).

In recent years, several studies have investigated the role of monetary policy and prudential regulation on the CIP deviation (e.g. Du et al, 2018; Brophy et al., 2019; Cenedese et al., 2019). Also the impact of swap line agreements, which were enforced in response to the financial crisis in 2008, on the CIP deviation has been intensively studied (e.g. Allen et al., 2017; Goldberg et al., 2010, Moessner and Allen, 2013; Bahah and Reis, 2021). The COVID-19 pandemic led to new interventions to those existing swap lines and provided a ground to study the impact of these interventions on the financial market during this turbulent stress period. Previous studies by Bahaj and Reis (2020) and Aizenman et al. (2022) find evidence for swap lines to reduce part of the deviations from the CIP during the COVID-19 pandemic.

By investigating the effect of the announcement and implementation effects of the swap line interventions in depth, our study makes two novel contributions to the existing literature. First of all, we make use of granular transaction-level data from the Money Market Statistical Reporting (MMSR) dataset. The dataset covers 70 to 80% of the FX swap transaction volume and allows for a unique assessment of the impact of central bank interventions on the money market taking into account the counterparty sector and maturity profile. Second, we are able to also identify the impact of the swap line interventions on the CIP distribution by estimating quantile treatment effects in our difference-in-difference model.

Our results provide empirical evidence for a significant negative effect of the swap line adaptions by the Federal Reserve and the ECB on the CIP deviation of EUR/USD FX swaps. These adaptions were effective in alleviating part of the mispricing of the EUR/USD FX swap. We find that the effect of the announcement of the swap line interventions itself is limited. By investigating the impact of swap line adaptions on the CIP distribution of EUR/USD FX swaps, we find – in line with our hypothesis – a larger negative impact on the upper quantiles of the CIP deviation distribution compared to the lower quantiles of the CIP deviation distribution.

Our findings contribute to the broader research area studying monetary intervention effectiveness. Especially, this study provides insight into the ability to affect the pricing of FX swaps in a situation where both demand and supply are disrupted. The results are relevant for policymakers since they provide insight into the behaviour of large European financial institutions in the FX market when central banks intervene with swap lines. The latter can support the objective of maintaining financial stability.

2. The FX swap market and hypotheses

Even before the 2008 financial crisis, Akram et al. (2008) provided evidence that the CIP rarely exactly holds. This comes with several implications for the financial system as well as for policymakers. Cerutti et al. (2021) touch upon the policy implications related to the transmission of monetary policy across borders, caused by the failure of the CIP. For example, if the CIP fails the claim that even small economies can exercise monetary policy independently from the Federal Reserve's interest rate choice is no longer true. Over the last years several researchers have investigated the mispricing of FX swaps, e.g. Brophy et al. (2019), Du et al. (2018) and Cenedese et al. (2019). Bahaj and Reis (2021) investigate the role and effectiveness of central bank lending programs, and reveal that central bank swap lines provide a theoretical ceiling for the CIP deviation and that they therefore can be seen as very effective in providing lender of last resort to financial markets.

More recently, both Bahaj and Reis (2020) and Aizenman et al. (2022) investigated the impact of the swap line adaptions during the March 2020 stress period. Bahaj and Reis (2020) find that the effect of the central bank swap line intervention seemed to reduce the CIP deviation and thereby relieved some of the stress in these funding markets. In turn, Aizenman et al. (2022) use a local projection model to study the difference in impact from the dollar liquidity lines between dollar auctions by an economy's own central bank with access to Fed facilities and those by the four major central banks (Bank of England, European Central Bank, Bank of Japan and the Swiss National Bank). Focusing on the period between January 2020 and May 2020, they find that the announcement of a new liquidity line reduced the CIP deviation for the partner currencies and that the dollar auctions of the four major central banks had spill-over effects - also in terms of reduced CIP deviations - to other economies.

Given the previous findings in the literature we expect the central bank swap line interventions to improve the supply of U.S. Dollar funding in the Eurozone and therefore expect a negative effect of the swap line interventions on the EUR/USD CIP deviation. This results in our first hypothesis:

H1: The swap line interventions by the Federal Reserve and ECB in March 2020 reduces the EUR/USD CIP deviation.

According to the findings by Bahaj and Reis (2021), the decreasing swap line rate tightens the ceiling for the CIP deviation. If the CIP deviation exceeds the ceiling, a potential arbitrage opportunity appears in the recipient country. Based on this theoretical result, it sounds reasonable that a decreasing swap line rate negatively affects the upper quantiles of the CIP deviation distribution more. This results in our second hypothesis:

H_2: The swap line interventions by the Federal Reserve and ECB in March 2020 impact the distribution of the EUR/USD CIP deviation, by having a larger negative impact on the upper quantiles of the CIP deviation distribution compared to the lower quantiles of the CIP deviation distribution.

3. Data and Methodology

3.1 A first look at the data

To study the effect of the swap line interventions on the mispricing of FX swaps measured by the CIP deviation, we use transaction-level data of FX swap agreements from the Money Market Statistical Report (MMSR) dataset, collected by the ECB. The MMSR dataset contains transaction-by-transaction data from a selection of large Euro Area reporting agents in the secured, unsecured, FX swap and overnight indexed swap markets covering 70 to 80% of all FX swap transactions in the euro money market.

The MMSR dataset provides the opportunity to study the CIP deviation related to Over-The-Counter (OTC) transactions in the FX swap market. To calculate the CIP deviation of a single transaction, adaptations of the standard expression for the CIP deviation2 are necessary to correct for the maturity and the properties of the underlying transaction. To calculate the CIP deviation we use the London Inter-Bank Offered Rates (LIBOR) as the risk-free interest rates for the Euro (EUR), Dollar (USD), Pound Sterling (GBP), Japanese Yen (JPY) and Swiss France (CHF) and the Stockholm Inter-Bank Offered Rate (STIBOR) for the Swedish Krona (SEK). These data are retrieved from Thomson Reuters' Datastream. Since the interbank rates are only observed for a limited number of maturities, we linearly interpolate the (annualised) interbank rates to obtain an estimate for the risk-free rate with matching maturity. Next, we scale all interest rates with the time to maturity of the underlying transaction and annualise the CIP deviations to make CIP deviations corresponding to transactions with different maturities comparable.3

This results in the following expression to derive the annualised transaction-level CIP deviations:

$$B_i^{(b,f)} = \frac{360}{T_i - t_i}\left[\left(1 + \hat{r}_{t_i,T_i}^{(b)} * \frac{T_i - t_i}{360}\right) - \frac{F_{t_i,T_i,i}^{(b,f)}}{S_{t,i}^{(b,f)}}\left(1 + \hat{r}_{t_i,T_i}^{(f)} * \frac{T_i - t_i}{360}\right)\right] \qquad (1)$$

[2] Multiple methods exist to arrive at the CIP. We rely on the so-called cross-currency basis, that estimates the difference between the risk-free rate in the base country and the corresponding risk-free rate implied by the CIP. The formula is as follows: $B_{i,t+1}^{(b,f)} = \left[\left(1 + r_{t,t+1}^{(b)}\right) - \frac{F_{t,t+1}^{(b,f)}}{S^{(b,f)}}\left(1 + r_{t,t+1}^{(f)}\right)\right]$

[3] In line with market practice, we use a 30:360 day convention for the risk-free rates corresponding to the USD, JPY, CHF and SEK currencies whereas for the GBP a 30:365 day convention is used.

where $B_i^{(b,f)}$ represents the derived CIP deviation of transaction *i*. For each transaction i ti represents the initial date and Ti – ti. the time to maturity. The term $\frac{T_i - t_i}{360}$ is used to scale all interest rates to the time to maturity and $\frac{360}{T_i - t_i}$ presents the annualisation. The interpolated annualised LIBOR and STIBOR rates are denoted by $\hat{r}_{t_i,T_i}^{(b)}$ and $\hat{r}_{t_i,T_i}^{(f)}$for respectively the base and foreign currency. $F_{t_i,T_i,i}^{(b,f)}$ and $S_{t,i}^{(b,f)}$ respectively represent the forward exchange rate4 and the reported spot exchange rate. Lastly, since we focus on the relationship between central bank swap lines and the CIP deviation, we set the initial date to the spot exchange rate date.

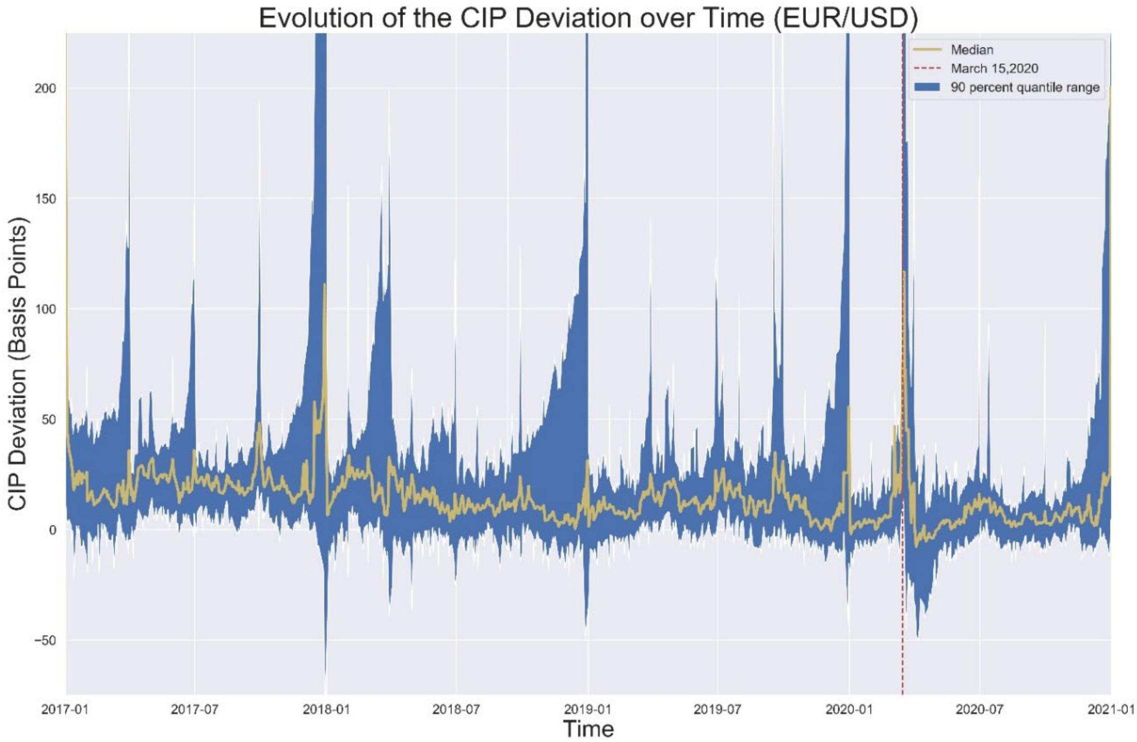
Figure 1 shows the evolution of the EUR/USD CIP deviation over time, based on the daily sample median.5 As one can observe, the median CIP deviation is positive for the majority of transactions implying that there is a premium to borrow U.S. Dollars in the market.6 The red-dotted line marks the day – March 15, 2020 - on which the swap line interventions were announced.

[4] The forward rates are indirectly reported in the MMSR dataset since the number of foreign exchange forward points is specified. The number of forward points provides information on the difference between the spot exchange rate and the forward exchange rate.

[5] The sample median is preferred over the sample mean for two reasons. First, the sample median is generally more robust for outliers and since the transaction-level data is not filtered for outliers, a robust method is preferable. Since the distribution corresponding to the CIP deviation is probably skewed, the sample median provides more information regarding the dense parts of the distribution. Outliers are less relevant since the pricing corresponding to these transactions is possibly affected by unobserved circumstances or frictions unrelated to no-arbitrage pricing.

[6] The positive CIP deviation in our study is in line with previous findings on a negative CIP deviation in the literature, since we use the EUR as the base currency (contrary to previous studies that use the USD as the base currency).

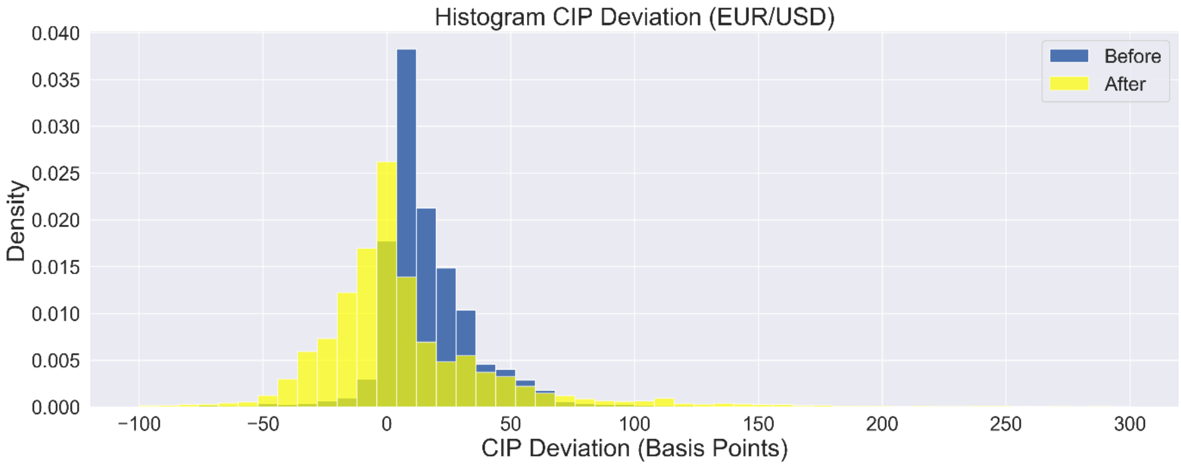
Figure 1: CIP deviation of EUR/USD swap over time



This figure shows the daily sample median and the 90% quantile range of the annualised CIP deviation over the period 2017-2021. The CIP deviation is derived from equation (1) and shown in basis points.
Source: MMSR, DNB and own calculations.

Figure 1 already provides a first indication of a change in the CIP deviation around the announcement date of the swap line interventions by the central banks, denoted by the vertical dashed line in Figure 1. For a better visual inspection of the CIP deviation before and after the swap line interventions, in Figure 2 we compare histograms corresponding to one month before the announcement date and one month after the implementation date of the EUR/USD swap line adaptions. This figure indicates a reduction in the CIP deviation for the period after the implementation date of the swap line interventions, suggesting that the changing swap line conditions negatively affect the EUR/USD CIP deviation.

Figure 2: CIP deviation before and after the swap line interventions



This figure shows the histograms of the EUR/USD CIP deviation one month before the announcement date of the swap line interventions (15 March 2020) and one month after the latest implementation date (23 March 2020).

Source: MMSR, DNB and own calculations.

3.2 Methodology

3.2.1 Model for the Average Treatment Effect on Treated (ATT)

We apply a difference-in-difference strategy to study the effect of changing swap line conditions on the mispricing of FX swaps. As such, we are able to obtain the estimated average treatment effect of the changing swap line conditions on the USD/EUR:

$$y_{i,t} = \alpha + \alpha_1 I_{t\geq Treatment} + \alpha^1 d_i + \hat{\alpha}^{ATT/QTT} d_{i,t} + \mu_t + \theta_k + \tau_{t,T} + \varepsilon_{i,t} \quad (2)$$

where $y_{i,t}$ is the observed CIP deviation corresponding to transaction *i* at time *t*. Subscripts *T* and *k* respectively denote the time to maturity and the counterparty sector. d_i is a dummy variable that is equal to 1 when transaction *I* corresponds to the treatment group, and 0 otherwise and $I_{t\geq Treatment}$ is an indicator variable that represents the post-treatment period. $d_{i,t}$ is a dummy variable that represents an interaction between d_i and $I_{t\geq Treatment}$, i.e. a dummy variable that is equal to 1 when both the transaction corresponds to the treatment group and the time *t* is after the treatment date.

The rationale behind the difference-in-difference approach is to compare the movements of the CIP deviations for the treated and non-treated currency pair before and after the swap line intervention. From an econometric point of view, it is however challenging to estimate the treatment effect on treated since the CIP deviation in the absence of treatment is not observed in the data. An approach to still estimate the average treatment effect on treated is to compare the treated observations with a control group that is not exposed to the treatment. In the context of the pricing of FX swaps, the control group could be an alternative currency pair not affected by the changing swap line conditions.

For the selection of a control group we considered the five aforementioned currency pairs, i.e. EUR/(SEK, GBP, USD, CHF and JPY). We selected the EUR/SEK FX swap transactions as the preferred control group for four reasons. First of all, an important assumption for the difference-in-difference model is the parallel trend assumption. Figure A.1 in the Appendix shows that the EUR/SEK seems to have the highest degree of similarity in pre-trends with the EUR/USD CIP deviation. Second, both the EUR/USD and the EUR/SEK are traded based on a floating exchange rate regime. Third, the Swedish Riksbank has no standing swap line with the U.S. Dollar at the date of the changing swap line conditions.[7] Lastly, there was a standing swap line between the ECB and the Swedish Riksbank during the period of the changing swap line conditions. However, there were no announced adaptations related to this swap line in the period of interest, and the swap line is one-sided (Albrizio et al., 2021). Since the swap-line is one-sided and euro-providing, the swap line will not put a ceiling on the EUR/SEK CIP deviation.

With the control group, we are able to estimate the so-called average treatment effect on the treated (ATT). We can write the ATT as:

$$\alpha^{ATT} = E\left[y_{i,t_1}^{(1)} | d_i = 1\right] - E\left[y_{i,t_1}^{(0)} | d_i = 1\right] \tag{3}$$

where $y_{i,t_1}^{(d_{i,t})} | d_i = 1$ is the CIP deviation corresponding to transaction i at time t belonging to group di with treatment status di,t. However, and as mentioned, since every transaction belonging to the EUR/USD currency pair ($d_i = 1$) is exposed to the changing swap line conditions ($d_{i,t} = 1$) we can't observe the counterfactual $E\left[y_{i,t_1}^{(0)} | d_i = 1\right]$.

To find an estimate, we make use of the EUR/SEK CIP deviation as the control currency pair and this underlies the general difference-in-difference estimator – that we already introduced in equation (2):

$$\begin{aligned} \hat{\alpha}^{ATT} = {} & E\left[y_{i,t}^{(1)} | \, t = t_1, d_i = 1\right] - E\left[y_{i,t}^{(0)} | \, t = t_0, d_i = 1\right] \\ & - E\left[y_{i,t}^{(0)} | \, t = t_1, d_i = 0\right] + E\left[y_{i,t}^{(0)} | \, t = t_0, d_i = 0\right] \end{aligned} \tag{4}$$

[7] However, the introduction of a U.S. Dollar swap line between the Federal Reserve and the Swedish Riksbank was announced on March 23, 2020 – a week *after* the USD/EUR swap line. The latter is essential to take into consideration, notwithstanding, at least theoretically, the supply and demand of the Swedish Krona relative to the Euro remain unaffected by the settlement of the swap line agreement.

Returning to equation (2), on top of the standard difference-in-difference model, we add time and counterparty sector fixed effects and include interaction terms between the time fixed effect and maturity classification. μ_t represents the time fixed effect and is included to control for unobserved time-specific effects. θ_k is the counterparty sector fixed effect and is included since trading constraints caused by prudential regulation could vary across sectors (Cenedese et al., 2019). The MMSR dataset distinguishes 19 counterparty sectors.8 Lastly, $\tau_{t,T}$ represents an interaction term between the time fixed effect and the maturity. This variable is included to control for heterogeneity. To limit the number of covariates in the model, the maturities are grouped in bins with thresholds equal to 7, 14, 30, 60 and 120 days.

To control for heteroscedasticity in the data we use two different types of robust standard errors. First of all, we consider the (default) robust standard errors (HC1). Following Abadie et al. (2017), we also estimate clustered standard errors to control for serial correlation and heterogeneity conditional on the group assignment, maturity of the underlying transaction and the spot exchange rate date.

Lastly, it is important to define the post-treatment period. We rely on Bahaj and Reis (2020) and distinguish five relevant different treatment dates:

- March 15, 2020: announcement date of the swap line interventions by the Federal Reserve and the ECB;
- March 18, 2020: first bids under the conditions announced on March 15, 2020.
- March 19, 2020: first settlements under the conditions announced on March 15, 2020.
- March 20, 2020: announcement date of increasing the frequency of one-week swap line operations.
- March 23, 2020: starting date of increasing the frequency of one-week swap line operations.

3.2.2 Model for the Quantile Treatment Effect on Treated (QTT)

As mentioned before, we also consider a quantile difference-in-difference model using an adapted version of the model by Callaway and Li (2019).

More specifically, we want to find an estimator for the following expression:

[8] Deposit-taking corporations except central banks, non-financial corporations, non-money market investment funds, other financial intermediaries, money market funds, financial auxiliaries, pension funds, captive financial institutions and money lenders, central banks, insurance corporations, central government, general government, social security funds, state government, non-profit institutions serving households, local government, households, financial corporations and none.

$$\alpha^{QTT} = F^{-1}_{y^{(1)}_{i,t_1|d_i=1}}(\tau) - F^{-1}_{y^{(0)}_{i,t_1|d_i=1}}(\tau) \tag{5}$$

where $F^{-1}(\tau)$ is the inverse cumulative distribution function corresponding to quantile τ of the CIP deviation $y^{(d_i,t)}_{i,t_1}$. Again, we do not have an estimate for $F^{-1}_{y^{(0)}_{i,t_1|d_i=1}}$ since every transaction belonging to the EUR/USD currency pair belongs to the treatment group (i.e. is exposed to changing swap line conditions). Therefore, we again use the difference-in-difference methodology to find an estimator for α^{QTT}. Equation (2) – our baseline model – will be used to retrieve the estimate $\hat{\alpha}^{QTT}$. The underlying minimisation problem however differs. Since the objective is to estimate conditional quantiles, the OLS regression applied in the baseline model will be replaced by parametric quantile regression. We consider the 0.2, 0.5 and 0.8 quantiles. The 0.5 QTT – i.e. the median – is relevant to study the contamination in the data and to compare the QTT with upper and lower quantiles.[9]

4. Results

4.1 Average Treatment Effect on Treated (ATT)

Figure 3 below plots the average treatment effects on the treated group corresponding to the baseline difference-in-difference model. The different time intervals are 1, 2, 3 and 4 weeks, respectively, and are included to study the variance/bias trade-off in more detail. In addition, we consider two separate cases based on the maturities of the underlying transactions. In the first case, we do not filter transactions based on maturity (left plot in Figure 3). In the second case, we only include transactions with a maturity between 6 and 85 days (right plot in Figure 3). The argument for filtering is to match the maturity of FX swaps with the maturities of the swap line operations; remember that the Federal Reserve swap line operations typically have a 7 or 84 day time to maturity. In addition, Table A.1 in the Appendix also contains these estimates, but including information on significance levels.

When the treatment date is set to March 15, 2020 – the day at which the swap line interventions were announced – we observe positive coefficients for both filtered and unfiltered transactions. This indicates that – surprisingly - the announcement itself led to

[9] Similar to the baseline model, we have to ensure that we select a control group that respects the parallel trend assumption. In the quantile difference-in-difference model, an adapted and stronger version of the parallel trend assumption is required to ensure that conditional quantiles are comparable across the treatment and control groups. More explicitly, it is necessary to assume that the distribution of the difference in CIP deviation between the pre and post-treatment period in the absence of treatment is independent of the group assignment. Figure A.2 in the Appendix plots the sample quantiles (0.2, 0.5 and 0.8) of the CIP deviation for the five different currency pairs over time. Again, the EUR/SEK CIP deviation has the largest degree of parallelism in terms of pre-trends with the EUR/USD CIP deviation and is therefore selected as the control group for the quantile model.

an even higher CIP deviation. The coefficients are in all cases significant when considering robust standard errors, but when we consider the clustered standard errors this is no longer the case. Since the clustered standard errors are always larger in magnitude we focus on the – more conservative – clustered standard errors.

For the later treatment days the estimated treatment effect on the treated group is, however, negative and larger in magnitude. This is in line with our expectations: central bank swap line interventions should reduce the CIP deviation. Overall, when we filter the transactions based on a maturity between 6 and 85 days, the results show a significant and negative treatment effect on the treated group for the treatment dates after March 19 in almost all cases. However, for the unfiltered results, the coefficients are mostly insignificant. A possible explanation is the large variation of the CIP deviation corresponding to transactions with a short time to maturity. This is also indicated by the lower standard errors.

To conclude, the empirical results provide evidence for the hypothesis that the changing swap line conditions negatively affect the expected CIP deviation. However, the results are only significant results when the transactions are filtered based on the maturity between 6 and 85 days and the treatment date is set close to the implementation date.

Figure 3: Impact of swap line adaptions on CIP deviation

Coefficient plot of Average Treatment effect on Treated (ATT)

Since the swap line interventions announced at the start of the COVID-19 pandemic are implemented on different dates, it could be relevant to estimate the overall effect of the changing swap line conditions on the CIP deviation. We do so by comparing the CIP deviations in the period before the changing swap line conditions (March 15, 2020) with the CIP deviations corresponding to the period after all the adaptations are implemented (March 23, 2020).

In Table 1, we include the estimates for the overall average treatment effect on treated (ATT) together with the corresponding robust and clustered standard errors. All the estimated coefficients are insignificant once we consider all transactions. For the specifications where the transactions are filtered based on the maturity between 6 and 85 days, the results are more in line with the previous results for the different treatment dates. More specifically, the estimated treatment effects are significantly negative when the interval is larger than seven days. This supports our hypothesis that the considered swap line adaptations negatively affect the expected EUR/USD CIP deviation.

Table 1: Impact of swap line adaptions on CIP deviation – Overall ATT

	All maturities				Filtered maturities			
	7 Days	14 Days	21 Days	30 Days	7 Days	14 Days	21 Days	30 Days
Overall								
$\hat{\alpha}^{ATT}$	6.30	4.82	2.06	-4.31	-7.27_{+}	-10.54^{*}_{++}	-11.15^{**}_{++}	-9.57^{**}_{++}
S.E. (HC1)	(5.63)	(3.30)	(2.55)	(2.45)	(3.17)	(2.03)	(1.64)	(1.40)
S.E. (Cluster)	(6.34)	(5.62)	(4.60)	(5.16)	(7.22)	(4.38)	(3.86)	(3.39)

This table shows the estimated overall treatment effect on treated for different interval sizes and maturity specifications. The estimated coefficient is denoted by $\hat{\alpha}^{ATT}$ and is measured in basis points. The corresponding robust (HC1) and clustered standard errors are included between brackets. Significant coefficients are indicated with * and ** for respectively the 0.05 and 0.01 significance levels based on the clustered standard errors, and + and ++ for respectively the 0.05 and 0.01 significance levels based on the robust (HC1) standard errors.

Source: DNB, MMSR, and own calculations.

4.2 Quantile Treatment Effect on Treated (QTT)

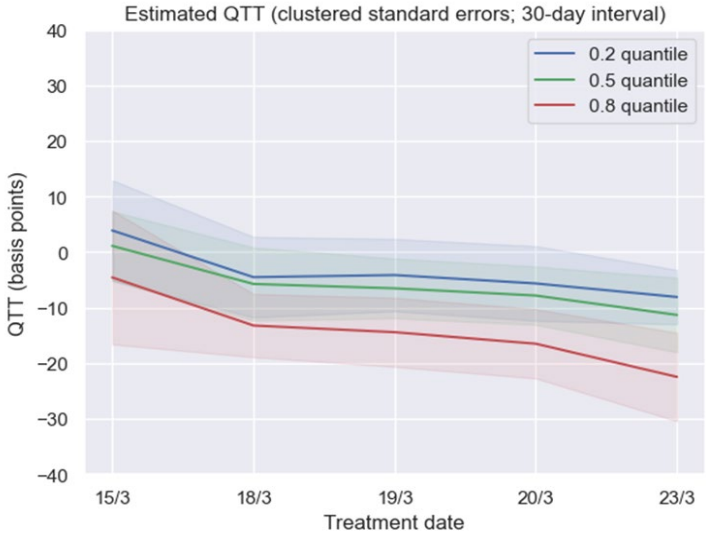
Next, we discuss the results based on the quantile difference-in-difference approach, which enables us to identify the impact of the interventions on the CIP distribution. Figure 4 below plots the estimates for the quantile treatment effect on treated (QTT) for the different quantiles corresponding to the quantile difference-in-difference methodology. Table A.2 in the appendix shows the coefficients for the three different quantiles, two sample specifications (unfiltered and filtered) and five treatment days.[10] We can draw a few conclusions based on these results.

First of all and similar to the results for the average treatment effect on treated, the estimated quantile treatment effects on treated are positive when the treatment date is set to March 15, 2020. However, and contrary to the results for the average treatment effect on treated they are insignificant in almost all cases when considering the clustered standard errors. For the treatment dates after March 15, the estimated quantile treatment effects on treated are in the majority of the specifications negative and become significant for the treatment dates close to the implementation date. A possible explanation is the limited effect of the announcement, together with an increasing degree of financial distress due to the COVID-19 pandemic in the period around March 15.

[10] To save space, we only show the clustered standard errors in the table since this is the most conservative approach. The robust standard errors are not shown, but we do show the significance of the coefficients based on the robust standard errors.

Figure 4: Impact of swap line adaptions on CIP deviation

Coefficient plot of Quantile Treatment effect on Treated (QTT)



Second, the results show that the estimated quantile treatment effects on treated are generally larger in magnitude for the 0.8 quantile compared to the 0.5 and 0.2 quantile estimates when the treatment date is set to March 20 or March 23. The latter supports our second hypothesis that the swap line adaptations have a larger effect on the upper quantiles of CIP deviation distribution. This supports the rationale behind the hypothesis, i.e. if the CIP deviation exceeds the ceiling, a potential arbitrage opportunity appears in the recipient country.

Third, the difference between the 0.8 and 0.5 quantile treatment effects on treated is larger in the majority of the specifications compared to the difference between 0.5 and 0.2 quantile treatment effects. An explanation is the skewed shape of the CIP deviation distribution.

We again estimate the overall effect of the changing swap line conditions, but now for the quantile treatment effect on treated group. Table 2 below shows the estimates for the overall quantile treatment effects on treated. First, there is a significantly negative treatment effect on treated for 0.8 quantiles for every specification of interval size and maturity filter. Second, in a majority of the specifications, the estimated treatment effect on treated corresponding to the 0.8 quantile is larger in magnitude compared to the corresponding 0.5 and 0.2 quantile treatment effects.

Table 2: Impact of swap line adaptions on CIP deviation – Overall QTT

	All maturities				Filtered maturities (6 ≤ T – t ≤ 85)			
Overall	7 Days	14 Days	21 Days	30 Days	7 Days	14 Days	21 Days	30 Days
$\hat{\alpha}_{0.5}^{QTT}$	-6.99++	-8.86++	-7.84*++	-6.35++	-12.94*++	-14.46**++	-11.20*++	-12.50**++
S.E. (Robust)	(0.75)	(0.41)	(0.21)	(0.14)	(0.80)	(0.51)	(0.24)	(0.16)
S.E. (Cluster)	(8.76)	(4.86)	(3.61)	(3.58)	(6.46)	(4.82)	(4.57)	(3.76)
$\hat{\alpha}_{0.8}^{QTT}$	-18.96*++	-14.86*++	-15.53**++	-17.26**++	-17.50*++	-16.69**++	-17.65**++	-17.17**++
S.E. (Robust)	(0.92)	(0.50)	(0.28)	(0.18)	(1.09)	(0.59)	(0.35)	(0.25)
S.E. (Cluster)	(8.86)	(5.83)	(3.14)	(4.48)	(7.86)	(5.22)	(4.32)	(5.14)
$\hat{\alpha}_{0.2}^{QTT}$	-5.33++	-4.81++	-4.25++	-3.55++	-11.37*++	-13.81**++	-12.93**++	-13.44**++
S.E. (Robust)	(0.82)	(0.49)	(0.27)	(0.18)	(1.26)	(0.75)	(0.36)	(0.24)
S.E. (Cluster)	(4.07)	(3.65)	(4.86)	(2.18)	(4.59)	(3.50)	(3.14)	(2.95)

This table shows the estimated overall quantile treatment effect on treated (QTT) for different treatment dates, interval sizes, and maturity specifications. The estimated coefficient corresponding to quantile τ is denoted by $\hat{\alpha}^{QTT}$ and is measured in basis points. The corresponding robust (HC1) and clustered standard errors are included between brackets. Significant coefficients are indicated with * and ** for respectively the 0.05 and 0.01 significance levels based on the clustered standard errors, and + and ++ for respectively the 0.05 and 0.01 significance levels based on the robust (HC1) standard errors.

Source: DNB, MMSR, and own calculations.

To summarise, the quantile difference-in-difference model reveals two takeaways that are interesting to remember. Firstly, in almost all cases, there is a negative quantile treatment effect on treated for the 0.8 quantiles when the treatment date is set to March 20 or 23. This is empirical evidence for the hypothesis that upper quantiles are affected by the changing swap line conditions, primarily when the new swap line conditions are implemented. Secondly, the treatment effect on treated is typically larger in magnitude for the 0.8 quantile compared to the 0.5 and 0.2 quantiles. The latter is empirical evidence for the hypothesis that upper quantiles are more affected by the changing swap line conditions compared to the lower quantiles of the CIP deviation distribution.

5. Conclusion

At the start of the COVID-19 pandemic, the degree of financial turbulence rose significantly, and the demand and supply of U.S. Dollar funding was disrupted (Avdjiev et al., 2020). The ECB and the Federal Reserve decided to lower the swap line rate on their standing swap line by 25 basis points, and to intensify the swap line operations to support the smooth functioning of international U.S. Dollar funding markets.

Investigating this type of monetary intervention, we find that the swap line interventions by the ECB and Federal Reserve were effective in the sense that they lowered the CIP deviation of the EUR/USD FX swap. The impact of the swap line interventions on the CIP deviation is statistically significant for EUR/USD FX swap transactions based on a maturity between 6 and 85 days. This is reasonable since the Federal Reserve swap line operations typically have a 7 or 84 day time to maturity. The estimated treatment effects are mainly significant for treatment dates close to the implementation date, indicating that the effect of the announcement of the swap line interventions is limited.

Our findings contribute to policy discussions on the effectiveness of central bank policies and swap line interventions more specifically. The failure of the CIP comes with implications for both financial markets and policymaking. We find evidence for central bank swap line adaptions as an effective monetary instrument to reduce mispricing of FX swaps. Hence, the main take-away of this study is the ability of central bank swap line interventions to affect the pricing of FX swaps in a situation where both demand and supply are disrupted. Interestingly, the effect of announcing swap line interventions seems limited. Thereby, these results are relevant for policymakers since they provide insight into the FX market when central banks intervene with swap lines. However, before treating swap line adaptions as the optimal solution to intervene in the markets, more research into its long-term effects, its interaction with other monetary policy instruments and potential drawbacks has to be done.

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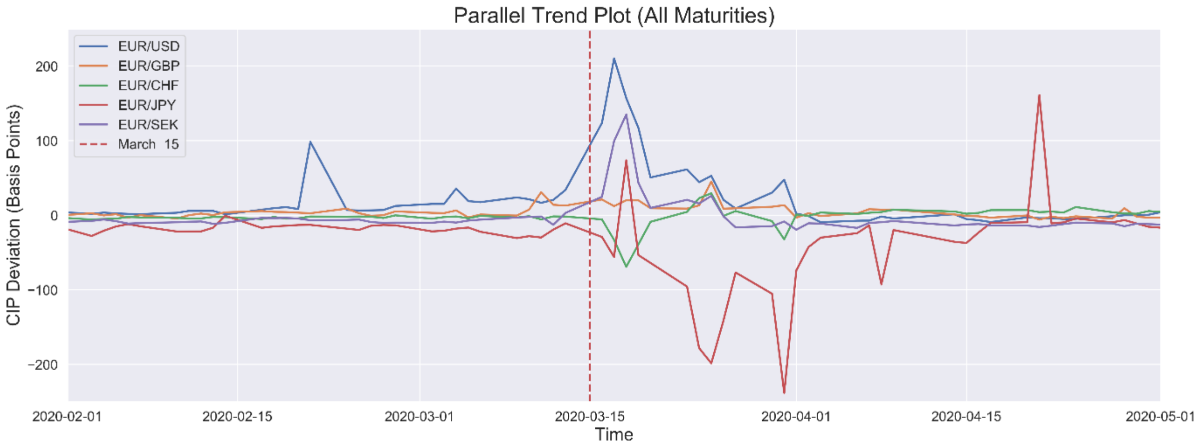
Appendix

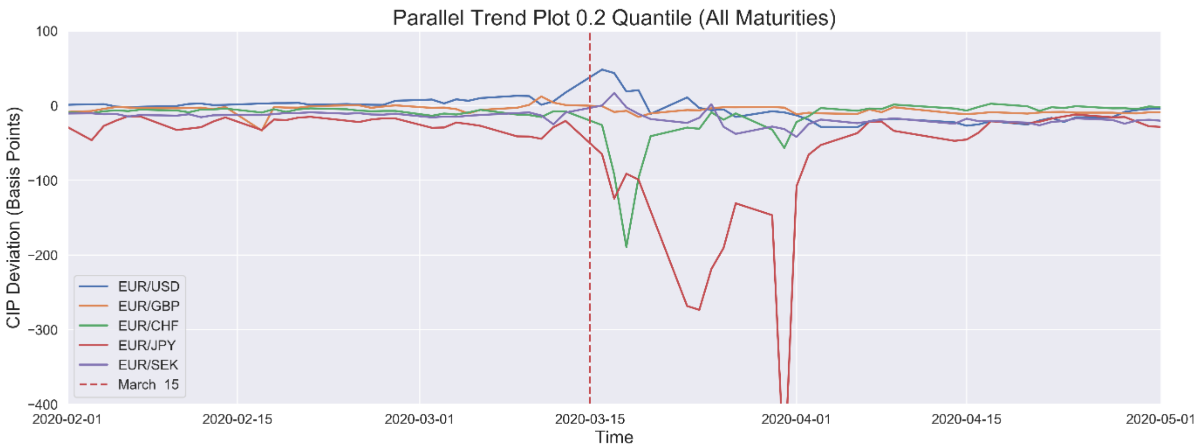
Figure A.1: Parallel Trend Plot for all currency pairs



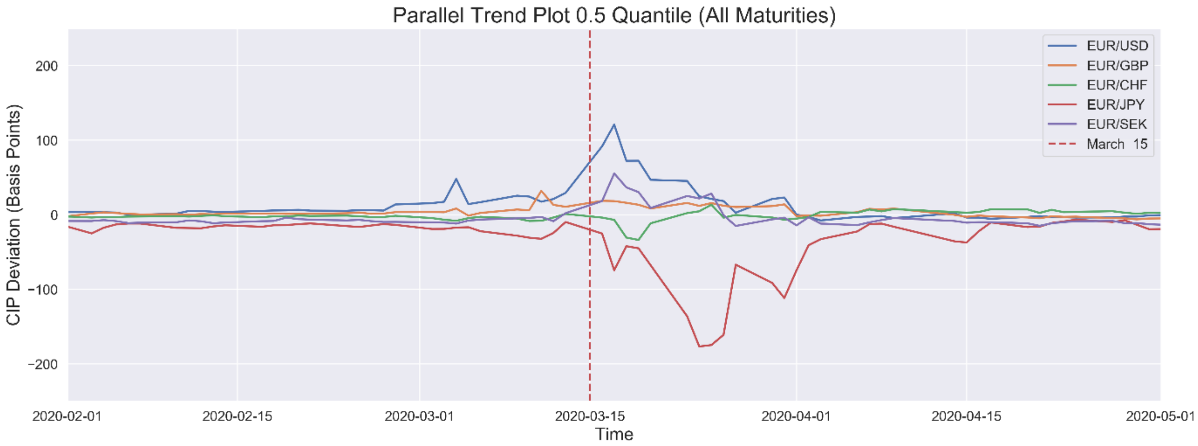
This figure shows the evolution of the daily average CIP deviation over time for the currency pairs EUR / (USD, GBP, CHF, JPY, SEK).

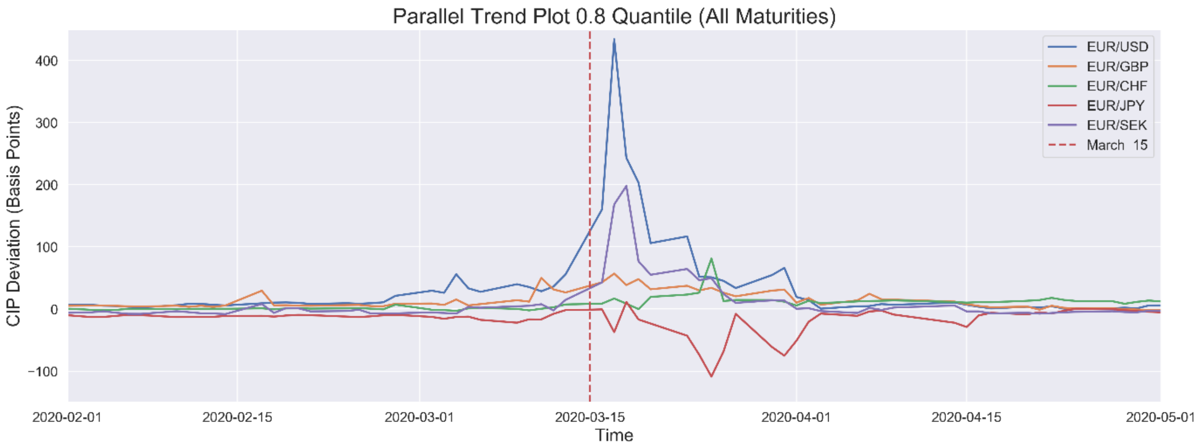
Source: DNB, MMSR, and own calculations.

Figure A.2: Quantile Parallel Trend Plots for all currency pairs



This figure shows the evolution of the daily 0.2, 0.5 and 0.8 quantiles of the CIP deviation over time for the currency pairs EUR / (USD, GBP, CHF, JPY, SEK).





Source: DNB, MMSR, and own calculations.

Table A.1: Impact of swap line adaptions on CIP deviation – ATT

	All maturities				**Filtered maturities ($6 \leq T - t \leq 85$)**			
	7 Days	14 Days	21 Days	30 Days	7 Days	14 Days	21 Days	30 Days
March, 15								
$\hat{\alpha}^{ATT}$	34.79^{*}_{++}	21.24^{*}_{++}	18.81^{**}_{++}	11.16_{++}	28.64^{**}_{++}	10.07_{++}	6.55_{++}	4.25_{++}
S.E. (HC1)	(5.37)	(4.03)	(2.90)	(2.79)	(4.87)	(2.78)	(1.90)	(1.62)
S.E. (Cluster)	(16.65)	(9.47)	(7.14)	(7.12)	(5.62)	(5.54)	(4.28)	(3.82)
March, 18								
$\hat{\alpha}^{ATT}$	-22.39_{++}	-7.07	-5.63	-8.95_{++}	6.43	-7.42_{+}	-7.52_{++}	-8.32^{*}_{++}
S.E. (HC1)	(6.55)	(4.18)	(3.02)	(2.77)	(5.44)	(2.90)	(1.97)	(1.58)
S.E. (Cluster)	(17.82)	(11.13)	(7.69)	(6.90)	(7.46)	(5.62)	(4.56)	(3.79)
March, 19								
$\hat{\alpha}^{ATT}$	-9.19	0.30	-3.99	-7.26_{+}	-12.58_{+}	-10.73^{*}_{++}	-13.01^{**}_{++}	-11.90^{**}_{++}
S.E. (HC1)	(7.74)	(4.40)	(3.03)	(2.72)	(5.34)	(3.05)	(2.01)	(1.58)
S.E. (Cluster)	(17.68)	(10.94)	(7.60)	(6.66)	(9.61)	(5.55)	(4.53)	(3.71)
March, 20								
$\hat{\alpha}^{ATT}$	-23.57_{++}	-9.28_{+}	-11.15_{++}	-12.13_{++}	-27.31^{**}_{++}	-20.82^{**}_{++}	-20.42^{**}_{++}	-16.87^{**}_{++}
S.E. (HC1)	(7.66)	(4.29)	(3.01)	(2.74)	(5.40)	(3.07)	(1.99)	(1.58)
S.E. (Cluster)	(17.28)	(10.93)	(7.60)	(6.64)	(9.15)	(5.55)	(4.51)	(3.71)
March, 23								
$\hat{\alpha}^{ATT}$	-29.09_{++}	-14.31_{++}	-14.48_{++}	-12.56^{*}_{++}	-35.58^{**}_{++}	-28.52^{**}_{++}	-28.53^{**}_{++}	-23.60^{**}_{++}
S.E. (HC1)	(7.54)	(4.30)	(3.23)	(2.42)	(5.38)	(3.07)	(2.22)	(1.63)
S.E. (Cluster)	(17.41)	(10.93)	(8.17)	(6.18)	(8.41)	(5.36)	(4.34)	(3.73)

This table shows the estimated average treatment effect on treated (ATT) for different treatment dates, interval sizes, and maturity specifications. The estimated coefficient is denoted by $\hat{\alpha}^{ATT}$ and is measured in basis points. The corresponding robust (HC1) and clustered standard errors are included between brackets. Significant coefficients are indicated with * and ** for respectively the 0.05 and 0.01 significance levels based on the clustered standard errors, and + and ++ for respectively the 0.05 and 0.01 significance levels based on the robust (HC1) standard errors.

Source: DNB, MMSR, and own calculations.

Table A.2: Impact of swap line adaptions on CIP deviation – QTT

	All maturities				**Filtered maturities ($6 \leq T - t \leq 85$)**			
	7 Days	14 Days	21 Days	30 Days	7 Days	14 Days	21 Days	30 Days
March, 15								
$\hat{\alpha}_{0.5}^{QTT}$	12.63_{++}	1.11_{++}	1.24_{++}	1.12_{++}	16.46^{**}_{++}	0.56	0.89_{++}	-3.32_{++}
S.E. (Cluster)	(8.20)	(4.48)	(3.29)	(3.17)	(4.12)	(7.60)	(4.89)	(3.69)
$\hat{\alpha}_{0.8}^{QTT}$	19.50^{**}_{++}	-1.28_{++}	1.35_{++}	-4.56_{++}	37.91^{**}_{++}	1.25	1.46_{++}	-4.14_{++}
S.E. (Cluster)	(5.76)	(5.73)	(4.53)	(6.14)	(9.88)	(8.81)	(5.11)	(4.46)
$\hat{\alpha}_{0.2}^{QTT}$	16.56_{++}	3.70_{++}	4.31_{++}	3.90_{++}	12.61^{**}_{++}	0.58	-1.53_{++}	-2.66_{++}
S.E. (Cluster)	(11.43)	(12.42)	(4.90)	(4.61)	(4.60)	(7.09)	(3.60)	(4.17)
March, 18								
$\hat{\alpha}_{0.5}^{QTT}$	-2.83_{+}	-4.52_{++}	-5.41_{++}	-5.73_{++}	16.94^{**}_{++}	-6.03_{++}	-6.81_{++}	-9.62^{**}_{++}
S.E. (Cluster)	(7.04)	(4.43)	(3.85)	(3.35)	(5.87)	(4.94)	(4.95)	(3.69)
$\hat{\alpha}_{0.8}^{QTT}$	2.69_{+}	-7.49_{++}	-10.89^{*}_{++}	-13.21^{**}_{++}	21.65_{++}	-11.28_{++}	-9.46_{++}	-13.39^{**}_{++}
S.E. (Cluster)	(10.70)	(4.78)	(5.49)	(2.90)	(11.21)	(7.42)	(5.58)	(4.69)
$\hat{\alpha}_{0.2}^{QTT}$	-13.84_{++}	-7.38_{++}	-5.02_{++}	-4.51_{++}	4.30_{++}	-7.49_{++}	-8.02^{*}_{++}	-10.25^{**}_{++}
S.E. (Cluster)	(12.39)	(5.62)	(3.59)	(3.70)	(6.95)	(5.21)	(3.61)	(3.09)
March, 19								
$\hat{\alpha}_{0.5}^{QTT}$	-12.16_{++}	-3.97_{++}	-7.65^{**}_{++}	-6.52^{*}_{++}	-12.78_{++}	-7.48_{++}	-11.62^{*}_{++}	-11.16^{**}_{++}
S.E. (Cluster)	(7.20)	(4.18)	(2.78)	(2.74)	(11.24)	(4.14)	(5.32)	(3.73)
$\hat{\alpha}_{0.8}^{QTT}$	-8.17_{++}	-6.04_{++}	-15.12^{**}_{++}	-14.42^{**}_{++}	-25.88_{++}	-14.67^{*}_{++}	-16.02^{**}_{++}	-15.52^{**}_{++}
S.E. (Cluster)	(9.28)	(5.92)	(5.23)	(3.17)	(13.95)	(5.77)	(5.38)	(5.20)
$\hat{\alpha}_{0.2}^{QTT}$	-13.84_{++}	-2.92_{++}	-4.91_{++}	-4.13_{++}	-9.23_{++}	-7.24_{++}	-11.16^{**}_{++}	-11.51^{**}_{++}
S.E. (Cluster)	(11.53)	(5.63)	(3.57)	(3.32)	(11.39)	(4.94)	(3.80)	(2.48)
March, 20								
$\hat{\alpha}_{0.5}^{QTT}$	-15.08_{++}	-7.26_{++}	-10.38^{**}_{++}	-7.82^{**}_{++}	-21.71^{*}_{++}	-13.15^{**}_{++}	-15.42^{**}_{++}	-12.80^{**}_{++}
S.E. (Cluster)	(8.28)	(4.55)	(2.96)	(2.67)	(10.83)	(4.64)	(4.45)	(3.78)
$\hat{\alpha}_{0.8}^{QTT}$	-22.62_{++}	-12.67^{*}_{++}	-22.05^{**}_{++}	-16.49^{**}_{++}	-41.88^{**}_{++}	-18.33^{**}_{++}	-23.25^{**}_{++}	-17.83^{**}_{++}
S.E. (Cluster)	(12.21)	(6.07)	(2.80)	(3.18)	(7.69)	(3.56)	(5.12)	(6.32)
$\hat{\alpha}_{0.2}^{QTT}$	-18.81_{++}	-6.93_{++}	-7.38^{*}_{++}	-5.64_{++}	-15.70_{++}	-13.35^{**}_{++}	-14.64^{**}_{++}	-13.03^{**}_{++}
S.E. (Cluster)	(12.31)	(5.87)	(3.69)	(3.43)	(8.85)	(4.43)	(3.40)	(2.92)
March, 23								
$\hat{\alpha}_{0.5}^{QTT}$	-20.18^{*}_{++}	-12.10^{*}_{++}	-14.88^{**}_{++}	-11.31^{**}_{++}	-28.84^{**}_{++}	-19.22^{**}_{++}	-22.41^{**}_{++}	-17.65^{**}_{++}
S.E. (Cluster)	(9.94)	(4.99)	(4.15)	(3.42)	(9.41)	(5.15)	(4.07)	(4.38)
$\hat{\alpha}_{0.8}^{QTT}$	-36.46^{**}_{++}	-20.87^{**}_{++}	-25.03^{**}_{++}	-22.46^{**}_{++}	-53.44^{**}_{++}	-23.50^{**}_{++}	-32.97^{**}_{++}	-24.80^{**}_{++}
S.E. (Cluster)	(10.86)	(5.02)	(3.64)	(4.06)	(8.42)	(4.16)	(4.53)	(4.07)
$\hat{\alpha}_{0.2}^{QTT}$	-23.20_{++}	-9.90_{++}	-10.15^{*}_{++}	-8.08^{**}_{++}	-25.77^{**}_{++}	-17.93^{**}_{++}	-19.45^{**}_{++}	-17.51^{**}_{++}
S.E. (Cluster)	(17.48)	(7.12)	(4.12)	(2.50)	(6.79)	(3.41)	(4.39)	(2.99)

This table shows the estimated quantile treatment effect on treated (QTT) for different treatment dates, interval sizes, and maturity specifications. The estimated coefficient corresponding to quantile τ is denoted by $\hat{\alpha}^{QTT}$ and is measured in basis points. The corresponding robust (HC1) and clustered standard errors are included between brackets. Significant coefficients are indicated with * and ** for respectively the 0.05 and 0.01 significance levels based on the clustered standard errors, and + and ++ for respectively the 0.05 and 0.01 significance levels based on the robust (HC1) standard errors.

Source: DNB, MMSR, and own calculations.