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ETF Settlement Clocks in Cryptocurrency Markets

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Abstract

Daniel Pastorek and Peter Albrecht: **ETF Settlement Clocks in Cryptocurrency Markets**

We study how post-trade settlement frictions introduced by spot ETFs reshape cryptocurrency market dynamics. Unlike crypto markets with near-instant delivery, crypto ETF trading is governed by an equity-style clearing and settlement clock, effectively importing a second timing regime into cryptocurrency markets. Using daily ETF failures-to-deliver (FTDs) data, securities-lending conditions, and close-aligned spot prices from ETF inception until 2025, we show that FTDs act as an intertemporal liquidity buffer. Local projections indicate that unexpected increases in FTD intensity do not raise contemporaneous spot volatility on the trade date. Instead, volatility materializes around the regulatory settlement date and spills over into the next session to some extent. In a competing-shocks framework, this response centered around the settlement date remains distinct from standard volatility shocks, which load immediately and mean-revert. Panel regressions further show that FTDs arise systematically when lending constraints bind. Finally, higher FTDs coincide with larger ETF spot tracking errors, consistent with temporary impairments in arbitrage. Overall, spot crypto ETFs import traditional settlement frictions into markets, where these frictions did not occur previously. It reallocates volatility over time and intermittently weakens price parity.

Key words

Bitcoin, Ethereum, ETFs, Volatility, Market dynamics, FTDs, Settlement frictions

JEL: G11, G12, G14, G23, C58

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None

Introduction

The approval and launch of spot Bitcoin exchange-traded funds (ETFs) in early 2024 represent a structural innovation in global financial markets and a new challenge for market microstructure. By embedding cryptocurrencies into the traditional ETF ecosystem, these instruments connect historically decentralized, near-instantaneously settled crypto markets with conventional equity-like trading, clearing, and settlement infrastructure (Katsiampa, 2017; Corbet et al., 2018). A growing body of research has already examined whether the introduction of Bitcoin ETFs affects volatility, price discovery, and market quality, drawing parallels with earlier evidence from equity and commodity ETFs (Babalos et al., 2025; Kia et al., 2025; Mohamad, 2025). Existing studies suggest that ETFs can materially reshape asset behavior by altering liquidity provision, arbitrage mechanisms, and the temporal structure of price adjustment (Aber et al., 2009; Glosten et al., 2021).

However, one important channel through which ETFs operate has received far less attention in the context of cryptocurrencies: the emergence of failures-to-deliver (FTDs). Before the introduction of spot crypto ETFs, such settlement frictions were absent from cryptocurrency markets. Trading in Bitcoin and Ethereum took place either on centralized exchanges with rapid internal settlement or on decentralized peer-to-peer networks where delivery failures of this type could not occur (Auer and Claessens, 2018; Ciaian et al., 2018; Yildirim & Bekun, 2023). The integration of crypto assets into the traditional ETF clearing framework, therefore, introduces an entirely novel market friction. It originates not from the crypto protocol itself, but from the institutional design of financial markets.

FTDs occur when securities cannot be delivered at the legally prescribed settlement date despite a valid trade execution (SEC, 2015). As explained in the literature, such failures are commonly operational rather than indicative of default, often reflecting timing mismatches in clearing, netting, securities lending, or the sequencing of ETF creation and redemption (Depository Trust & Clearing Corporation, 2024). In the context of spot cryptocurrency ETFs, these frictions are further amplified by the coexistence of two settlement clocks: one governing equity-market settlement and another governing crypto custody and asset transfers. While the underlying mechanisms are well documented in equity and commodity markets, their presence in crypto instruments is new and economically significant.

It is crucial because FTDs are not merely a back-office phenomenon. Literature shows that they have systematic and economically meaningful effects on prices and volatility (Madhavan, 2017; Ben-David et al., 2018; Engelberg et al., 2018). On the one hand, FTDs can act as a short-term liquidity buffer (Fotak et al., 2014; Evans et al., 2024). When trading activity surges, intermediaries such as market makers or authorized participants may supply ETF shares without immediately delivering the underlying asset. By doing so, they absorb excess demand or supply at moments of peak pressure, smoothing immediate price adjustments and preventing extreme intraday dislocations. Empirical evidence from equity (Israeli et al., 2017) and commodity (Todorov, 2024) ETFs indicates that elevated FTD activity is associated with lower contemporaneous volatility and improved short-term liquidity conditions. Motivated by this mechanism, we formulate the first hypothesis:

H1: Conditional on their occurrence, failures-to-deliver are associated with lower contemporaneous volatility on the trade date, consistent with a short-term liquidity buffering role.

At the same time, the literature emphasizes that this buffering effect is inherently intertemporal. Failed deliveries must eventually be resolved, typically through subsequent purchases of the underlying asset, securities recalls, or delayed ETF creations (Laborda et al., 2024). As a result, the price pressure that was deferred at trade date reappears in the following days. Studies document (see Asmar & Trimbath, 2022; Schultz, 2024) that high FTD activity is associated with volatility persistence, delayed price adjustment, and clustering of returns around settlement and close-out periods. Rather than eliminating volatility, FTDs redistribute it over time; they lower its peak while extending its duration. This motivates the second hypothesis:

H2: Delayed trade settlement caused by failures to deliver extends volatility into subsequent trading days.

While these dynamics are well documented for equities and commodity ETFs, a critical research gap remains. To date, no study has empirically examined whether ETF-related FTDs exert similar effects in cryptocurrency markets. If settlement frictions introduced by ETFs materially alter the volatility structure of Bitcoin and Ethereum, then ETFs do not merely provide new investment access, but they fundamentally change the nature of the underlying assets by importing traditional market imperfections into previously friction-light environments.

An important implication of this argument is that settlement frictions should not only affect the timing of volatility, but also the effectiveness of the ETF arbitrage mechanism itself. Failures-to-deliver arise precisely when the creation, redemption, or delivery of ETF shares is delayed relative to trading activity. During such episodes, authorized participants and market makers are temporarily unable to fully align ETF prices with the underlying spot market. If settlement failures reflect binding constraints in inventory management and securities lending, they should therefore be associated with larger short-horizon deviations between ETF and spot prices. This leads to the third hypothesis:

H3: Failures-to-deliver are associated with increased short-horizon ETF–spot price dislocations, reflected in higher tracking errors between ETF returns and the underlying cryptocurrency.

Our study addresses these hypotheses by examining the relationship between settlement failures, volatility dynamics, and arbitrage efficiency in U.S. spot Bitcoin and Ethereum ETFs from their inception until the end of 2025. Using daily ETF-level data on failures-to-deliver, securities-lending conditions, and close-aligned spot prices, we document three central findings. First, innovations in settlement failures shift volatility away from the trade date and into the settlement window, generating a delayed but economically meaningful volatility response. Second, this volatility transmission centered around the settlement date remains distinct from conventional volatility shocks and cannot be explained by standard volatility clustering or trading-intensity effects. Third, settlement failures arise systematically when lending constraints bind and are accompanied by larger ETF–spot tracking errors, indicating temporary impairments in arbitrage efficiency.

The remainder of the paper is structured as follows. Section 2 describes the ETF clearing and settlement mechanism, the sources of failures-to-deliver, and their documented market effects in other asset classes. Section 3 introduces the data. Section 4 outlines the empirical methodology, combining local projections and ETF-level panel regressions. Section 5 presents the results, and the Appendix provides additional descriptive evidence and robustness analyses.

1 Literature review

1.1 ETF clearing mechanism

In U.S. markets, the post-trade lifecycle of exchange-traded fund (ETF) transactions is anchored by Depository Trust and Clearing Corporation subsidiaries: the National Securities Clearing Corporation (NSCC), which interposes itself as the central counterparty to broker to broker equity trades via its Continuous Net Settlement (CNS) system, and The Depository Trust Company (DTC), which effects final book-entry securities and cash movements. CNS nets each member’s obligations to a single long/short position per CUSIP and guarantees settlement once trades reach validation, thereby minimizing gross deliveries and centralizing fail-control. DTC then transfers beneficial ownership electronically (Depository Trust & Clearing Corporation, 2024). Through NSCC’s automated infrastructure, ETF creations and redemptions are settled by exchanging ETF shares for the fund’s underlying exposure (portfolio composition files), either through direct delivery of the relevant securities or, when direct delivery is not feasible, through a cash substitution mechanism that allows settlement to proceed without delay. The portfolio composition file is published T-1 by the ETF’s index receipt agent to APs and NSCC, setting the next day’s basket to deliver in order to create or redeem ETF shares. NSCC’s timelines specify primary and supplemental input cycles and cut-offs under the accelerated (T+1) regime (Shreck & Antoniewicz, 2012).

The principal counterparties across the ETF structure are: (i) Authorized Participants - self-clearing broker-dealers and NSCC/DTC members that transact directly with the fund to exchange baskets for “creation units”; (ii) lead market makers and other liquidity providers quoting on exchanges; (iii) the ETF sponsor/distributor, transfer agent, and custodian; and (iv) the clearing agencies (NSCC/DTC) that guarantee and settle the trades. Authorized participants regulate supply via primary-market creations/redemptions to arbitrage deviations between the ETF’s price and its net asset value but are not obligated to create/redeem shares; many are large bank dealers. During secondary-market trading, retail and institutional investors interact with market makers; at the end of the day, broker-to-broker ETF trades enter CNS netting with NSCC as the central counterparty. Then, primary-market creations/redemptions submitted by APs are cleared through NSCC’s specialized workflow and then settled at DTC (Ben-David et al., 2018).

1.2 Occurrence of Fail-to-deliveries

On May 28, 2024, the standard U.S. settlement cycle for most broker-dealer transactions (equities, corporate and municipal bonds, and ETFs) shortened from T+2 to T+1, via amendments to Exchange Act Rule 15c6-1 (SEC, 2024). The change compresses operational timelines (allocations, confirmations, affirmations) to the trade date and tightens close-out clocks under Regulation SHO . Guidance issued by U.S. regulators (Securities Exchange Commission or Options Clearing Corporation) makes clear that exchange-traded funds are subject to the shortened one-day settlement cycle, while also identifying limited exceptions, such as firmly underwritten offerings priced after 4:30 p.m. Eastern Time, which continue to settle two business days after the trade. Documents released by Depository Trust and Clearing Corporation explain how ETF creation and redemption processes have been adjusted for next-day settlement and highlight recommended securities-lending recall practices intended to limit settlement failures (SEC, 2024).

Within this next-day clearing environment, a failure to deliver arises when, at legal settlement, one side of the obligation (ETF shares or a component of the creation/redemption basket) is not in place for book-entry transfer, even though a trade was validly executed and netted (Fotak et al., 2014). Importantly, an FTD is an operational shortfall in timely delivery rather than an economic repudiation of the trade: positions are typically hedged or intended to be completed, but some part of the post-trade workflow misses a cut-off, and the security cannot be delivered on the prescribed day (Pastorek et al., 2023).

From the process described above, it is intuitive, that there might appear situations when there is higher chance of occurrence the fail to delivery volumes: (i) Secondary market ETF trades must be affirmed on the trade date to enter NSCC's netting; any delay in confirmations, allocations, or internal reconciliations shrinks the window to source shares and can push an otherwise valid obligation past DTC cut offs (Asmar & Timbath, 2022). (ii) Authorized participants often provide liquidity by selling ETF shares first and completing the matching primary market creation afterward; if the creation does not finalize quickly enough, the seller reaches legal settlement without deliverable shares (Israeli et al., 2017). (iii) Creations and redemptions depend on assembling the exact basket specified by the fund; if even one required security is updated late, mismatched in the data feed, or simply unavailable in time, the order moves into exception handling and cannot be released for settlement, so delivery fails until the basket is complete (Todorov, 2021). (iv) Delivery frequently relies on securities lending; when recall notices arrive late, or borrowing supply is thin during heavy flow, brokers may be unable to return or re deliver shares before close outs, producing a short lived delivery gap (Schultz, 2024). (v) Because NSCC nets obligations across participants, a shortfall at one member can propagate and deprive others of expected incoming shares, creating cascading fails under a limited time to cure (Engelberg et al., 2018). (vi) Although most incidents reflect benign frictions, poor practices and human errors can magnify them: sloppy locate discipline, misrouted recalls, miskeyed identifiers, or weak exception monitoring let small discrepancies persist into settlement; in rarer cases, aggressive inventory management that leans on anticipated creations or unconfirmed borrows heightens the risk that deliverables will not be in place on time (Pastorek et al., 2023). (vii) Furthermore, for spot Bitcoin ETFs, there might appear another reason for FTD occurrences, although yet not explored. There are two clocks that must stay in sync: the equity clock (NSCC/DTC cut offs) and the crypto custody clock (internal approvals and transfer windows for moving Bitcoin). When the equity side moves faster than the crypto side (e.g., during busy periods when multi signature approvals take longer or when transfers are queued) the ETF share is due at settlement before the underlying Bitcoin has been positioned to support it. That temporary mismatch does not imply the exposure is unhedged; it simply means the paper leg is ready while the asset leg is still catching up (Pastorek & Albrecht, 2025). The result is a time bound delivery shortfall at DTC that is typically cured once the crypto movement completes.

Viewed together, these channels explain why failures to deliver surface precisely when the system operates under tight timelines: liquidity is provided first, and the corresponding deliverables follow with a short delay. It might present an operational pattern that dampens the initial price move but can extend volatility as cures arrive in subsequent sessions.

1.3 Fail-to-deliveries existence and market impact

The previous sections explained the clearing process in the trading of ETFs. Furthermore, it was explained how and under which conditions failure to deliver volumes appears during this process. From the above, the question arises: What are the impacts of these processes on the markets? A central finding in prior studies is that elevated operational shorting and FTD activity can smooth contemporaneous price movements during periods of heavy trading pressure (e.g., Madhavan, 2012; Fotak et al., 2014; Ben-David et al., 2017). By allowing intermediaries to absorb demand or supply without immediate delivery of the underlying, FTDs act as a liquidity buffer that dampens intraday volatility and narrows effective spreads at the peak of trading intensity (Evans et al., 2024). Ben-David et al. (2018) document that ETF activity can insulate underlying securities from abrupt liquidity shocks, while operational shorting in ETFs is associated with lower same-day volatility and improved market depth, particularly when high-frequency traders are active. Similar buffering effects are observed in commodity ETFs, where creation and redemption frictions allow prices to adjust more gradually despite extreme flows (Todorov, 2024). In this sense, FTDs can enhance short-term market resilience by preventing abrupt price dislocations that would otherwise arise from inventory shortages or binding settlement constraints.

At the same time, the literature highlights a less benign, though tightly related, consequence: the postponement of settlement generates delayed price pressure once FTDs are cured. Obligations arising from failed deliveries must eventually be resolved via purchases of the underlying assets, securities recalls, or primary-market creations, typically over subsequent trading sessions. This delayed realignment has been shown to extend volatility beyond the initial shock, producing higher volatility in the days following periods of intense ETF activity (Laborda et al., 2024). Fotak et al. (2014) demonstrate that high FTD levels are linked to predictable return and volatility patterns consistent with delayed covering, while studies on equity and commodity ETFs report that volatility becomes more persistent and clustered around settlement and rebalancing events. The implication is that FTDs do not eliminate volatility; instead, they redistribute it across time, lowering its peak but increasing its duration.

The advantages and disadvantages identified in prior research, therefore, coexist. On the positive side, FTDs facilitate immediacy, improve liquidity provision under stress, reduce temporary order-book imbalances, and support tighter spreads and smoother intraday price dynamics. They can moderate extreme price reactions and help ETFs continue to track their reference assets during episodes of intense demand or supply (Aber et al., 2009; Glosten et al., 2021). On the negative side, they may impair price discovery by deferring the incorporation of fundamental trading pressure, increase volatility persistence, generate temporary deviations between ETF prices and net asset values, andamplify intertemporal spillovers across related markets as settlement cures and hedging trades cluster in subsequent days. In some settings, particularly when combined with aggressive inventory management, FTDs have also been associated with heightened co-movement and the risk of forced trading under close-out rules, which can exacerbate market stress rather than alleviate it (Madhavan, 2012; Israeli et al., 2017).

These trade-offs are especially relevant in the context of spot cryptocurrency ETFs. Until their recent introduction, crypto markets operated largely on immediate or near-immediate settlement within decentralized or centralized exchange infrastructures, leaving little scope for ETF delivery failures to arise. The integration of cryptocurrencies into the traditional ETF clearing and settlement framework introduces an entirely new channel through which FTDs can occur, driven by the interaction between equity-market settlement timelines and the operational constraints of crypto custody and transfer processes. To date, the impact of ETF-related FTDs on cryptocurrency markets has not been empirically studied, despite the evidence from other asset classes that such frictions can materially alter volatility dynamics and market quality.

Experience from equities and commodities suggests that the introduction of ETFs and the associated possibility of FTDs has changed asset behavior by increasing volatility persistence, lengthening adjustment periods after shocks, generating time-varying tracking errors, and shifting elements of price discovery from underlying markets to ETFs themselves (e.g., Evans et al., 2024; Todorov, 2024). If similar mechanisms operate in crypto markets, FTDs induced by ETFs could meaningfully change the temporal structure of crypto volatility, the interaction between spot and derivative markets, and the way large demand shocks are absorbed and resolved. Understanding this channel is therefore crucial, as it may signal a structural transformation in the behavior of cryptocurrencies as financial assets, analogous to the changes observed when ETFs became dominant intermediaries in equity and commodity markets.

2 Data and methods

2.1 Data

The empirical analysis is based on a daily ETF dataset covering U.S. spot cryptocurrency exchange-traded funds linked to Bitcoin and Ethereum (excluding futures-based ETFs). The sample period runs from January 1, 2025, to December 31, 2025, a window in which spot Bitcoin and Ethereum ETFs are jointly available, and market settlement operates exclusively under the T+1 regime following the transition from T+2 (previous rule). The final ETF dataset comprises eleven tickers for Bitcoin and seven for Ethereum. Specifically, ARKB, BITB, BRRR, BTC, BTCO, BTCW, EZBC, FBTC, GBTC, HODL, and IBIT for Bitcoin, and ETH, ETHA, ETHE, ETHV, ETHW, EZET, and FETH for Ethereum.

Failures-to-deliver (FTD) data are obtained from U.S. regulatory settlement disclosures (SEC). If there is no record, we thread these missing FTD observations as zeros. For scale stability, FTD quantities are transformed using the logarithmic transformation log(1+FTD). Importantly, FTDs are reported by regulators on the settlement date. To align settlement outcomes with the trading conditions under which they arise, we construct a trade-date proxy of settlement failures by shifting the aggregated FTD series backward by one trading day. Under the T+1 settlement regime prevailing in our sample, this convention associates failures recorded on settlement date S with market conditions on the preceding trade date T. The shifted series is used in analyses that relate settlement frictions to contemporaneous trading activity and spot-market dynamics.

Short-selling and securities-lending data are obtained from FINRA databases. The FINRA files contain intraday observations on total reported volume, total short volume, total long volume, and borrowing costs for each ETF. From this data, we construct daily measures of short-selling activity and borrowing conditions. For each ETF and trading day, we compute short-selling intensity as the ratio of total short volume to total reported trading volume. Borrowing costs are constructed from intraday FINRA borrowing-fee observations. We aggregate intraday borrowing-fee data to daily frequency by computing the daily mean borrowing fee for each ETF. This approach yields a smooth and representative measure of daily financing conditions faced by short sellers.

ETF prices and trading volumes, as well as underlying spot cryptocurrency prices, are obtained from Refinitiv Eikon. For the underlying cryptocurrencies, we start from intraday price data and construct daily spot series using a close-aligned convention anchored at the U.S. equity market close. Specifically, we compute a daily spot price and return based on intraday observations at 16:00, ensuring temporal alignment with ETF closing prices. In addition, we construct intraday range-based volatility measures from the same intraday data. These spot variables are mapped to ETFs by underlying asset, so that on each date, all Bitcoin ETFs share the same spot Bitcoin series and all Ethereum ETFs share the same spot Ethereum series. The descriptive statistics are provided in Table A1, and the correlation matrix is provided in Table A2.

2.2 Methods

This section describes the empirical framework used to analyse settlement frictions in cryptocurrency markets. We begin by documenting the reduced-form dynamic response of spot cryptocurrency volatility to unexpected variation in failures-to-deliver using local projections (Jordà, 2005), which allows us to conceptualize the timing, magnitude, and persistence of volatility effects without imposing parametric restrictions on the underlying data-generating process. We then assess whether settlement-driven shocks can be distinguished from conventional volatility shocks (as investigated by Albrecht & Kočenda, 2026) and examine the market conditions under which settlement failures arise using ETF-level panel regressions. Finally, we study the implications of settlement frictions for short-horizon arbitrage by relating failures-to-deliver to deviations between ETF and underlying spot returns, providing evidence on the link between settlement disruptions and price dislocations at the ETF level.

2.2.1 Local Projections: Baseline Dynamics

To establish a reduced dynamic relationship, we examine the dynamic response of spot cryptocurrency volatility to settlement frictions in spot-crypto ETFs, measured by failures-to-deliver. FTDs are disclosed on the regulatory settlement date S. To align the disturbance with the day on which settlement frictions are most likely to affect trading behavior, we construct a trade-date proxy by shifting the settlement-dated series by one day $FTD_T(t) = FTD_S(t+1)$. This convention treats the settlement-reported failure on day S as s reflecting a trade-date imbalance realized on day T, so that horizon h = 0 corresponds to the trade-date proxy and h = 1 to the settlement date. The series are transformed as $x_t = log(1 + FTD_T(t))$, to reduce the influence of extreme realizations and yields a stable scale for daily innovations. The FTD series exhibits a pronounced point mass at zero and intermittent positive realizations. Zero observations are treated as a distinct state (no failure), rather than as low realizations of a continuous intensity process. While auxiliary diagnostics model the occurrence and the magnitude of failures separately, the baseline analysis constructs a shock as an innovation in the log-intensity series x_t defined consistently for the full sample.

Formally, the FTD innovation ε_t is defined as the residual from a linear forecasting regression for x_t that includes lagged FTD intensity, contemporaneous trading volume, and lagged spot volatility. These residual captures unanticipated variation in settlement frictions that are orthogonal to predictable persistence and prevailing market conditions. Finally, to estimate the local projections for each horizon *h* = 0, …, *H*, we estimate

$$Y_{t+h} = \alpha_h + \beta_h \varepsilon_t + \delta_h' W_t + u_{t+h}, \qquad (1)$$

where Y_t is spot cryptocurrency volatility, proxied by the absolute daily log return. The control vector W_t includes lagged volatility, the contemporaneous spot return, and $log(1 + Volume_t)$. Specifications are estimated separately for Bitcoin and Ethereum.

Because the dependent variables Y_{t+h} overlap across horizons, regression residuals exhibit serial dependence even in the absence of persistent shocks. Inference therefore relies on heteroskedasticity and autocorrelation robust Newey–West standard errors, with the lag length matched to the projection horizon. Cumulative impulse responses, defined as

$$CumIRF(h) = \sum_{j=0}^{h} \hat{\beta}_j, \tag{2}$$

These cumulative IRFs are then reported to summarize the accumulated change in volatility following an FTD innovation. The representation highlights whether settlement frictions generate only transitory volatility spikes or whether their effects persist over subsequent days. Confidence bands for cumulative responses are constructed by cumulating squared standard errors across horizons.

2.2.2 Local Projections with Competing Shocks

While the baseline local projection framework captures the dynamic response of volatility to unexpected settlement frictions in reduced form, it does not by itself rule out alternative interpretations. In particular, failures-to-deliver may be systematically correlated with periods of elevated volatility, either because settlement frictions tend to arise in turbulent market conditions or because volatility itself exhibits persistence and spills over across days. In such a setting, the estimated responses could mechanically reflect volatility propagation rather than the causal impact of settlement disruptions.

To address this concern, we extend the baseline specification to a horse-race framework that jointly accounts for settlement-driven shocks and contemporaneous volatility shocks. The objective of this extension is not to maximize explanatory power, but to disentangle the informational content of settlement frictions from conventional sources of volatility persistence and market stress.

Specifically, we augment equation (1) with an orthogonalized volatility shock, which is constructed as the innovation from a forecasting regression of spot volatility on its own lag and contemporaneous trading volume. The stress shock captures unexpected movements in volatility that are unrelated to settlement outcomes and reflects standard volatility clustering dynamics. Both the FTD innovation and the volatility stress shock are standardized to have unit variance, ensuring comparability of impulse responses across shocks and assets. The augmented local projection takes the following form:

$$Y_{t+h} = \alpha_h + \beta_h \varepsilon_t^{FTD} + \gamma_h \varepsilon_t^{Stress} + \delta_h' W_t + u_{t+h}, \tag{3}$$

where ε_t^{FTD} denotes the FTD innovation defined above and ε_t^{Stress} denotes the volatility stress innovation. As before, W_t includes lagged volatility, contemporaneous returns, and log trading volume, and specifications are estimated separately for Bitcoin and Ethereum.

The horse-race design allows us to assess whether settlement frictions contain predictive content for future volatility beyond what is captured by standard volatility shocks. If the estimated response to ε_t^{FTD} remains after conditioning on ε_t^{Stress}, this provides evidence that settlement failures represent an independent transmission channel rather than a passive reflection of turbulent market conditions.

2.2.3 Panel Evidence: Determinants of Settlement Frictions

Building on the evidence from local projections of this reduced form, we next examine the economic conditions under which settlement frictions arise. While the local-projection framework characterizes the dynamic consequences of unexpected failures-to-deliver, it does not directly identify the market mechanisms that generate such failures. To this end, we estimate panel regressions that relate daily FTD intensity to measures of trading activity, short-selling pressure, and securities-lending constraints across cryptocurrency spot ETFs.

The empirical design exploits a daily panel comprising U.S. spot Bitcoin and Ethereum ETFs. The dependent variable is the logarithm of one plus the number of failures-to-deliver for ETF i on day t. All explanatory variables are lagged by one trading day to mitigate simultaneity concerns and to align the timing of lending and trading conditions with subsequent settlement outcomes. Formally, we estimate specifications of the form

$$log(1 + FTD_{i,t}) = \beta' X_{i,t-1} + \alpha_i + \gamma_{a,t} + \varepsilon_{i,t}, \tag{4}$$

where $X_{i,t-1}$ is a vector of lagged covariates capturing trading intensity and lending market conditions, α_i denotes ETF fixed effects, and $\gamma_{a,t}$ represents asset-by-date fixed effects, with $a \in$ {BTC,ETH}.

The inclusion of asset-by-date fixed effects absorbs all shocks common to a given underlying cryptocurrency on a particular day, including movements in spot prices, volatility, macro news, and network-wide market conditions. Identification, therefore, arises from cross-ETF variation within the same asset and trading day. Such a design ensures that estimated coefficients reflect differences in settlement outcomes driven by ETF-specific exposure to lending and short-selling frictions, rather than by aggregate crypto-market dynamics.

Trading activity is proxied by the logarithm of ETF trading volume, while short-selling pressure is measured by the share of reported short volume in total trading volume, following the ETF and short-selling literature (Fotak et al., 2014; Ben-David et al., 2018). Conditions in the securities-lending market are captured using two complementary measures. First, borrowing fees are transformed by logarithms to account for their highly skewed distribution and to capture economically meaningful proportional changes in borrowing costs, consistent with prior evidence that borrowing fees reflect lending tightness and inventory constraints faced by intermediaries (Evans et al., 2024). Second, to identify periods of binding lending constraints, we construct an indicator for low borrow availability that equals one when an ETF's borrow availability falls into the bottom five percent of the asset-specific distribution. The indicator isolates extreme scarcity episodes, in which the supply of lendable shares is most likely to constrain settlement and impair ETF arbitrage (Schultz, 2024).

All specifications include ETF fixed effects, which absorb time-invariant heterogeneity in fund characteristics, such as size, structure, or authorized participant networks. Standard errors are adjusted for heteroskedasticity and dependence using clustering. In the full sample, standard errors are two-way clustered by ETF ticker and date. In asset-specific subsamples, inference relies on date-level clustering, as the limited number of ETFs implies that ETF fixed effects are nested within ticker clusters, rendering two-way clustering infeasible.

We estimate the panel regressions for the full sample as well as separately for Bitcoin and Ethereum ETFs. The split allows us to assess whether the determinants of settlement frictions differ systematically across assets with distinct market depth, liquidity, and securities-lending capacity. By linking observed failures-to-deliver to contemporaneous trading and lending conditions, this panel framework complements the local-projection analysis and provides direct evidence on the economic mechanisms underlying settlement frictions in cryptocurrency ETF markets.

2.2.4 Panel Evidence: Arbitrage Frictions

The final empirical block examines the relationship between settlement failures and short-horizon arbitrage frictions at the ETF level. While the preceding analyses focus on the dynamic implications of settlement frictions and their determinants, this subsection evaluates whether failures-to-deliver are systematically associated with deviations from price parity between ETFs and their underlying spot assets. We measure arbitrage frictions using a tracking-error-based metric constructed from close-aligned ETF and spot returns. For each ETF i and day t, we compute the ETF return using the closing price and the corresponding return of the underlying cryptocurrency over the same close-aligned window. The tracking error is defined as the difference between the ETF return and the spot return, and the outcome variable is the logarithm of one plus the squared tracking error:

$$TE_{i,t}^{2} = (r_{i,t}^{ETF} - r_{a,t}^{Spot})^{2}, Y_{i,t} = log(1 + TE_{i,t}^{2}). \tag{5}$$

The transformation yields a scale-stable measure of short-horizon deviations between ETF and spot returns and reduces the influence of extreme observations. Moreover, to relate arbitrage frictions to settlement failures, we estimate ETF-level panel regressions of the following form:

$$Y_{i,t} = \theta \log(1 + FTD_{i,t}) + \beta' Z_{i,t-1} + \alpha_i + \lambda_t + u_{i,t}. \tag{6}$$

Here, $log(1 + FTD_{i,t})$ captures the intensity of settlement failures for ETF i on day t. The vector $Z_{i,t-1}$includes lagged controls for trading activity and market conditions, namely the logarithm of ETF trading volume, the share of short-selling volume, and borrowing fees. All controls are lagged by one trading day to mitigate simultaneity concerns. The specification includes ETF fixed effects α_i, which absorb time-invariant fund characteristics, and date fixed effects λ_t, which capture common shocks affecting all ETFs on a given day. Standard errors are two-way clustered by ETF and date.

To assess whether the relationship between settlement failures and arbitrage frictions depends on binding lending constraints, we augment the baseline specification with an indicator for extreme borrow scarcity. The indicator equals one when an ETF's borrow availability falls into the bottom five percent of the asset-specific distribution. Including this variable allows us to examine whether the association between failures-to-deliver and tracking error varies systematically across different lending market states, without imposing a specific causal interpretation.

3 Results

In this section, we proceed in three steps that mirror the empirical design and progressively tighten the link between settlement frictions, volatility dynamics, and arbitrage outcomes. First, we document the dynamic response of spot cryptocurrency volatility to unexpected failures-to-deliver using local projections, focusing on the timing of the response relative to the trade and settlement dates. Then, we examine the economic determinants of settlement failures at the ETF level to identify the market conditions under which these frictions arise. Finally, we assess whether settlement failures are associated with short-horizon deviations between ETF and spot returns, providing evidence on the implications of settlement frictions for arbitrage efficiency.

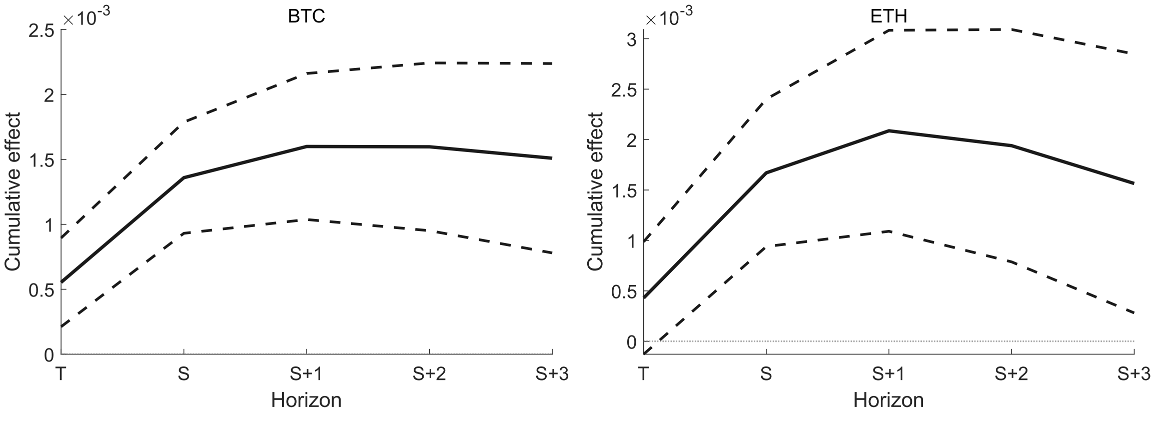
3.1.1 Volatility Transmission through the Settlement Process

A key identifying feature of settlement frictions in spot cryptocurrency ETFs is that they decouple the timing of trading from the timing of delivery. Under frictionless conditions, such as direct peer-to-peer trading on a blockchain, imbalances in demand and supply are settled contemporaneously. Any volatility induced by trading pressure would therefore materialize immediately on the trade date T, with no systematic displacement into subsequent days. In such an environment, there is no economic mechanism through which volatility generated by trading activity could be deferred to the settlement date.

Spot cryptocurrency ETFs operate under a fundamentally different infrastructure. Trades are executed on day T, but the delivery of the underlying cryptocurrency is completed through authorized participants and custodians at settlement. When this process breaks down, failures-to-deliver are recorded on the regulatory settlement date S, even though the underlying imbalance originates at T. As a result, volatility generated by unresolved delivery obligations is not reflected immediately but is instead shifted forward to the settlement window. The institutional feature yields a sharp empirical implication: if settlement frictions are operative, volatility should peak around S, not T.

Figure 1 provides direct evidence consistent with this mechanism. The figure reports cumulative impulse responses of spot cryptocurrency volatility to an innovation in settlement frictions of one standard deviation, where the shock is defined as the orthogonalized FTD innovation constructed in Section 3.1. By construction, this shock captures unexpected variation in failures-to-deliver that is realized on the trade-date proxy T. The local projection framework then traces the response of spot volatility over subsequent horizons $h = 0, \ldots, H$.

Figure 1: Cumulative volatility response to FTD shocks



Note: The figure reports cumulative impulse responses from local projections of spot-cryptocurrency volatility to an FTD innovation. FTDs are aligned to a trade-date proxy defined as settlement-reported FTD shifted back by one trading day. The outcome variable is daily absolute returns. Control variables include lag volatility, the spot return, and log trading volume. Dashed lines denote 95% confidence bands constructed from Newey–West standard errors.

The estimated responses show little to no contemporaneous effect on volatility at horizon $h = 0$, corresponding to the trade date T. In contrast, volatility increases sharply at horizon $h = 1$, which coincides with the regulatory settlement date S. The cumulative response rises modestly into $S + 1$, consistent with the gradual resolution of outstanding settlement failures, but stabilizes thereafter.

Importantly, the cumulative effect does not continue to grow beyond the settlement window, ruling out an interpretation in which the estimated response merely reflects generic volatility persistence or slow-moving market stress unrelated to settlement frictions. This timing pattern indicates that failures-to-deliver do not simply coincide with volatile periods but actively reallocate volatility across calendar time by shifting trading-induced uncertainty from the trade date into the settlement process. Such a finding is in alignment with previous findings. However, these studies observed the pattern in the area of either stock (Evans et al., 2024) or commodity (Todorov, 2024) ETFs. The absence of a contemporaneous response at T is particularly informative: if FTDs merely proxy for demand shocks or trading intensity, volatility would increase immediately. Instead, the delayed response points to settlement frictions as a distinct transmission channel.

The dynamics are present for both Bitcoin and Ethereum, confirming identical pattern: volatility is displaced from T to S and partially to $S + 1$, after which the effect dissipates. While the baseline local projections provide clear evidence on the timing and settlement-centred nature of volatility responses, they do not, by themselves, fully rule out the possibility that failures-to-deliver are correlated with broader volatility shocks. In particular, periods of elevated market stress may simultaneously generate higher volatility and a greater incidence of settlement failures, raising the concern that the estimated FTD responses partly reflect conventional volatility clustering rather than a distinct settlement mechanism.

To address this concern, we further extend the baseline framework by explicitly allowing for competing sources of volatility shocks. In Figure A1 (see the Appendix), we report local projections in which the FTD innovation is estimated jointly with an orthogonalized volatility shock that captures unexpected movements in spot volatility unrelated to settlement outcomes. The competing shock is constructed as the innovation from a forecasting regression of spot volatility on its own lag and contemporaneous trading volume, thereby isolating standard volatility dynamics from settlement-driven disturbances.

Furthermore, the results in Figure A2 show a clear separation between the two channels. Volatility shocks generate an immediate response on the trade date T, followed by rapid mean reversion, consistent with well-known volatility clustering dynamics in cryptocurrency markets. In contrast, the response to an FTD innovation remains concentrated around the settlement date S, with little contemporaneous impact at $T$and only limited persistence beyond $S + 1$. Importantly, the inclusion of the competing volatility shock leaves the timing and shape of the FTD-induced response largely unchanged relative to the baseline specification.

These findings confirm that the settlement-related volatility dynamics documented are Figure 1 are not an artifact of correlated volatility shocks. Instead, they reflect an independent transmission channel operating through the clearing and settlement process of spot-crypto ETFs.

3.1.2 Determinants of Settlement Frictions

The local projection analysis establishes that failures-to-deliver propagate volatility through the settlement process and that this effect is distinct from conventional volatility shocks. A natural following question is whether settlement failures themselves arise randomly, or whether they reflect systematic frictions in the ETF arbitrage and lending infrastructure (as noted by Pastorek et al. (2023) for stocks). In Table 1, we address this question by examining the determinants of FTD intensity in cryptocurrency spot ETFs.

Table 1: Determinants of Settlement Failures in Cryptocurrency ETFs

Dependent variable: Fails-to-Deliver

VARIABLES	Full sample	Bitcoin ETFs	Ethereum ETFs
Trading Volume (log)	0.132 (0.125)	0.260** (0.127)	-0.016 (0.173)
Short Interest (share of volume)	0.927* (0.425)	0.354 (0.359)	2.002** (0.655)
Borrowing Fee (log)	0.507*** (0.134)	0.371** (0.149)	0.574*** (0.151)
Low Borrow Availability (bottom 5%)	0.602* (0.297)	6.886*** (0.144)	0.539** (0.249)
Constant	-1.612 (1.606)	-3.328* (1.805)	-0.019 (2.452)
Observations	5,529	3,352	2,177
R^2 adj.	0.315	0.251	0.369

Note: This table reports panel regressions of failure-to-deliver intensity in cryptocurrency spot ETFs. The dependent variable is the logarithm of one plus the number of failures-to-deliver. All explanatory variables are lagged by one trading day. Trading volume is measured as the logarithm of ETF share volume. Short-selling pressure is proxied by the share of reported short volume in total trading volume. Borrowing fees are log-transformed to account for their highly skewed distribution. Low borrow availability is an indicator equal to one if borrow availability falls into the bottom five percent of the asset-specific distribution. All regressions include ETF fixed effects and asset-by-date fixed effects. Standard errors are two-way clustered by ETF ticker and date in the full sample and clustered at the date level in asset-specific subsamples. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

The results provide evidence that settlement failures are tightly linked to conditions in securities lending and short-selling markets. Across specifications, measures of lending tightness, proxied by borrowing fees and low borrow availability, emerge as the primary drivers of FTD intensity. Higher borrowing fees are strongly associated with a greater incidence of settlement failures in both Bitcoin and Ethereum ETFs, consistent with binding inventory constraints faced by arbitrageurs and authorized participants. Similarly, days in which borrowing availability falls into the lower tail of its asset-specific distribution are characterized by a sharp increase in settlement failures, particularly for Bitcoin ETFs.

In this context, short-selling pressure also plays an important role. The share of short interest in trading volume is positively related to FTD intensity, with the effect especially pronounced for Ethereum ETFs. Such a pattern suggests that settlement failures tend to arise when short demand is elevated relative to available lendable supply, amplifying frictions in the delivery of the underlying asset (in line with Todorov (2024), who examined this effect for commodities). By contrast, trading volume alone has limited explanatory power once lending conditions are taken into account, indicating that FTD events are not simply a mechanical byproduct of high turnover. Taken together, findings from Table 1 reinforce the interpretation of the local projection results. Settlement failures originate from economically meaningful constraints in the arbitrage and lending channel rather than from random operational noise or generalized market stress. It extends the arbitrage opportunities in crypto markets investigated by Makarov & Schoar (2020). When lending markets become tight and short demand intensifies, the ETF arbitrage mechanism is temporarily impaired, giving rise to failures-to-deliver. These failures are then transmitted into spot cryptocurrency volatility through the settlement process, as documented local projection analyses.

This evidence closes the causal loop between the reduced volatility responses and the underlying market mechanism. It implies that settlement failures are both predictable from observable lending frictions and capable of generating economically significant volatility dynamics around settlement dates.

3.1.3 Settlement Failures and Arbitrage Frictions

The preceding analyses show that settlement failures generate volatility responses that are tightly concentrated around the settlement window, and these failures arise systematically when lending and short-selling constraints bind. Such results have been observed by Ben-David et al. (2018). However, our analysis extends these findings to the realm of cryptocurrencies. The next step is to assess whether the same settlement frictions are also associated with disruptions in ETF arbitrage efficiency. If failures-to-deliver reflect temporary impairments in the arbitrage mechanism, they should be accompanied by larger deviations between ETF and spot returns.

Table 2 further corroborates this link by relating ETF-level tracking error to settlement failures and trading controls. The dependent variable is the logarithm of one plus the squared close-aligned tracking error between ETF and spot returns, which captures short-horizon deviations from price parity. All specifications include ETF and date fixed effects, so identification comes from variation within ETFs over time relative to other funds on the same day.

The first model reports the baseline specification. Settlement failures enter with a positive and statistically significant coefficient, indicating that days with higher FTD intensity are associated with larger discrepancies among spot ETFs. It suggests that settlement frictions are not only relevant for volatility dynamics, as shown in the local projection analysis (Chang et al., 2013; Engelberg et al., 2018), but also coincide with impaired arbitrage efficiency at short horizons. In contrast, standard trading controls, trading volume, short interest, and borrowing fees do not exhibit a robust association with tracking error once ETF and date fixed effects are included.

The second model augments the baseline specification by explicitly controlling for extreme lending tightness through an indicator for low borrow availability. This variable enters with a large and highly significant coefficient, confirming that binding inventory constraints are a key source of arbitrage inefficiencies in spot cryptocurrency ETFs. Importantly, however, the coefficient on settlement failures remains positive and statistically significant, and its magnitude is only modestly affected by the inclusion of the low-availability indicator. This stability implies that failures-to-deliver capture more than contemporaneous scarcity in securities lending. Even after conditioning on extreme borrow constraints, higher FTD intensity is associated with larger deviations from price parity. Settlement failures therefore appear to represent an additional layer of friction in the arbitrage process, reflecting disruptions in the timely creation, redemption, or delivery of ETF shares rather than merely elevated borrowing costs or limited lendable supply.

Taken together, the tracking-error results deliver two key insights. First, they show that settlement failures are associated with economically meaningful deviations between ETF and spot returns, indicating that FTDs are linked not only to delayed volatility around settlement dates but also to short-horizon breakdowns in arbitrage efficiency. Second, the strong role of low borrow availability highlights that these distortions arise from institutional features specific to the ETF trading and settlement process. Similar results regarding the tracking errors in spot ETFs were first captured by Pastorek & Albrecht (2025). However, due to the novelty of the instruments, the authors performed only an analysis based on visual inspection and did not further account for ETH ETFs. In contrast to direct peer-to-peer trading on a blockchain, where delivery is immediate and does not rely on securities lending, ETF arbitrage depends critically on the availability of lendable shares. The significance of borrow scarcity therefore underscores that settlement failures and lending constraints represent genuine, ETF-specific frictions that jointly impair price alignment with the underlying asset.

Table 2: Settlement Failures and Arbitrage Frictions

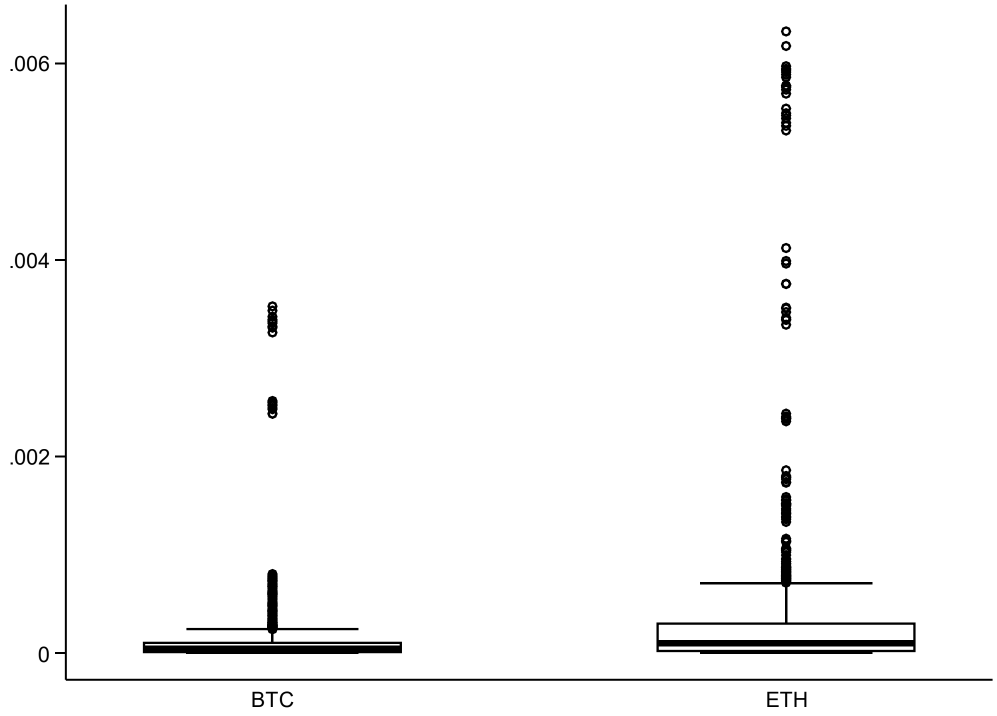
Dependent variable: Tracking error

	(1)	(2)
Fails-to-Deliver (log)	0.070^{*} (0.030)	0.060^{*} (0.030)
Trading Volume (log)	−0.250 (0.160)	−0.190 (0.170)
Short Interest (share of volume)	−0.530 (0.610)	−0.540 (0.620)
Borrowing Fee (log)	0.150 (0.490)	0.050 (0.500)
Low Borrow Availability (bottom 5%)		1.790^{***} (0.510)
Constant	5.710^{**} (2.340)	4.860^{*} (2.310)
Observations	2,863	2,863
R^2 adj.	0.700	0.702

Note: This table reports panel regressions of ETF tracking error on settlement frictions and trading controls. The dependent variable is the log of one plus the squared tracking error, *ln(1 + TE²),* where the tracking error is defined as the difference between ETF and spot returns. Column (1) reports the baseline specification, while column (2) augments the model with an indicator for extreme borrow scarcity, equal to one when borrow availability falls into the bottom 5 percent of the asset-specific distribution. All coefficients and standard errors are scaled by 10,000 and are therefore expressed in basis points. Regressions include ETF fixed effects and date fixed effects. Standard errors are clustered at the ETF and date levels. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

Furthermore, Figure 2 illustrates the cross-sectional distribution of tracking error intensity across ETFs by underlying asset. The boxplot shows that ETH ETFs exhibit a systematically higher median and substantially greater dispersion of tracking error defined as ln(1 + TE²) than BTC ETFs, even outside extreme events. The figure highlights the highly skewed nature of tracking error realizations, with most observations clustered close to zero (as expected) but occasional multiplicative deviations driving the overall dispersion. The pattern is consistent with the regression evidence, which suggests that settlement frictions do not generate persistent mispricing but instead give rise to episodic, short-lived disruptions in arbitrage efficiency that tend to arise during periods of elevated settlement stress.

Figure 2: Distribution of Tracking Error Intensity



Note: This figure shows the distribution of ETF tracking error intensity by underlying asset. Tracking error is defined as the close-aligned difference between ETF and spot returns and is summarized as *ln(1 + TE²).* The boxplots report the median and interquartile range, with circles denoting outlying observations. The sample consists of daily ETF–date observations for spot Bitcoin and Ethereum ETFs. Spot prices are aligned to the ETF close using a 16:00 window. The figure is intended as a descriptive illustration of the dispersion and tail behaviour of short-horizon deviations from price parity across assets.

Conclusions

In this paper, we study how the introduction of spot Bitcoin and Ethereum ETFs reshapes cryptocurrency markets through a channel that has so far been absent from native crypto trading: post-trade settlement frictions. By embedding crypto assets into an equity-style clearing and settlement infrastructure, ETFs introduce a settlement clock into markets that previously operated with near-instant delivery. Such an institutional change creates scope for failures-to-deliver (FTDs), and accompanied by them, a new mechanism through which trading pressure is absorbed and resolved over time.

Our empirical results show that ETF-related settlement frictions materially alter the temporal structure of cryptocurrency volatility. Innovations in FTD intensity do not increase volatility on the trade date. Instead, volatility emerges around the regulatory settlement date and partially spills into the following session. This timing pattern is inconsistent with standard demand-shock or volatility-clustering explanations and points to settlement frictions as a distinct transmission channel. In a competing-shocks framework, the settlement-driven volatility response remains clearly separable from conventional volatility shocks, which load contemporaneously and mean-revert quickly.

We further document that settlement failures are not random operational noise. Panel evidence shows that FTDs arise systematically when securities-lending constraints bind: higher borrowing fees, decreased borrowing availability, and elevated short-selling pressure strongly predict settlement failures, whereas trading volume alone plays a limited role once lending conditions are accounted for. These findings link settlement disruptions directly to frictions in ETF arbitrage and inventory management. Consistent with this interpretation, higher FTD intensity is associated with larger short-horizon tracking errors on spot ETFs, indicating temporary impairments in arbitrage efficiency when delivery obligations cannot be met on time.

Our results imply that spot crypto ETFs act as an intertemporal liquidity buffer. By allowing trades to clear without immediate delivery, ETFs dampen contemporaneous price pressure but shift volatility into the settlement window, prolonging its persistence rather than increasing its average level. The mechanism represents a structural departure from the behavior of cryptocurrencies in purely decentralized or instant-settlement environments.

More broadly, the findings suggest that the financialization of cryptocurrencies through ETFs does more than expand investor access. It imports traditional market imperfections into crypto markets and changes when and how trading pressure is reflected in prices. For regulators and market participants, this highlights the importance of settlement design, securities lending, and arbitrage infrastructure in shaping crypto market stability. For researchers, the results open new areas for studying how institutional frictions interact with decentralized assets, particularly as crypto exposure becomes increasingly intermediated through traditional financial vehicles.

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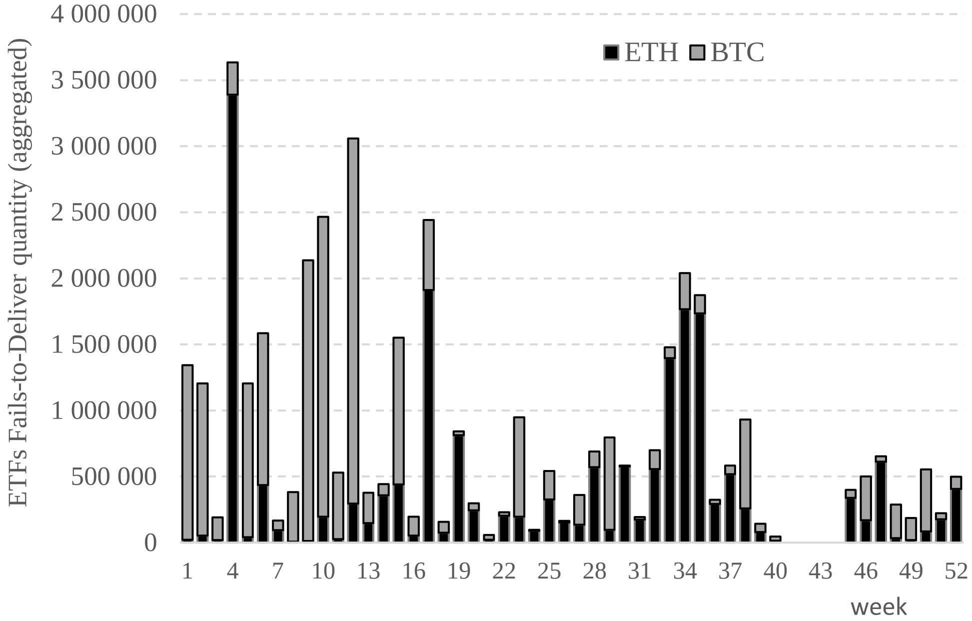
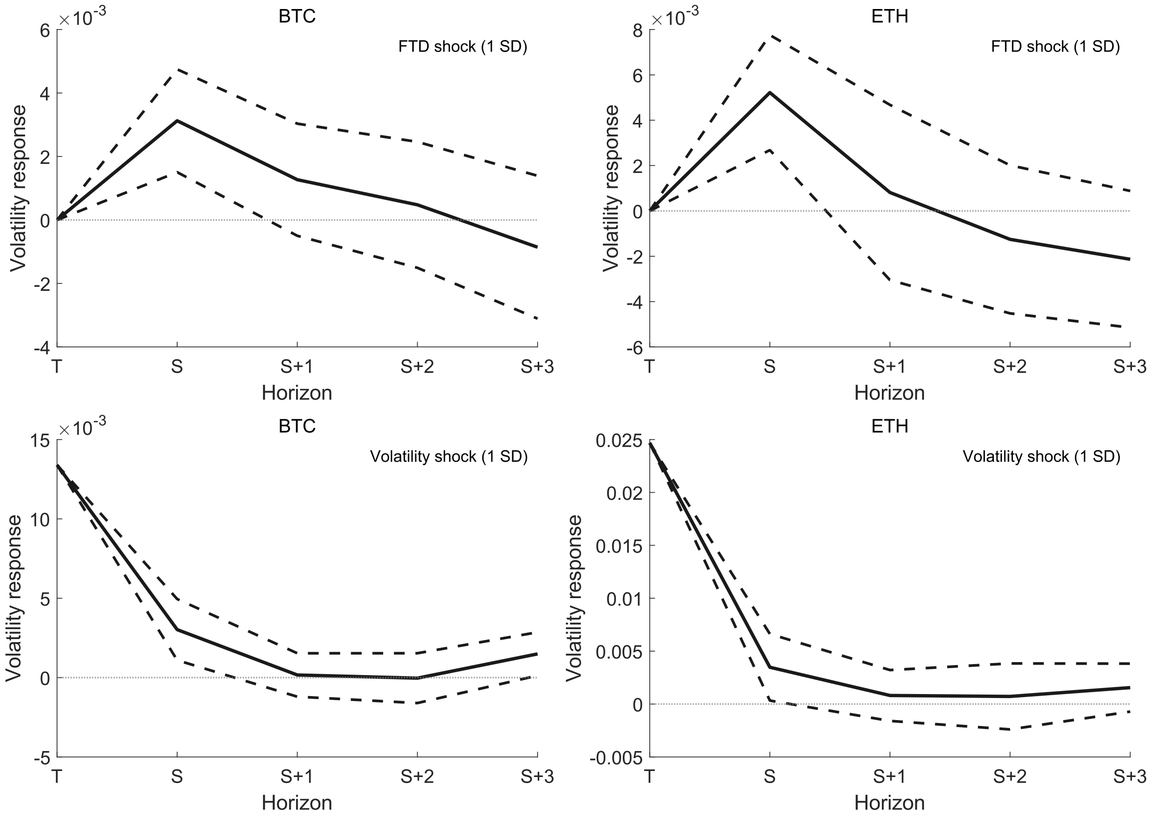
Appendix:

Figure A1: Weekly Aggregated Failures-to-Deliver in Spot Cryptocurrency ETFs



Note: The figure reports aggregated weekly quantities of failures-to-deliver for U.S. spot cryptocurrency ETFs in 2025, disaggregated by underlying asset. Bars show the total number of ETF shares that failed to settle within the prescribed settlement window, summed across ETFs linked to Ethereum (ETH group) and Bitcoin (BTC group). The measure captures settlement quantities only, i.e., the count of units not successfully delivered on time.

Figure A2: Local Projections with Competing Shocks



Note: This figure reports local projection impulse responses of volatility to competing shocks. The top panels show the response to an innovation in settlement failures (FTD shock) of one standard deviation, while the bottom panels show the response to a volatility stress shock of one standard deviation. The volatility stress shock is constructed as the innovation from a forecasting regression of spot volatility on its own lag and contemporaneous trading volume and captures unexpected volatility unrelated to settlement outcomes. Both shocks are orthogonalized and standardized to unit variance to ensure comparability across assets and specifications. Dashed lines denote 95% confidence bands constructed from Newey–West standard errors. All specifications include lagged volatility, contemporaneous returns, and trading volume as controls and are estimated separately for Bitcoin and Ethereum.

Table A1: Descriptive Statistics

Variable	N	Mean	Std. Dev.	Min	P25	Median	P75	Max
Trading volume	4,428	6,300,000	15,000,000	4,900	240,000	1,300,000	3,900,000	170,000,000
Short share	3,779	0.54	0.16	0.00	0.44	0.55	0.64	1.00
Borrowing fee (mean)	5,521	1.09	0.77	0.25	0.55	0.95	1.31	10.99
Borrow availability	5,521	5,000,000	4,300,000	0.00	310,000	4,800,000	10,000,000	10,000,000
FTD quantity	6,480	569.20	66,060.49	0.00	0.00	0.00	0.00	270,000

Notes: This table reports descriptive statistics for the main variables used in the analysis. Trading volume, borrowing fees, borrowing availability, and failures-to-deliver are measured at the daily ETF level. Sample sizes differ across variables due to data availability across sources.

Table A2: Pairwise Correlations

	Volume (log)	Short share	Borrow fee (log)	Borrow avail (log)	FTD quantity (log)
Volume (log)	1.000				
Short share	-0.247	1.000			
Borrow fee (log)	-0.178	0.058	1.000		
Borrow avail (log)	0.561	-0.035	-0.275	1.000	
FTD quantity (log)	0.266	-0.067	-0.055	0.102	1.000

Notes: This table reports pairwise Pearson correlations among the main variables. Variables are defined as in Table A1. Logarithmic transformations are applied where indicated.