HONG KONG INSTITUTE FOR MONETARY AND FINANCIAL RESEARCH

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HKIMR Working Paper No.15/2023

November 2023

Hong Kong Institute for Monetary and Financial Research
香港貨幣及金融研究中心
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Stablecoin price dynamics under a peg-stabilising mechanism

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Abstract

As an analogy for a currency board, this paper uses the theory of the quasi-bounded target-zone model based on the standard flexible-price monetary framework to study the peg-stabilising mechanism for stablecoin prices and associated dynamics. The solution to the model equation illustrates that the price is more stable in a narrower trading bandwidth and less sensitive to changes in the fundamental (demand for the stablecoin) with a stronger stabilising force in the fundamental dynamics, less ample stablecoin supply, and more anchored expectation of the price. The empirical results using Tether demonstrate that the model can describe its price dynamics. The mean reversion in the Tether price dynamics representing the stabilising force is positively related to market liquidity in the stablecoin market and volatility in the Bitcoin price, suggesting that the increased market liquidity and safe haven characteristic of Tether stabilise its price. The implications for prudential treatment of stablecoins, including trading bandwidths, market liquidity condition and the quality of backing reserves are discussed.

Keywords: Cryptocurrency, stablecoins, Tether, target zone, quasi-bounded process

JEL Classification: F31, G13

Acknowledgments

This paper represents the views of the authors, which are not necessarily the views of the Hong Kong Monetary Authority, Hong Kong Academy of Finance Limited, or Hong Kong Institute for Monetary and Financial Research. The above-mentioned entities except the authors take no responsibility for any inaccuracies or omissions contained in the paper.

1. Introduction

A stablecoin, first created in 2014, is a cryptocurrency designed to maintain a stable value vis-a-vis a reference asset, typically a fiat currency such as the US dollar (USD), by maintaining a collateralised peg. One way to do this is to back the stablecoin with a portfolio of traditional financial assets with stable values and may offer a promise that the coins can be redeemed at the pegged value. Depending on the assets under reference, stablecoins may be used for investment or payment purposes if the underlying value is linked to a fiat currency. Users or market players may differentiate a stablecoin from other types of cryptocurrencies, with a perception or expectation that it may be more readily developing into a widely acceptable means of payment, or store of value, thus having a higher potential to be incorporated into the mainstream financial system across the globe. As such, the stablecoin has the ability to solve a fundamental issue of conventional cryptocurrencies, such as Bitcoin and Ethereum, which are too volatile to be efficiently used as a means of payment or store of value, by providing both the efficiency of blockchain technology and the stability of their values. In addition to such functions, the use of stablecoins for earning yields and liquidity provision in the fast-rising decentralised finance (DeFi) segment have further stimulated the growth of stablecoins. DeFi offers access to basic financial services (e.g., borrowing and lending) without the need for a financial intermediary, such as banks. Placing stablecoins instead of "un-backed" crypto in the DeFi lending protocol allows DeFi market participants to enjoy a higher yield compared with traditional bank deposits without being affected by the volatility of the crypto market.

Another typical usage of stablecoins in DeFi is to form a liquidity pool for facilitating trades between stablecoins and crypto, where holders of stablecoins receive transaction fees in return. This institutional feature favouring stablecoins highlights their usability across crypto exchanges. For example, those exchanges that have "trusted volume". According to a report filed with the SEC, just two exchanges, Binance and Poloniex, only accept stablecoins as a medium of exchange. On some exchanges, fees are often imposed when US dollar withdrawals are frequent or large. In fact, the size of Tether, the largest stablecoin by market capitalisation "pegged" to the US dollar at 1 to 1 ratio and claimed to be backed by cash and equivalent assets, had US$66 billion of total market capitalisation, according to CoinMarketCap. This was equivalent to 7.7% of all US prime money market funds at the end of June 2022. The ratio was just 0.4% before 2020. In an increasingly concentrated stablecoin market, the two dominant coins are Tether and USD Coin, which had a capitalisation of US$81.8bn and US$30.5bn, respectively, in April 2023. The development of stablecoins and the corresponding regulatory and financial stability issues are discussed in the International Monetary Fund (2023), Basel Committee on Banking Supervision (2022b), Financial Stability Board (2022), Azar et al. (2022), and Arner et al. (2020).

As an analogy for a currency-board system, and essential to the stability of a stablecoin is a rule that requires any change in the supply of the stablecoin to be brought about only by a corresponding change in reserves in an anchor currency at a fixed price. The supply of the stablecoin and the reserves should be on the liability and asset side of the balance sheet of the stablecoin treasury, respectively. In other words, for full solvency, the dollar value of assets held in the stablecoin issuer's accounts must at least equal the dollar value of its liabilities. For a currency board system, although in theory an exchange rate commitment involving only currency might, through arbitrage, also lead to a convergence between the exchange rate in the market and the fixed rate for currency. However, this did not happen in practice. A wider exchange rate commitment for market participants is necessary to enhance arbitrage. To achieve this, there is an announced or unannounced boundary of a band at which a central bank is ready to purchase its currency to prevent a weakening of the currency beyond the fixed rate. Genberg and Hui (2011) examine how an exchange-rate band with such commitment can have benefits in terms of increased credibility and enhance arbitrage for the Hong Kong dollar pegged to the US dollar under a currency board since 1983.

It is crucial that the stablecoin treasury is fully committed to carrying out its operation by purchasing or selling the stablecoin at the fixed price or at the boundary of the band, such that market participants trust the commitment and are willing to arbitrage in the market, when the stablecoin price deviates from the fixed price. Through the operation of price arbitrage, the price will revert towards the fixed price, if the treasury's commitment is credible. The stabilising expectation in the market prevents the price from deviating substantially from the fixed price and the need for the treasury to purchase or sell a large quantity of the stablecoins. This arbitrage mechanism ensures that the stablecoins are traded in narrow bands around their pegs. However, if for some reasons stablecoin holders start to doubt the treasury's commitment, the diminished demand for the stablecoin will lead to a fall in its price. Therefore, the stabilising mechanism and the credibility of the treasury's commitment are similar to that of the exchange-rate target-zone system.

Krugman (1991) proposes a target-zone model for exchange rates in a currency band assuming a fully credible target zone. To improve the empirical performance of the basic Krugman model, extensions to the basic model were developed to capture features of intra-marginal interventions and imperfect credibility.[1] Lo et al. (2015) and Hui et al. (2016) develop a quasi-bounded target-zone model in which the possible realignment condition for the band is determined by the value of the drift and diffusion coefficients of the exchange rate dynamics. The driving forces behind this mean-reverting property of the fundamental dynamics in the

[1] To improve the basic Krugman model, extensions of the basic model were developed to capture features of intra-marginal interventions and imperfect credibility. Froot and Obstfeld (1991) and Delgado and Dumas (1992) incorporate a simple way to model such interventions with imperfect credibility by specifying that the drift term of the fundamentals towards central parity is proportional to the deviation from central parity. Bertola and Svensson (1993) extend the basic target-zone model by including a time-varying realignment risk with stochastic jumps in the central parity. Also see the references in Lo et al. (2015) and Hui et al. (2016) about the extensions of the Krugman model.

model are either central bank intervention within the target zone or “stability arbitrage” by market participants, producing forces to pull the exchange rate back to its central parity whenever it deviates from this. The exchange rate dynamics derived from the model are shown to follow a mean-reverting square-root process and are able to describe the market data for the Hong Kong dollar against the US dollar in a target zone, and the Swiss franc against the euro during the target zone regime of September 2011 – January 2015. The intervention policy incorporated in the model is consistent with the empirical evidence in Fratzscher et al. (2019) showing that central banks typically "lean against the wind" by actively counteracting the private trades of market participants, which has a stabilising effect.

To study the mechanism and the price dynamics of the stablecoin, this paper adopts the quasi-bounded target-zone model, in which the exchange rate in a trading band can breach a floor under a restricted condition. To the best of our knowledge, the literature has so far not yet explored the relationship between the stabilising mechanism and price dynamics of the stablecoin using a target-zone approach. The solution to the target-zone model equation illustrates that the stablecoin price is more stable in a narrower trading bandwidth and less sensitive to the changes in the fundamental (demand for the stablecoin) with a stronger stabilising force in the fundamental dynamics, less ample stablecoin supply, and a more anchored expectation of the price. Model calibration using Tether demonstrates that the model is able to describe its price dynamics. Empirical tests are conducted to study how the stablecoin market liquidity and the volatility of the Bitcoin price impact the Tether price dynamics, and their implications for the peg-stabilising mechanism, in particular, during the migration of Tether to the Ethereum blockchain in April 2019, and the collapse of the algorithmic stablecoin Terra and the FTX crypto exchange in 2022.

Indeed, there is recent and growing literature on investigating properties of stablecoins. Eichengreen (2019) comments that stablecoin systems can be vulnerable to speculative attack if there is a perception that the peg is under-collateralised by either national currencies or cryptocurrencies. Recent work including Baur and Hoang (2020), Baumöhl and Vyrost (2020), and Wang et al. (2020) find stablecoins playing a role of safe-haven assets. Another area of research studies the relationship between stablecoins and risky cryptocurrencies. Griffin and Shams (2020) find that Tether influenced Bitcoin and other cryptocurrency prices during the 2017 boom. A concurrent study by Wei (2018) finds no effect of Tether issuance on the price of Bitcoin. More recent studies including Ante et al. (2020), Kristoufek (2021) and Lyons and Viswanath-Natraj (2023) find evidence of stablecoin issuance being driven by periods of market downturns in Bitcoin. Klages-Mundt and Minca (2021) demonstrate that the stablecoin market faces deleveraging feedback effects causing illiquidity during crises, exacerbates collateral drawdown, and characterises stable dynamics of the system under particular conditions. Other studies of market developments and functions of stablecoins are in Berentsen and Schär (2019), Bullmann et al. (2019), Dell'Erba (2020), Routledge and Zetlin-Jones (2022), Frost et al. (2020), ECB Crypto-Assets Task Force (2020) and Bianchi et al. (2020).

Given that the stabilising mechanism of stablecoins is similar to central banks' intervention to maintain their currencies' exchange rate stability, this paper also relates to the policy works in smoothing the path of exchange rates, and in stabilising the exchange rate of currencies under either a narrow band or flexible exchange-rate regimes (surveyed in Dominguez and Frankel (1993); Sarno and Taylor (2001); Dominguez (2003, 2006); Neely (2005); Hoshikawa (2008); Menkhoff (2010); Engel (2014); Pasquariello (2018)). Authorities in both developed and emerging market countries operate their foreign exchange interventions according to their exchange rate or monetary policies or on a necessary basis. Dominguez and Frankel (1993) and Sarno and Taylor (2001) find that most currency interventions were co-ordinated among multiple government agencies to enhance their effectiveness. Pasquariello (2018) constructs a sample that includes official trading activity of developed and emerging market countries in the foreign exchange markets between 1980 and 2009. The studies of the role of central bank intervention in maintaining fixed exchange rates or pegs are in Fratzscher et al. (2019), Ferreira et al. (2019), Flood and Jeanne (2005) and Vitale (1999).

In the next section, we develop a target-zone model for the stablecoin. Section 3 presents the results of model calibration. Section 4 discusses the dynamic relationship between the Tether price dynamics and market liquidity including market stress in the crypto market. The conclusion and discussion on the implications for prudential treatment of stablecoins are in Section 5.

2. Target-zone model for stablecoins

2.1 Solution for stablecoin price dynamics

A target zone is a nonlinear compromise between fixed exchange rates and freely flexible exchange rates. The traditional theoretical literature on exchange rate regimes does not distinguish narrow target zones from completely fixed exchange rates. Only when Krugman (1991) presented the first fully credible target-zone model with explicit rational expectations for the nominal exchange rate in a small open economy, researchers started to rigorously model and understand the details of exchange rate determination within a trading band. The model predicts a nonlinear relationship (an S-shaped curve) between the exchange rate and its fundamental with a greater number of observations lying close to the edges of the band. The Krugman model simply does not specify government or market behaviour inside the band such that policy and market actions can direct the exchange rate movements according to the policy goals or market expectations. In other words, either central bank intervention within the target zone or "stability arbitrage" by market participants can be incorporated into the fundamental dynamics of the model to produce forces to pull the exchange rate back to its central parity whenever it deviates from this.

The Krugman model is based on the standard flexible-price monetary framework assuming a fully credible target zone. The log exchange rate s at time t is governed by the following equation of motion:

$$s(t) = m + \nu(t) + \alpha \frac{E[ds(t)]}{dt} \tag{1}$$

where $-\infty < s \leq 0$, m is the logarithm of the money supply and assumed to be constant, α is the absolute value of the semi-elasticity of the exchange rate to its expected rate of change, and E the expectation operator. The stochastic variable $\nu(t)$ measures all fundamental factors other than the money supply and expected exchange rate. The last term captures the expected exchange rate change under the time-t information set.

However, the theoretical predictions regarding exchange rate dynamics of the Krugman model were rejected by empirical evidence.[2] To improve the empirical performance of the basic Krugman model, extensions to the basic model were developed to capture features of intra-marginal interventions and imperfect credibility.[3] In the quasi-bounded target-zone model proposed by Lo et al. (2015) and Hui et al. (2016), the possible realignment condition for one side of the band is determined by the value of the drift and diffusion coefficients of the exchange rate dynamics. By imposing the smooth-pasting boundary condition at the side of the band with realignment risk, a central bank's intervention policy is incorporated with a stronger mean-reverting force at the boundary. The associated exchange rate dynamics and interest rate differentials derived from the model can describe the market data for the Hong Kong dollar against the US dollar in a target zone and the Swiss franc against the euro during the target zone regime of September 2011 – January 2015.

The stablecoin price is assumed to move in a quasi-bounded target zone with the upper and lower boundaries of S_U and S_L respectively. The stablecoin treasury commits to keep the

[2] Examples can be found in Diebold and Nason (1990), Meese and Rose (1991), Flood et al. (1991), and Svensson (1991a, 1991b).
[3] See footnote 1.

price S close to one USD and between these two boundaries. When the stablecoin is under depreciation pressure, its treasury needs to keep the price above the lower boundary by using the backing reserves to buy back the stablecoin. With no loss of generality, the normalised dimensionless log price x is scaled as:

$$x \equiv -s = -\ln\left[\frac{(S_U - S)}{(S_U - S_L)}\right], \tag{2}$$

such that $0 \leq x < \infty$, where $x = 0$ corresponds to the lower boundary S_L, and $x = \infty$ corresponds to the inaccessible upper boundary S_U.

The associated fundamental ν ($-\infty < \nu \leq 0$) in Eq.(1) is given by the Rayleigh process:

$$d\nu = \left(\frac{A_{-1}}{\nu} + A_1 \nu\right) dt + \sigma_\nu dZ, \tag{3}$$

which is a unique choice as shown by Hui et al. (2022) with the smooth-pasting boundary condition for Eq.(1) under a target zone:

$$\left.\frac{dx(\nu)}{d\nu}\right|_{\nu=0} = 0 \tag{4}$$

at the boundary $\nu = 0$. The optimal approximate solution of Eq.(1) is:

$$x(\nu) \approx \phi + \frac{\epsilon(m+\phi)}{\alpha(\sigma_\nu^2 + 2A_{-1})}\nu^2 = \epsilon B_0 \nu^2, \tag{5}$$

where ϵ is a positive parameter determined by minimising the total error between the approximate solution and the power series solution, and ϕ is an arbitrary constant (see Lo et al., 2015 and Hui et al., 2016). If we choose $\phi = 0$, then the normalisation of the target-zone exchange rate is $x(\nu = 0) = 0$, where is the lower boundary.

By applying Ito's lemma to the Rayleigh process for the fundamentals ν of Eq.(3) with Eq.(5), x is shown to follow a mean-reverting square-root process and also known as the Cox-Ingersoll-Ross (CIR) process (Cox, Ingersoll and Ross, 1985).:

$$dx = \kappa(\theta - x)dt + \sigma_x \sqrt{x} dZ \tag{6}$$

where κ determines the speed of the mean-reverting drift towards the long-term mean θ, σ_x is the instantaneous standard deviation, and dZ is a Wiener process with $\mathrm{E}[dZ]=0$ and $\mathrm{E}[dZ^2]=dt$. The solution links up the model parameters in the stochastic processes for the fundamental ν and price x as follows:

$$\kappa = 2|A_1|, \tag{7}$$

$$\theta = \varepsilon \left|\frac{B_0}{A_1}\right| \left(A_{-1} + \frac{1}{2}\sigma_\nu^2\right), \tag{8}$$

$$\sigma_x = 2\sigma_\nu\sqrt{|B_0|}\,. \tag{9}$$

According to Feller's classification of boundary points, it can be inferred that there is a non-attractive natural boundary at infinity (i.e., inaccessible) and that the one at the origin is a boundary of no probability leakage for $(\sigma_x^2/4\kappa\theta) < 1$ in Eq.(6), and it is not otherwise [see Karlin and Taylor (1981)]. When the no-leakage condition holds, it prevents the exchange rate x (S) to breach the lower boundary at zero (S_L); otherwise, the exchange rate may pass through the lower boundary, i.e., the price x is quasi-bounded at the origin.

The probability density function (PDF) of x under the CIR process is given by:

$$\begin{aligned} G(x,t;x',t') = {} & \frac{2}{\sigma_x^2 C_1(t-t')}\left(\frac{x}{x'}\right)^{\omega/2} \exp\left[-\frac{\omega+2}{2}C_2(t-t')\right]\times \\ & \exp\left\{-\frac{2x'+2x\exp[-C_2(t-t')]}{\sigma_x^2 C_1(t-t')}\right\}\times \\ & I_\omega\left\{\frac{4x^{1/2}x'^{1/2}\exp[-C_2(t-t')/2]}{\sigma_x^2 C_1(t-t')}\right\} \end{aligned}, \tag{10}$$

where $\omega = 2\kappa\theta/\sigma_x^2 - 1$, $C_1(\tau) = [\exp(\kappa\tau) - 1]/\kappa$, and $C_2(\tau) = -\kappa\tau$, I_ω is the modified Bessel function of the first kind of order ω.

2.2 The Peg-stabilising mechanism and associated fundamental dynamics

The drift term in Eq.(3) exhibits a mean-reverting property for the fundamental dynamics. When $|v|$ is small (approaching to the lower boundary), the term A_{-1}/ν will push ν away from zero. Such dynamics represents that market participants will react at some level of ν in order to move the stablecoin price away from the level of $x = 0$ towards some targets (or mean levels). Under depreciation pressure when the stablecoin is traded at discounts, dealers will buy stablecoin from the stablecoin treasury at the pegged price such that the stablecoin strengthens. Conversely, the term $A_1\nu$ will take place to push ν back towards the origin, indicating that market participants will sell the stablecoin to the treasury to revert the price movement if the stablecoin is traded at premiums.

The two terms (A_{-1}/ν and $A_1\nu$) determine the mean-reverting process of the fundamental ν which is interpreted as an error-correction behaviour on the part of the market arbitrage mechanism reacting to a shock. However, the mean-reverting forces contributed by the two terms in the quasi-bounded model are not symmetric. The restoring force (strengthening the stablecoin) given by A_{-1}/ν is, in general, stronger than that given by $A_1\nu$ (weakening the stablecoin). The asymmetric mean-reverting fundamental dynamics is consistent with the intuition that when the demand for the stablecoin is extremely weak, such that its price falls sharply, market participants who hold significant amounts of the stablecoin have an incentive to defend the price above the lower boundary. In addition, the stablecoin treasury is expected to buy the stablecoin from the market to maintain its price in a narrow band around the peg. These market actions and expectations enhance the arbitrage mechanism. Conversely, when the stablecoin appreciates, there is no such urge for them to sell the stablecoin and take profits. Decreasing the magnitude of the parameters A_{-1} or A_1 reduces the mean-reverting force for the fundamental, such that the fundamental variable simply moves randomly above the lower boundary, i.e., increasing the probability of ν breaching the origin.

Figure 1 plots the relationship between the price S in the original price measure and the fundamental ν expressed in Eq.(5) based on the estimated coefficient εB_0 using the market data of the Tether price against the USD.[4] It shows that changes in the price flatten with changes in the fundamental at the two boundaries. This implies that even when the fundamental changes substantially, the price is bounded in the band. When a negative demand shock pushes the price towards its lower boundary and ν towards zero, there is a stabilising force which is the term A_{-1}/ν in Eq.(3) to limit a further drop in the price. When the stablecoin appreciates towards the upper boundary, another stabilising force which is the term $(A_1\nu)$ will pull the price lower. The strength of the mean reversion in the fundamental dynamics determines the effectiveness of the stabilising mechanism through the arbitrage process for the stablecoin price, and thus reflects the credibility of the stablecoin treasury's commitment to the peg.

Based on the model, as changes in the demand alter the fundamental dynamics, the price could move between D and A; or D and C in Figure 1, where the paths depend on the coefficient εB_0 in Eq.(5). εB_0 represents the state of the stablecoin market determined by the parameters (A_{-1} and A_1), the stablecoin supply (m), and sensitivity (α) of the price to its expected rate of change. A larger εB_0 suggests that the price is more sensitive to changes in the fundamental (demand). This scenario of larger εB_0 occurred during the Covid-19 pandemic in March 2020 as shown in Figure 2 of the empirical estimations using the Tether price. This suggests that the price is less stable with inactive arbitrage (larger A_{-1} and A_1), more ample stablecoin supply,

[4] The coefficient of Eq.(5), i.e., εB_0, are estimated by a simple procedure as follows. By substituting Eq.(5) into Eq.(3) yields

$$s(t) = m - \sqrt{\frac{s(t)}{\varepsilon B_0}} + \alpha\,\frac{E[ds]}{dt},$$

From the time series of s we can construct the time series of both $\sqrt{s}$ and ds/dt. These two newly generated time series can be combined to form a new time series of χ, which is defined by the right-hand side of the above equation. The parameter εB_0 of the time series can be determined by best fitting to the time series of s. The construction of the series $\frac{E[ds]}{dt}$ is done by using the 30*24-hour moving average of ds. The estimation covers the hourly data of the Tether/USD price from April 2017 to May 2023 using a 180*24-hour rolling window. The constrained least square method is applied for the estimation.

and a less anchored expectation of the price, as illustrated by the price moving between C and D with $\varepsilon B_0 = 1.2$.

2.3 Implicit trading bandwidth of the target zone

According to Eq.(5) with $\phi = 0$, in the original measure of S we have

$$S(\nu) = S_U - (S_U - S_L)\exp(-\epsilon B_0 \nu^2) \ . \tag{11}$$

When there is a change in the trading bandwidth of the target zone given that the band is moving, in the case of non-vanishing ϕ, Eq.(5) can be re-written as

$$\tilde{x}(\nu) \equiv x(\nu) - \phi = \frac{\epsilon(m+\phi)}{\alpha(\sigma_\nu^2+2A_{-1})}\nu^2 \equiv \frac{\epsilon\tilde{m}}{\alpha(\sigma_\nu^2+2A_{-1})}\nu^2 \text{ or } \frac{\epsilon m}{\tilde{\alpha}(\sigma_\nu^2+2A_{-1})}\nu^2, \tag{12}$$

where

$$\tilde{m} = m + \phi \tag{13}$$

$$\tilde{\alpha} = \frac{\alpha}{1+(\phi/m)} \ . \tag{14}$$

Assuming that the change in bandwidth is given by

$$\tilde{S}_U - \tilde{S}_L = (S_U - S_L)e^{\phi} \tag{15}$$

and that the central parity remains unchanged, i.e.

$$\tilde{S}_C \equiv \frac{1}{2}\left(\tilde{S}_U + \tilde{S}_L\right) = \frac{1}{2}(S_U + S_L) \equiv S_C \ , \tag{16}$$

we have

$$\tilde{S}(\nu) = S(\nu) + \frac{1}{2}\left(1 - e^{\phi}\right)(S_U - S_L) \ . \tag{17}$$

Hence, according to the target-zone model, the change in the bandwidth of the target zone is controlled either by the change in stablecoin supply m or the change in the elasticity factor α, as shown in Eq.(12) and Eq.(14). If $\phi > 0$, then the bandwidth will increase; otherwise, it will shrink. $\phi > 0$ also suggests a more ample stablecoin supply ($\tilde{m} > m$) and less anchored expectation of the price ($\tilde{\alpha} < \alpha$) according to Eqs.(13) and (14). Consistent with the stabilising mechanism discussed in subsection 2.2, widening the trading bandwidth will cause the price to be less stable, while the pegged price (central parity) remains the same. In addition, the spot price will experience a shift when the bandwidth changes. As shown in Eq.(17), as the bandwidth increases (shrinks), the spot price experiences a downward (upward) shift.

3. Model calibration

After establishing the target-zone model in Section 2, we then investigate whether the CIR process derived from the model can describe the price dynamics of Tether (USDT). The maximum likelihood estimation is used to estimate the model parameters of the CIR process using the log-likelihood function of Eq.(10) with a 180-day rolling window. We set boundary ranges for the relevant parameters in the optimisation step using MATLAB. Given the availability of high frequency data, the estimation uses hourly closing price (USDT/USD) data from the Kraken crypto exchange between 1 April 2017 and 31 May 2023. The choice of using hourly data from Kraken is in line with the literature (for instance, Alexander and Dakos, 2020; Crépellière et al., 2023; Lyons and Viswanath-Natraj, 2023).[5] We follow the approach proposed by Kladivko (2007) to estimate the CIR process for the data of the 3-hour moving average hourly closing price.

Figure 2 shows the time series of the hourly closing price of the USDT/USD pair, and the transformed price in *x*. Given that Tether is pegged with the USD, the market allows it to be traded within a few percentage points deviation from the one-to-one parity even though there is no explicit band for its price.[6] In the data sample, the 0.5th and 99.5th percentiles of the distribution of the time series are 0.94 and 1.03 respectively. S&P Global (2023) also

[5] Kraken is the first exchange to provide a trading platform for the Tether/USD pair. Data from Kraken are considered to be transparent and trustworthy as it is licensed and regulated in the US. It is also among the few exchanges that the SEC did not find fraudulent trading activities in trading volume or spreads in the SEC report released in 2019 (https://www.sec.gov/comments/sr-nysearca-2019-01/srnysearca201901-5164833-183434.pdf). Kraken is one of the few major exchanges that Tether can be exchanged for the US dollar officially up to end-2018 (see Griffin and Shams, 2020), and remains a popular platform for the USDT/USD pair trading in 2022 according to Kaiko (see Medalie, et al., 2022).

[6] See https://protos.com/history-of-tethers-peg-every-time-usdt-traded-above-or-below-one-dollar/

statistically examined the price stability of five selected major stablecoins, including BUSD, USD Coin (USDC), USDT, DAI, USDP, between June 2021 and June 2023, where their lowest price levels ranged between 0.85 and 0.98 (with USDT at 0.95). With reference to the historical fluctuation ranges of USDT and other USD-pegged stablecoins, we employ 0.95 and 1.05 to be the lower and upper boundaries respectively for the USDT/USD pair and used for the transformation of the price in Eq.(2). The +/- 5% price range for a trading band allows a sufficiently wide range for price fluctuation while maintaining the peg.[7]

Panel A of Figure 3 shows the estimates of the mean-reverting parameter $\ln(\kappa)$ with the corresponding z-statistic. The value of $\ln(\kappa)$ stayed between 2 to 6, significantly above the 5% significance level (1.96) during most of the estimation period, reflecting the existence of the restoring force in the Tether price dynamics towards its equilibrium level. However, $\ln(\kappa)$ had declined since October 2018 and became statistically insignificant between October 2018 and mid-2019. Subsequently, it gradually recovered to higher levels and the corresponding z-statistics were above the 1.96 level, indicating a stronger restoring force present in the later period of the sample. Nonetheless, amid a handful of very short time periods, insignificant $\ln(\kappa)$ occurred in three short time periods when the Tether's price dynamics were under external shocks. This is studied in the next section.

Panel B shows a steady estimated mean θ with the values ranging between 0.5 and 0.9 and the corresponding z-statistic usually staying above the 1.96 level. In particular, its value was very flat at the 0.7 level in the period after mid-2019, which shows that the equilibrium level in the Tether price dynamics was steady. For some short periods in October 2018, May 2022 and November 2022, θ fell to zero. The periods coincide with those when $\ln(\kappa)$ was

[7] In the second consultation document issued by the Basel Committee on Banking Supervision (BCBS) on prudential treatment of cryptoasset exposures (BCBS 2022a), a stablecoin will fail to be a Group 1b cryptocurrency if "the peg-to-market value difference of a cryptocurrency exceeds 20 basis points more than 10 times over the prior 12 months". However, in the final version of the document (BCBS, 2022b), this proposed basis risk test is not included given that the usefulness of the test on classifying cryptocurrencies is not conclusive.

insignificant as shown in Panel A. This suggests that the external shocks made the mean reversion in the price dynamics vanish and the equilibrium level moved towards the lower boundary of $S = 0.95$. The estimated volatility σ_x shown in Panel C ranges between 0.2 and 8. The corresponding z-statistic is much higher than the 5% significance level, indicating that the estimated σ_x is highly significant. The results suggest that the estimation of the square-root-process part of the Tether price dynamics is robust. σ_x declined substantially during the period from October 2017 – October 2018. While σ_x increased subsequently, its value decreased and stayed at low levels after 2019.

Given that the condition of $(\sigma_x^2/4\kappa\theta) < 1$ indicates no probability leakage at the lower boundary, this measure examines the associated implications for the credibility of Tether's stabilising mechanism. If the condition of $(\sigma_x^2/4\kappa\theta) > 1$, the pegged price of Tether to the US dollar may not be held, indicating that the price could breach the lower boundary. The measure shown in Figure 4 usually stays below 0.2 during the estimation period, indicating that the stabilising mechanism for Tether has been working for most of the time. However, a few spikes are observed in Tether's price dynamics, showing that the market questioned the credibility of its pegged price. On 15 October 2018 the Tether price briefly fell to \$0.88 due to the perceived credit risk as traders on Bitfinex exchanged Tether for Bitcoin, driving up the price of Bitcoin. This event triggered the measure to breach the level of 1 in two short periods of time. Such probability leakage conditions are consistent with the falls in the values of $\ln(\kappa)$ and θ illustrated in Figure 3.

Subsequently, the measure of the probability leakage condition gradually lowered to levels close to zero with two spikes in May 2022 and November 2022 respectively, when there were falls in $\ln(\kappa)$ and θ. The first surge in the measures was due to the collapse of the algorithmic stablecoin USD Terra whose price fell apart within a few days in May 2022. Terra's US dollar peg began to waver on 9 May 2022 and slid to US\$0.479 on 11 May 2022. The price rebounded a day later before it plunged below US$0.10 on 19 May 2022.[8] The second was the result of the collapse of FTX in early November 2022 following a report by CoinDesk highlighting potential leverage and solvency concerns involving the FTX-affiliated trading firm Alameda Research. The FTX collapse shook the volatile crypto market, which lost billions at the time, falling below a US$1 trillion valuation. Figure 3 showed that these two events had material impact on the Tether price dynamics, in particular diminishing its mean-reverting force (ln(κ) and θ in Panels A and B), but not its volatility (Panel C).

Regarding the COVID-19 outbreak in March 2020 and US banking turmoil in March 2023, these two episodes did not have significant impact on the leakage condition because of the upward movements of the Tether price as shown in Figure 2. The underlying shocks in these two episodes were originated from the public health crisis and the US banking sector respectively instead of the crypto market. In the latter case, the issuer of USDC, Circle, was reported to have deposits of around US$3.3 billion with Silicon Valley Bank (SVB), one of the failed US regional banks. DAI, another major dollar-pegged cryptocurrency that is partially backed by USDC, traded as low as 10% below the pegged price during that period. Before the stablecoin market began to rebound after Circle released a blog post saying that it would "cover any shortfall using corporate resources, USDC and DAI experienced substantial outflows and temporarily de-pegged.[9] Tether, which is viewed as more insulated from this incident, on the other hand experienced considerable inflows and temporarily surged above the pegged price. As our study is related to the peg-stabilising mechanism, we focus on the negative impacts from the collapses of Terra and FTX on Tether in section 4.2.

4. Tether price dynamics and arbitrage mechanism

[8] USD Terra had a market capitalisation as high as almost US$18.7 billion in April 2022. Liu et al. (2023) study the anatomy of the Terra crash.
[9] See https://www.cnbc.com/2023/03/12/signature-svb-silvergate-failures-effects-on-crypto-sector.html

In the previous section, the calibration results show that the target-zone model is able to describe the price dynamics of Tether. Given that the mean reversion in the price dynamics represents the effectiveness of the arbitrage (i.e., stabilising) mechanism for Tether's price, in this section we examine and identify which factors determine the mean-reverting force and draw some policy implications. The data source and descriptions for the variables used for the estimations are provided in Table 1.

4.1 Price volatility spillover from Bitcoin to Tether and assessment of Tether's arbitrage efficiency

Figure 5 plots the daily (24-hourly averaged) σ_x of the estimated Tether price dynamics and the 180-day price volatility of the Bitcoin/USD pair, showing a positive relationship between them, especially in the early period of the sample series. In this subsection, we investigate the dynamic relationship between Tether and Bitcoin. It is well documented in the literature that stablecoins, especially Tether, serve as the preferred financial instruments for cryptocurrency transactions compared with the fiat US dollar. Studies including Xie et al. (2020), Wang et al. (2020), Baur and Hoang (2020), Hoang and Baur (2020), Grobys et al. (2022), Barucci et al. (2022), and Diaz et al. (2023), find evidence that most stablecoins, particularly Tether, act as safe haven assets for cryptocurrency investments, albeit with varying degrees of such property. The dynamic relationship between Tether and Bitcoin demonstrates how the linkage between the safe-haven feature of Tether and the risk (volatility) of Bitcoin evolves over time. In particular, we focus on analysing the effect of the migration of Tether to the Ethereum blockchain in April 2019 on the linkage and the implication for the arbitrage mechanism of Tether.

We hypothesise that the volatility of Bitcoin (BTCvol) exhibits a positive cointegration relationship with the mean-reversion parameters [$\ln(\kappa)$, θ_x] in the Tether price dynamics because of the safe-haven characteristic of Tether. This suggests that when BTCvol increases with the downside risk of Bitcoin or risk in the crypto market in general, there will be an inflow to Tether and the corresponding arbitrage will enhance the mean-reverting force to stabilise Tether at the pegged price. A positive relationship between BTCvol and σ_x as shown in Figure 5 is expected due to the volatility spillover among cryptocurrencies in the crypto market. The safe-haven characteristic of Tether suggests that ln(κ) and θ_x increase with BTCvol. As such, we propose Eq.(18) to test if there is any cointegration relationship between the three model parameters governing the Tether price dynamics and price volatility of Bitcoin. This sets as the baseline estimation for the study of the effect of the migration of Tether from the Omni to the Ethereum blockchain using a regime-switching analysis.

If a long-run equilibrium relationship exists between the model parameters and price volatility of Bitcoin, their short-run dynamics can be studied through the following dynamical error-correction representation:

$$\Delta y_t = a_0 + \alpha_1(y_{t-1} - \beta_1 X_{t-1}) + \sum_k b_{1k}\Delta y_{t-k} + \sum_k c_{1k}\Delta X_{t-k} + d_t Z_{t-1} + \varepsilon_{yt} \,, \tag{18}$$

where y_t is [ln(κ), θ_x, σ_x] at time t, and α_1 is less than zero. X_{t-1} is daily 180-day price volatility of Bitcoin (denoted as BTCvol) at time t-1. Under this representation, the model parameters (as represented by y_t) will respond to stochastic shocks (represented by ε_{yt}) and the long-run equilibrium deviation in previous period (i.e., $y_{t-1} - \beta_1 X_{t-1}$,). The estimated speed of adjustment (i.e., α_1) should be negative and nonzero for the cointegration relationship to be validly specified by the error-correction. In terms of absolute magnitude, a larger estimated value of α_1 reflects a higher sensitivity of y_t to the long-run equilibrium deviation in the previous period. For the control variables Z_{t-1}, we include the lagged terms of retail investors share and logarithm of circulating supply of Tether in the equation to control for any potential effect of changes in investor concentration and Tether supply on the parameters.

We apply 24-hour moving average transformation on the model parameters from the hourly calibration results in Section 3 to construct the daily time series. The summary statistics of the six variables in the cointegration regressions are provided in the upper panel of Table 2 and the standard Augmented Dicky-Fuller (ADF) tests support that BTCvol, $\ln(\kappa)$, θ_x and σ_x are all I(1) time series. To test the validity of cointegration analysis, we apply the Engle-Granger single equation cointegration test and report the ADF and Phillips-Perron tests statistics results in Table 3. The Engle-Granger cointegration tests favour the hypothesis that there are cointegration relationships between BTCvol and the three model parameters respectively.

Table 4 reports the result for the estimated cointegrating vectors between BTCvol and the model parameters $\ln(\kappa)$, θ_x and σ_x. In Table 4, the positive coefficients β_1 for $\ln(\kappa)$ and θ_x are 100.1 and 3.73 respectively at the 1% significance level, suggesting that $\ln(\kappa)$ and θ_x increases with BTCvol. The speeds of adjustment α_1 are negative but greater than -1, reflecting that there is a restoring force to subsequently adjust $\ln(\kappa)$ and θ_x towards their long-run equilibria. The results show that $\ln(\kappa)$ and θ_x are positively correlated with BTCvol, supporting the hypothesis of a positive cointegration relationship between the mean-reversion in the Tether price dynamics and the Bitcoin price volatility given the safe-haven characteristic of Tether. The intuition is that when BTCvol increases with a negative shock in the crypto market, some investors move their investments from Bitcoin to stablecoins, such as Tether. Given that Bitcoin investors holding Tether enjoy higher convenient premiums than the US dollar, Tether provides higher usability among various cryptocurrency exchanges and involves lower intermediation fees as argued by Lyons and Viswanath-Natraj (2023). Therefore, under a negative stock in the crypto market, those Bitcoin investors prefer to hold Tether rather than the US dollars that reinforces the stabilising mechanism with increased mean-reverting force in the Tether price dynamics.

The cointegration analysis shows that BTCvol is positively cointegrated with σ_x, as indicated by the highly significant β_1 of 43.71 reported in the last column of Table 4. The speed of adjustment α_1 is also negative but greater than -1, reflecting there is a restoring force to subsequently adjust σ_x towards its long-run equilibrium. The results reflect the highly interconnected crypto market and the volatility spillover among cryptocurrencies. The analysis illustrates that when σ_x^2 increases with BTCvol, ln(κ) and θ_x will increase as well to hold the no leakage condition consistent with the stabilising mechanism. For the control variables, the volume of circulating supply has no effect on all three model parameters, while the RETshare increases with ln(κ), and lower σ_x. The stabilising effect of RETshare is consistent with Lyons and Viswanath-Natraj (2023)'s finding that increasing investor access lowers the Tether price volatility.

After establishing the baseline results, we study the effect of the migration of Tether from the Omni to the Ethereum blockchain on its price dynamics. Based on a sample of USDT/USD spot trading prices and activities during April 2017 – March 2020, Lyons and Viswanath-Natraj (2023) find that improved investor access to Tether enhanced its arbitrage mechanism and hence its peg efficiency. In view of this finding suggesting that the enhanced arbitrage mechanism reduces the impact of negative shocks in the crypto market on Tether, we hypothesise that Tether's blockchain migration with a larger investor base weakens the spillover effect from Bitcoin price volatility to the model parameters of the Tether price dynamics. As such, we propose a regime-switching cointegration model to test the hypothesis. Specifically, we modify Eq.(18) to include the change in the regime element as determined by the time of the migration event as follows:

$$\Delta y_t = a_0 + \alpha_1(y_{t-1} - \beta_1 X_{t-1})_{region1,\ t\leq Apr2019} + \alpha_2(y_{t-1} - \beta_2 X_{t-1})_{region2,\ t>Apr2019} + \sum_k b_{1k}\Delta y_{t-k} + \sum_k c_{1k}\Delta X_{t-k} + d_t Z_{t-1} + \varepsilon_{yt}\ , \tag{19}$$

where α_1 and α_2 are the speed of adjustment before and after the migration, β_1 and β_2 are the respective cointegrating vectors, and other specification details are the same as in Eq.(18). We set the change in regime date (i.e., the date of Tether's blockchain migration) to be the end of April 2019, and compare the cointegrating dynamics before and after the event.

Table 5 reports the results of the regime-switching model of Eq.(19). In columns (1) to (3) of Table 5 (i.e., the regime-1 period before the migration in April 2019), the speeds of adjustment α_1 are negative and statistically significant at the 1% or 5% levels for the two parameters $\ln(\kappa)$ and σ_x. However, α_1 for θ_x is not significant. Similarly, the coefficients β_1 for $\ln(\kappa)$ and σ_x are 101.07, and 63.99 at the 1% significance level. For the regime-2 period, while we still find the cointegrating vectors β_2 to be statistically significant after the blockchain migration, β_2 are smaller than β_1 for both $\ln(\kappa)$ and σ_x with estimated values of 91.06, and 41.66 respectively. In particular for the σ_x regression, the null hypothesis H_0 that $\beta_1 = \beta_2$ can be rejected at the 1 % level significance. Similarly, β_2 is smaller than β_1 for θ_x, which are both statistically significant. The results of the regime-switching model support the hypothesis that Tether's blockchain migration with a larger investor base enhances the arbitrage mechanism and thus weakens the spillover effect from the Bitcoin price volatility to the model parameters of the Tether price dynamics.

In summary, because of the safe-haven characteristic of Tether, we find a positive cointegration relationship between the mean-reversion in the Tether price dynamics and the Bitcoin price volatility. This suggests that under a negative stock in the crypto market, Bitcoin investors prefer to hold Tether than the US dollar that reinforces the stabilising mechanism with increased mean-reverting force in the Tether price dynamics. In the regime-switching cointegration analysis, given that Tether's blockchain migration provides a larger investor base that enhances arbitrage mechanism, the results demonstrate that the spillover effect from the Bitcoin price volatility to the Tether price dynamics was dampened after the migration. This indicates that enhanced investors' access to Tether increases its peg efficiency by reducing the impact from negative shocks in the crypto market on the Tether price dynamics. The results also support that the price dynamics captured by the target-zone model is consistent with the arbitrage mechanism and the peg stability as described by the model.

4.2 Negative shocks on stabilising the mechanism of Tether

While the migration of Tether to the Ethereum blockchain has improved the peg efficiency as discussed in subsection 4.1, there were negative shocks including the collapse of USD Terra and FTX in 2022 on the Tether price, which increased its peg deviations as shown in Figure 2, and raised concern over the credibility of the peg. As negative shocks in general reduce the market liquidity of assets, the two shocks in the crypto market increased the market liquidity risk of Tether. In particular, Tether pegged with the US dollar is considered a key conduit for trading other cryptocurrencies (i.e., the preferred medium of exchange compared with the fiat US dollar), its tightened market liquidity under the shocks could induce its peg deviations. This subsection studies how market liquidity condition affects Tether's peg-stabilising mechanism.

Given that market liquidity risk is the most prominent factor in explaining changes in bid-ask spreads in the literature and greater uncertainty regarding the spot rate is likely to result in a widening of the spread (see Becker and Sy, 2006), we use the bid-ask spread of the Bitcoin-Tether (BTC/USDT) trading pair to measure the liquidity condition of Tether. The corresponding estimator follows the one proposed by Abdi and Ranaldo (2017) based on the closing, high and low prices from hourly Open-High-Low-Close (OHLC) data. This estimator aims to proxy the bid-ask spread of a trading pair by exploiting a wider information set (such as close, high and low prices) when comprehensive quote data are not readily available.

Brauneis et al. (2021) find that this estimator is one of the two useful transaction-based measures to describe the liquidity conditions of Bitcoin and Ethereum between 2017 and 2019.

The credibility of a stablecoin depends on the usefulness of its backing reserves. A stablecoin's reserves can be seen as analogous to the accumulation of foreign exchange reserves by a central bank. For a central bank which adopts a currency board to peg its currency, an adequate amount of high-quality liquid assets in the bank's reserves enable the bank to deploy resources to support its exchange rates, such as interventions in the foreign exchange market to stabilise the exchange rate or its corresponding volatility (see Chang and Velasco, 1998; Borio et al., 2008). In the foreign exchange market, given a central bank needs to liquidate its foreign assets to support its pegged currency under speculative or negative shocks, the liquidity condition of the currency reflects the corresponding liquidity of the assets in the central bank's foreign reserves. In the case of Tether, if it trades at a discount, investors would then redeem their dollar deposits such that the Tether treasury withdraws Tether from circulation. The redemption requires the Tether treasury to sell the backing assets in the reserves to obtain US dollars. Therefore, investors' confidence in the peg-stabilising mechanism depends on the liquidity and adequacy of Tether's reserves, which impact the market liquidity of trading Tether. Adachi et al. (2022) and Yip (2022) suggest that the loss of confidence in Tether's pegged price during the collapse of Terra and FTX in 2022 was associated with the opacity of its reserve's composition.

The Terra collapse indicated that the standalone algorithmic stabilising mechanism without holding sufficient liquid reserves was not able to uphold the Terra price during the period of large outflows. Terra's reserve composition was opaque and criticised by market participants for the lack of transparency. Therefore, it encountered outflow pressure as investors worried about the opaqueness of its reserves and thus the credibility of its peg. FTX was reported to have mishandled their clients' funds and operated without proper internal controls and risk management. As evidenced from the subsequent developments, the two episodes drove substantial volatility across the crypto market.

We therefore hypothesise that the weakening in the mean-reverting force measured by κ in the Tether price dynamics during the collapse of Terra and FTX reflects an erosion of the credibility of Tether's peg-stabilising mechanism triggered by these two events in the crypto market. This erosion increased the valuation risk premium embedded in holding Tether, which then prompted a significant withdrawal of arbitrage in the market. Using the bid-ask estimator of BTC/USDT as a measure for the liquidity of Tether (i.e., a higher estimator means lower liquidity), we expect a relationship between this estimator and κ to be negative. Azar et al. (2022) indicate that the stablecoin USDC collateralised by higher quality assets compared with Tether saw a little more than US$4 billion of new inflows after the Terra collapse, while Tether saw redemptions of around $10 billion. This substitution from Tether into USD Coin illustrates that the quality and liquidity of backing assets is problematic for the peg-stabilising mechanism. Figure 6 shows the bid-ask estimators for the BTC-Tether and BTC-Coin pairs respectively during the collapse of Terra and FTX. Both estimators surge, while the estimator for the BTC-Tether pair is higher than that for the BTC-Coin pair. This observation indicates that the liquidity condition in the stablecoin market measured by the bid-ask estimators has an impact on Tether's peg-stabilising mechanism. To assess such impacts from the USD Coin, we also apply the bid-ask estimator for BTC-USDC to estimate its effect on κ.

Specifically, we estimate the following equation (20) on daily frequency *t*:

$$\Delta AR\_spr_{i,t} = c_0 + c_1 \Delta\ln(\widehat{\kappa_t}) + \varepsilon_{ct} \ , \quad \text{or} \quad \Delta AR\_spr_{i,t} = c_0 + c_1 \Delta\ln(\widehat{\kappa_{t-1}}) + \varepsilon_{ct} \qquad (20)$$

where *i* is BTC-USDT or BTC-USDC on the Binance, Coinbase, Kraken and Kucoin exchanges. $AR\_spr_{i,t}$ is the daily bid-ask estimator constructed following Brauneis et al. (2021) for each of the crypto pairs *i*. We use 1-hour frequency data to estimate liquidity measures at the daily frequency and the choice of the 'two-day corrected' estimator by employing high/low prices from two adjacent hourly subintervals to calculate the spread measure. Hourly subinterval data are weighted by the transaction volume average to obtain the daily measures. $\widehat{\kappa_t}$ is the minimum value of κ_t obtained from calibrating the target-zone model in the same calendar day prior to the snapshot time (i.e., T12:00:00) and scaled by division of 10000. We examine the tightening in liquidity condition of the crypto pairs based on a 60-day event window during the collapse of Terra on 12 May 2022 and FTX on 10 November 2022.

According to the hypothesis of the negative relationship between the liquidity of Tether measured by AR_spr and the mean-reverting force in the Tether price dynamics measured by κ, c_1 is expected to be negative. We also expect c_1 to be more negative for the BTC-Tether pair than the BTC-Coin pair. The results in Table 6 show that the coefficients of c_1 are negative and statistically significant for the BTC-Tether pair (in Columns (1), (3), (5) and (7)). The results are consistent with the hypothesis that the reduction in the liquidity of Tether has a negative impact on its peg-stabilising mechanism. The estimations for the BTC-Coin pair (in Columns (2), (4), (6) and (8)) are negative and significant, while the degrees of its impact on κ_t are smaller than those of the BTC-Tether pair. The results suggest that not only the liquidity condition of Tether itself, but also the liquidity condition of USD Coin collateralised by higher quality assets, has negative impacts to a lesser extent on Tether's peg-stabilising mechanism during the collapse of Terra and FTX. The connection between the two stablecoin is probably through the substitution from Tether into USD Coin during the two events.

5. Discussion and conclusion

As an analogy for a currency-board system, essential for a stablecoin to be stable, requires a peg-stabilising mechanism to keep the stablecoin price to be traded around the fixed price within a narrow band through efficient arbitrage. By using the quasi-bounded target-zone model to study the peg-stabilising mechanism for stablecoin prices and associated dynamics, the model suggests that the price is more stable in a narrower trading bandwidth and less sensitive to changes in the fundamental (demand for the stablecoin) with a stronger stabilising force in the fundamental dynamics, less ample stablecoin supply, and more anchored expectation of the price. The cointegration analysis using Tether demonstrates that the dynamics captured by the model is consistent with the arbitrage mechanism and the peg stability of the stablecoin. The regime-switch model shows that Tether's blockchain migration provided with a larger investor base enhanced arbitrage mechanism, while the spillover effect from the Bitcoin price volatility to the Tether price dynamics was dampened after the migration. Given that the market liquidity condition of Tether measured by its bid-ask spreads reflects the corresponding liquidity of the assets in Tether's reserves, the empirical results show erosion of the credibility of Tether's peg-stabilising mechanism was triggered by the collapse of USD Terra and FTX. The erosion of the credibility prompted a significant withdrawal of arbitrages in the market.

The results in this paper have the following implications for the prudential treatment of stablecoins. In view of the stablecoin price being more stable in a narrower trading bandwidth, regarding the fragility of the stablecoin issuer, a stability measure can be constructed based on the narrowness of the bands around the pegged price and the frequency of beaching of the band. To maintain adequate market liquidity under negative shocks, the issuer should be required to have adequate and high-quality liquid assets in its reserves to ensure that its stablecoin is stable and credible, such that it is able to be redeemed even under adverse market conditions in the crypto market. In addition, an adequate investor base is an important factor to ensure the peg-stabilising and arbitrage mechanisms are effective in maintaining the stablecoin price within the band.

Figure 1: Relationship between Tether-USD spot price (S) and fundamental (v) based on Eq. (5) with εB_0 = 0.4 and 1.2 respectively.

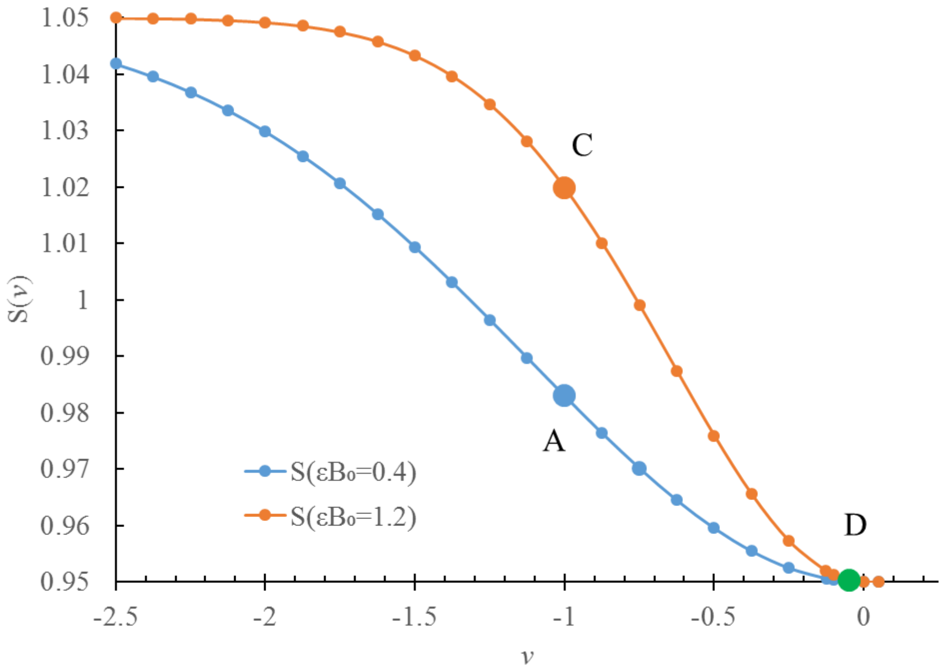


Figure 2: Hourly closing price of Tether-USD and corresponding 3-hour moving average transformed series $x(t)$.

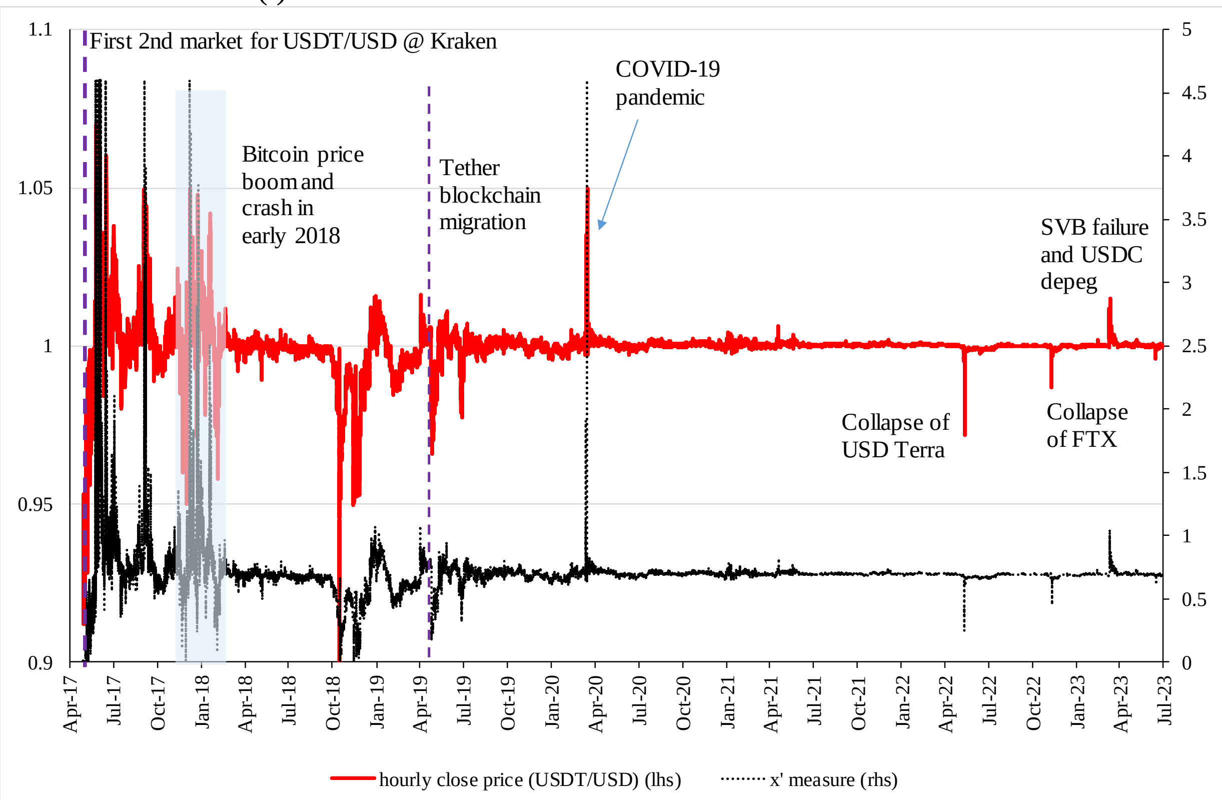
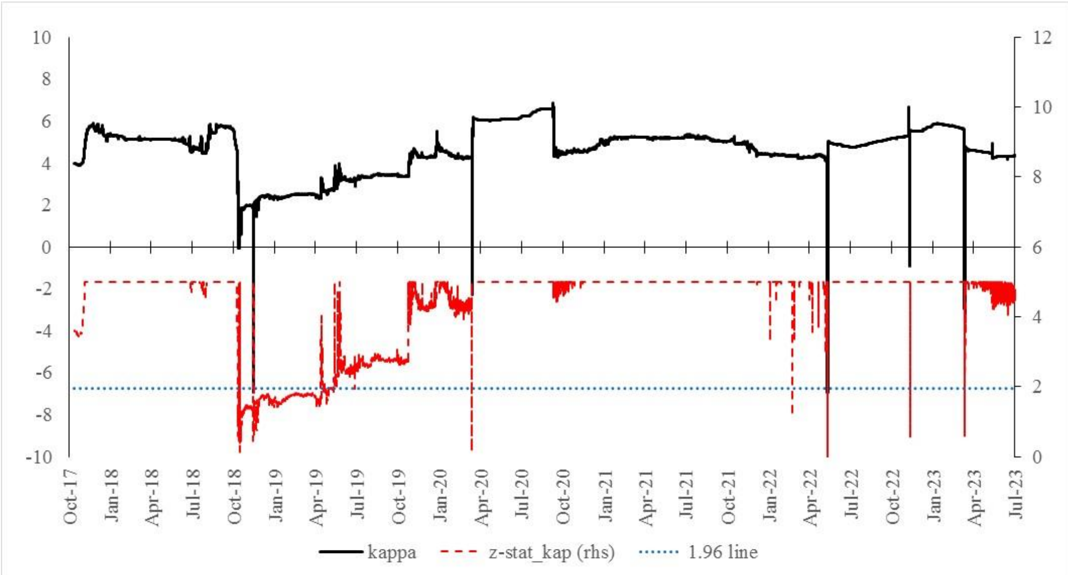
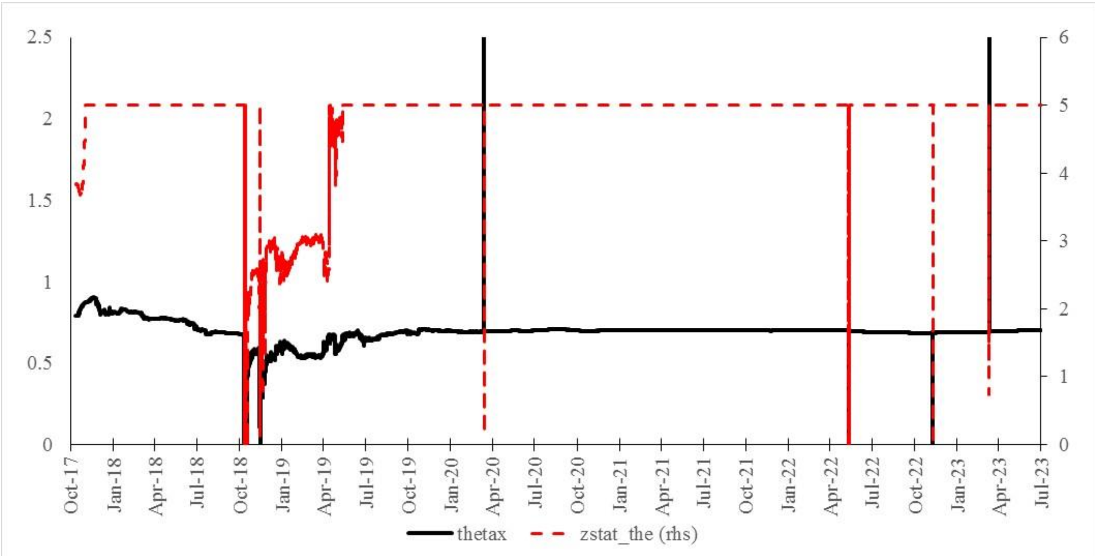


Figure 3: Estimated ln(κ) (Panel A), θ (Panel B) and σ_x (Panel C) and their corresponding z-statistics in hourly frequency

Panel A



Panel B



Panel C

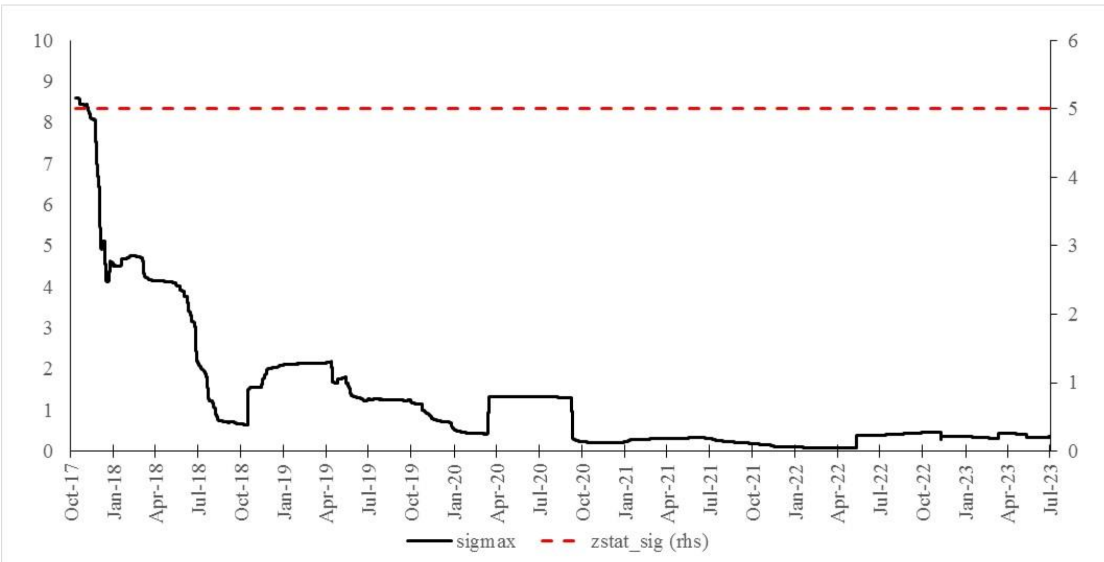


Figure 4: Probability leakage condition ($\sigma_x^2/4\kappa\theta$)

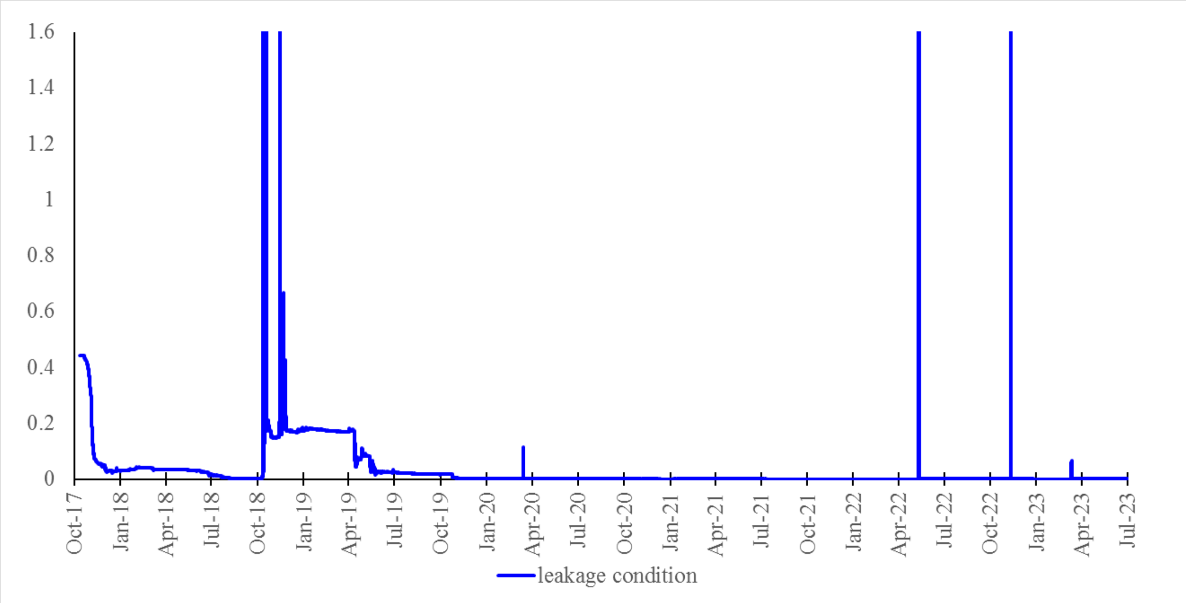


Figure 5: Daily frequency σ_x (averaging on hourly data in Panel C of Figure 3) and 180-day Bitcoin price volatility

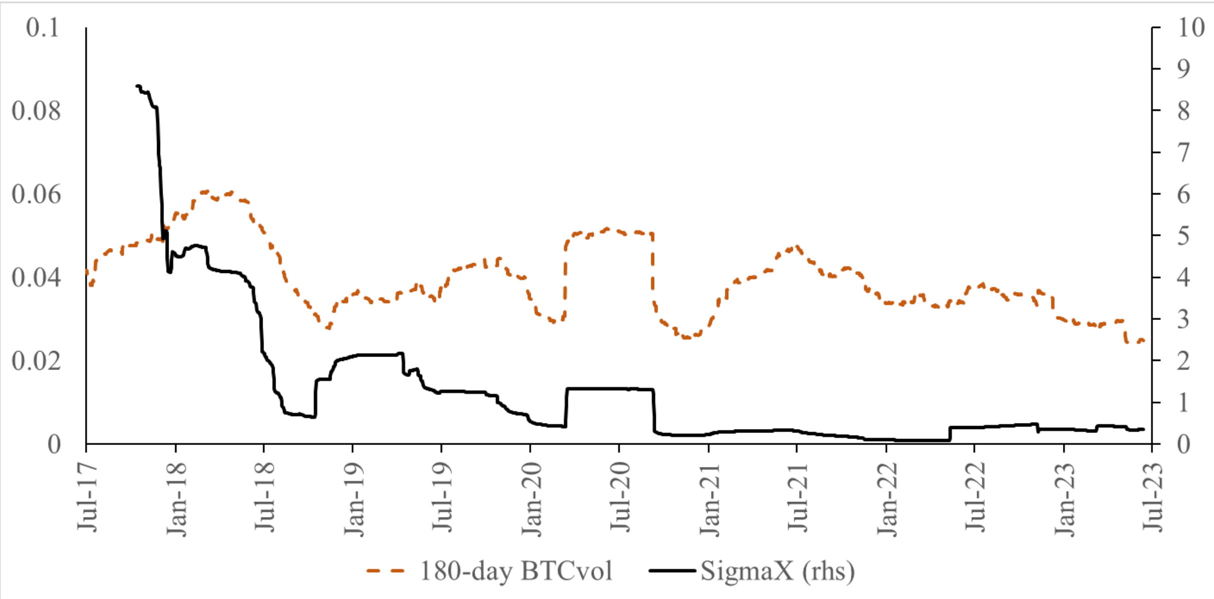
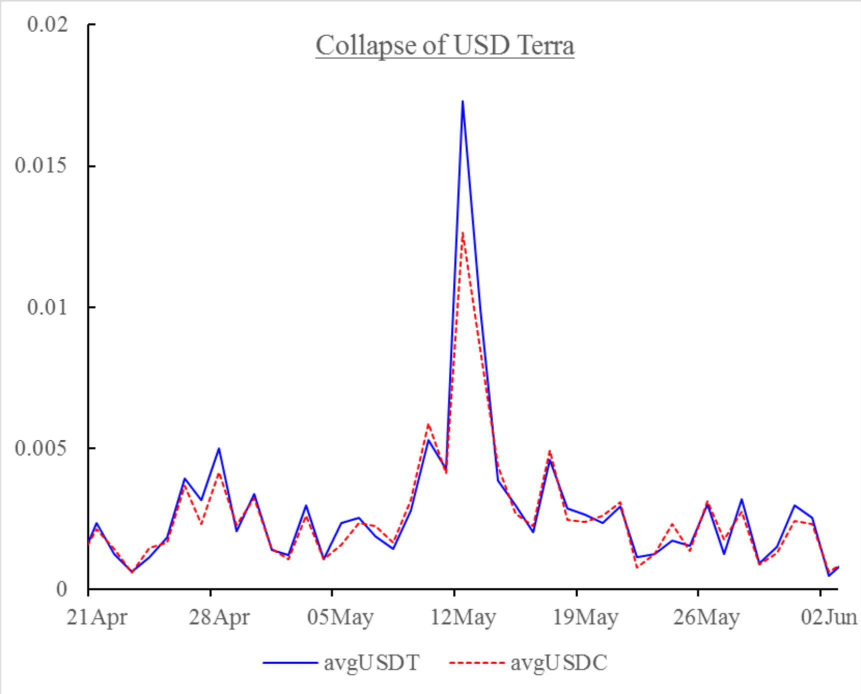
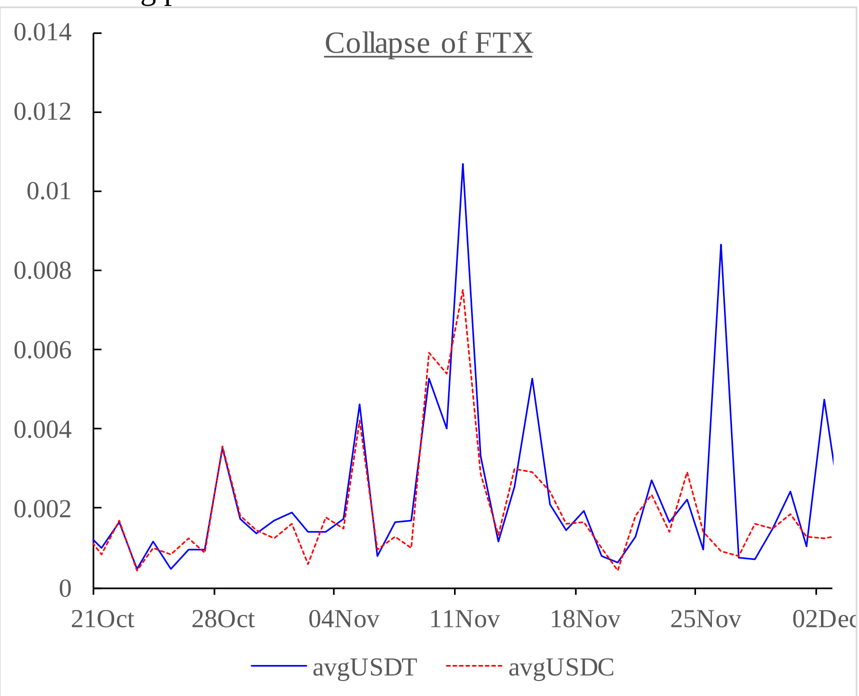


Figure 6: Liquidity estimators for BTC-Tether and BTC-Coin pairs during Terra collapse (Panel A) and FTX collapse (Panel B)

Panel A: Average of AR_spr indicators based on data from Binance and Coinbase exchanges for each trading pair



Panel B: Average of AR_spr indicators based on data from Kraken and Kucoin exchanges for each trading pair



Note: AR_spr indicator computed based on OHLC data as described in Section 4.2.

Table 1: Descriptions of data series and their sources

Variable (frequency)	Short description	Source
Closing price of USD Tether - USD pair (Hourly)	Closing price of spot USD Tether- fiat US dollar pair from the exchange Kraken from 2017 to May 2023	CoinAPI.com
Price volatility of Bitcoin (daily)	Price volatility of Bitcoin in the 180-day interval	Coinmetric.com
Circulating supply (daily)	The distribution of a crypto-asset's circulating supply.	IntoTheBlock.com
Share of retail address holding (daily)	The distribution of a crypto-asset's circulating supply belonging to retail addresses (that is, addresses holding Tether with less than 0.1% of circulating supply).	IntoTheBlock.com
OHLCV data of Bitcoin-USDT pair (hourly)	Open, High, Low, Close price and Volume of spot Bitcoin-USD Tether pair from 4 major exchanges (Binance, Coinbase, Kucoin, Kraken) between 2020 to Mar2023	CoinAPI.com
OHLCV data of Bitcoin-USDC pair (hourly)	Open, High, Low, Close price and Volume of spot Bitcoin-USD Coin from four major exchanges (Binance, Coinbase, Kucoin, Kraken) between 2020 to Mar2023	CoinAPI.com

Table 2: Summary statistics

Variable	Obs.	Mean	Std. Dev.	Min	Max	ADF test statistics
Model estimates in daily frequency						
ln(κ)	1,999	4.642	1.077	0.426	6.598	-2.858
Δ ln(κ)	1,998	-0.001	0.118	-2.055	2.936	-13.377***
θ	1,999	0.692	0.094	0.006	2.730	-0.806
$\Delta\theta$	1,998	0.000	0.039	-0.785	0.787	-18.471***
σ_x	1,999	1.129	1.293	0.079	6.953	-3.166
$\Delta\sigma_x$	1,998	-0.004	0.035	-0.388	0.211	-15.628***
BTCvol	1,999	0.039	0.009	0.024	0.061	-1.901
ΔBTCvol	1,998	0.000	0.001	-0.014	0.016	-11.213***
control variables						
Retshare	1,999	0.385	0.249	0.000	0.749	/
Ln(cirsupp)	1,999	23.30	1.53	20.33	25.15	/

Notes:
1. *** indicates significance at the 1% level.
2. The ADF tests check the null hypothesis of unit root existence in the time series with the number of lags up to 10, assuming the possible existence of a trend in the test equation.

Table 3: Engle-Granger single equation tests for cointegration of ln(κ), θ and σ_x with BTCvol

	Engle-Granger single-equation test[2] (Null hypothesis: residual has a unit root)	
	ADF test statistic	Phillips-Perron test statistic
Equation: *ln(κ)* on BTCvol	-2.492**	-13.937***
Equation: θ on BTCvol	-7.163***	-691.67***
Equation: σ_x on BTCvol	-3.984***	-19.316***

Notes:
1. *** and ** indicate significance at the 1% and 5% levels respectively.
2. The Engle-Granger single-equation tests (ADF and Phillips-Perron tests) examine the null hypothesis that the residuals of the respective regressions are non-stationary. The tests assume the existence of zero mean of the residuals in the test equation and numbers of lags up to 10.

Table 4: Estimation results of error cointegration model for BTCvol on $\ln(\kappa)$, θ and σ_x

Dependent variables:	**$\Delta\ln(\kappa_t)$**		**$\Delta\theta_t$**		**$\Delta\,\sigma_{xt}$**	
Constant	0.0138		0.0419		0.00123	
	(0.0820)		(0.0546)		(0.0116)	
Speed of adjustment (α_1)	-0.0194	**	-0.103		-0.00618	**
$\ln\kappa_{t-1}/\theta_{t-1}/\sigma_{xt-1}$	(0.00781)		(0.108)		(0.00242)	
$BTCvol_{t-1}(\alpha_1\beta_1)$	-1.955	***	-0.384		-0.270	*
	(0.722)		(0.540)		(0.144)	
Cointegrating vector (β_1)	100.7	***	3.730	**	43.71	***
	(13.83)		(1.528)		(9.836)	
$\Delta\ln\kappa_{t-1}/\Delta\theta_{t-1}/\Delta\sigma_{xt-1}$	-0.0191		-0.0709		0.670	***
	(0.219)		(0.203)		(0.0811)	
$\Delta BTCvol_t$	0.197		-0.191		0.453	
	(2.456)		(0.874)		(0.932)	
$\Delta BTCvol_{t-1}$	8.925		15.98		8.910	***
	(8.775)		(13.36)		(1.031)	
ln(circulating supply)$_{t-1}$	-0.00132		0.000468		-0.0002	
	(0.00384)		(0.000976)		(0.0005)	
Retshare$_{t-1}$	0.0767	***	0.00945		-0.0144	**
	(0.0231)		(0.0131)		(0.00724)	
No. of observations	1,997		1,997		1,997	
Adj. R-squared	0.0142		0.125		0.525	

Notes: ***, ** and * indicate significance at a level of 1%, 5% and 10% respectively. Robust (Newey-West) standard error is applied and reported in parentheses.

Table 5: Estimation results of regime-switching error correction model for BTCvol on ln(κ), θ_{xt} and σ_x

	(1)		(2)		(3)	
Dependent variables:	**$\Delta \ln(\kappa_t)$**		**$\Delta\ \theta_{xt}$**		**$\Delta\ \sigma_{xt}$**	
	NW standard errors		NW standard errors		NW standard errors	
	Before migration	After migration	Before migration	After migration	Before migration	After migration
$\ln(\kappa)_{t-1}$ / θ_{t-1} / σ_{xt-1}	-0.0122*	-0.0282*	-0.122	-0.106	-0.00878**	-0.00555**
(speed of adjustment α_1/α_2)	(0.00663)	(0.0162)	(0.0910)	(0.115)	(0.00400)	(0.00267)
$BTCvol_{t-1}(\alpha_1\beta_1, \alpha_2\beta_2)$	-1.237*	-2.570**	-0.671	-0.273	-0.562*	-0.231***
	(0.633)	(1.286)	(0.543)	(0.615)	(0.328)	(0.0888)
$\Delta\ln\kappa_{t-1}$ / $\Delta\ \theta_{xt-1}$ / $\Delta\sigma_{xt-1}$,	-0.0163		-0.0664		0.668***	
	(0.215)		(0.200)		(0.0807)	
$\Delta BTCvol_t$	0.329		-0.181		0.661	
	(2.470)		(0.892)		(0.969)	
$\Delta BTCvol_{t-1}$	8.550		16.07		9.114***	
	(8.733)		(13.34)		(1.044)	
$Retshare_{t-1}$,	0.114**		0.0210		-0.00195	
	(0.0554)		(0.0252)		(0.00462)	
ln(circulating supply) $_{t-1}$	-0.00173		-2.47e-05		-0.000405	
	(0.00344)		(0.000948)		(0.000742)	
Constant	0.0244		0.0538		0.00473	
	(0.0722)		(0.0553)		(0.0188)	
Observations	1997		1997		1997	
Long-run coefficients β_1/β_2 (based on non-linear combination test)	101.1***	91.06***	5.488*	2.573	63.99***	41.66***
	(21.98)	(11.63)	(2.863)	(3.243)	(10.619)	(18.26)
H_0: β_1 - β_2 = 0	10.012		2.915		22.33**	
	(15.917)		(5.869)		(10.19)	

Notes: ***, ** and * indicated significance at the level of 1%, 5% and 10% respectively. Robust (Newey-West) standards are reported in parentheses.

Table 6: Regression result for Eq. (20) based on BTC-USDT and BTC-USDC pairs from selected exchanges

Column	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Exchange	Binance Exchange		Coinbase Exchange		Kucoin Exchange		Kraken Exchange	
Crypto pair i	BTC-USDT	BTC-USDC*	BTC-USDT	BTC-USDC*	BTC-USDT	BTC-USDC	BTC-USDT	BTC-USDC
Y: AR_spr								
	Event 1: Collapse of USD Terra on 12 May 2022							
c_0	0.501	0.457	0.443	0.567	0.498	0.134	0.322	0.245
	(2.184)	(1.837)	(2.450)	(2.323)	(2.013)	(2.040)	(2.934)	(4.384)
c_1 $(\Delta\ln(\widehat{\kappa_t}))$	-8.831***	-5.751***	-8.868***	-5.200**	-7.670***	-5.758***	-6.537***	-3.599
	(2.028)	(1.067)	(2.203)	(2.059)	(1.713)	(1.555)	(2.014)	(5.540)
No. obs.	59	59	59	59	59	59	59	59
	Event 2: Collapse of FTX exchange on 10 Nov 2022							
c_0	-0.151	N/A	-0.178	N/A	-0.0869	0.00845	-0.143	-0.0262
	(1.440)		(1.701)		(1.562)	(1.484)	(4.857)	(2.090)
c_1 $(\Delta\ln(\widehat{\kappa_{t-1}}))$	-6.025***		-5.881***		-6.142***	-3.986**	-16.10***	-6.679***
	(0.446)		(0.111)		(0.415)	(1.626)	(0.0852)	(1.122)
No. obs.	58		58		58	58	58	58

Notes: ***, ** and * indicate significance at a level of 1%, 5% and 10% respectively. Robust (Newey-West) standard error is applied and reported in parentheses. N/A for results from Coinbase and Binance Exchanges during the FTX collapse episode as BTC-USDC trading pair are no longer offered for trading since 13July2022 on Coinbase and since September on Binance exchange

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