Price Discovery Overnight: Evidence from Pre- and After-Market Trading

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Abstract

We study when overnight price discovery occurs by decomposing the close-to-open return into after-market, pre-market, and dark returns, where the dark return is measured from the last after-market trade to the first pre-market trade. Using one-minute trade data for S&P 500 stocks over October 2008 to December 2023, we show that on average, dark returns are positive while pre-market returns are negative, offsetting a substantial share of dark returns. The reversal is strongest when pre-market liquidity is low. Cross-sectional explanatory power for close-to-open returns rises smoothly through the pre-market, implying that overnight valuation changes are incorporated gradually before the regular-session open.

Keywords: Overnight returns; Close-to-open returns; Pre-market trading; After-market trading; Price discovery.

JEL: G12, G14, C23

1. Introduction

Since the global financial crisis, a substantial share of the S&P 500's cumulative return has accrued overnight (Berkman et al., 2012; Bondarenko and Muravyev, 2023; Boyarchenko et al., 2023; Haghani et al., 2022; Lachance, 2021, 2023). In addition, cross-sectional overnight returns show a striking momentum effect (Lou et al., 2019). To better understand these anomalies, we decompose overnight returns into distinct components using after-market and pre-market trading. After- and pre-market trading have expanded in recent years yet remain comparatively understudied. Taken together, these patterns suggest that economically meaningful price discovery occurs outside the regular session, raising a fundamental question: when and how are overnight returns formed?

Prior research suggests that price discovery may shift into extended-hours trading, particularly during the pre-market and especially for high-volume stocks (Barclay and Hendershott, 2008; Levi and Zhang, 2020; Xiao and Yamamoto, 2024). At the same time, market quality during pre- and after-hours remains lower, with reduced depth and wider spreads (Cboe Global Markets, 2022). While extended-hours trading has expanded substantially, the overnight return continues to be treated as a single object, leaving the timing of price discovery within that window largely unresolved. We therefore examine which part of the variation in close-to-open returns can be explained by returns realized at different phases of the overnight window. This raises a central question: Does overnight price discovery occur gradually within extended hours, or discretely at the regular-session open?

Two competing mechanisms can rationalize the formation of overnight returns. First, an international-markets channel posits that U.S. overnight returns primarily reflect information revealed in foreign markets that are open while U.S. equity markets are closed. Using near-24-hour E-mini S&P 500 futures, Bondarenko and Muravyev (2023) show that average night returns con-

centrate around the European open, consistent with international price discovery driving U.S. off-hours price adjustment. Under this view, a substantial fraction of the overnight return should already be incorporated in early pre-market prices. Accordingly, cross-sectional differences in close-to-open returns should become visible already at the onset of pre-market trading, as prices adjust to information revealed abroad while U.S. equity markets are closed. Second, an opening-auction channel attributes overnight returns to price formation frictions at the start of the regular session. Berkman et al. (2012) provide evidence that measured overnight returns largely reflect inflated opening prices driven by demand imbalances. Complementary evidence is provided by Lou et al. (2019), who argue that retail-like trades cluster disproportionately near the open, whereas institutional trading is concentrated near the close, consistent with systematic demand imbalances at 09:30. Recent work further links the overnight–intraday return gap to retail trading intensity (Ahn et al., 2024). Under this view, price discovery should occur primarily at the opening print rather than during the pre-market. This implies that little of the cross-sectional variation in overnight returns should be visible in pre-market transaction prices; instead, explanatory power should materialize primarily at the 09:30 regular-session opening.

To discriminate between these competing mechanisms, we trace the timing of price discovery using a cross-sectional explanatory-power measure. If information from international markets (that trade while U.S. markets are closed) drives U.S. overnight returns, then cumulative returns in the first minutes of pre-market trading should already account for a substantial fraction of the overnight return. If instead price discovery occurs at the opening auction, explanatory power should be concentrated at the opening print, with a discrete increase at 09:30. We implement this idea by regressing the full close-to-open return on cumulative close-to-τ returns for each cutoff τ and tracking the resulting $R^2(\tau)$ path over time.

Our findings are difficult to reconcile with explanations based solely on the opening auction

or international market information and instead indicate systematic price formation during pre-market trading. First, the decomposition of overnight returns reveals a robust sign split across segments. On average, dark-period returns (from the last after-market transaction price to the first pre-market transaction price) are positive, while pre-market returns are negative. This "scissor-like" pattern suggests that part of the dark return reflects temporary price pressure arising from thin pre-market liquidity that partially reverses as depth and competition return at the open. Second, the strength of this reversal depends systematically on pre-market liquidity. The negative relation between dark and pre-market returns is strongest when pre-market trading activity is low and attenuates monotonically as liquidity increases. This cross-sectional pattern is consistent with a liquidity compensation that diminishes in deeper markets. Third, the $R^2(\tau)$ path rises gradually throughout the pre-market rather than exhibiting a discrete jump at 09:30. Price discovery is therefore gradually pulled forward into the pre-market window. Securities that trade earlier in the pre-market display an earlier and smoother increase in explanatory power, reinforcing the view that overnight information becomes incorporated before the regular-session open.

This paper contributes to the literature in three ways. First, we provide a systematic decomposition of the conventional close-to-open return into after-market, dark-period, and pre-market components, thereby sharpening the measurement of overnight returns. By distinguishing between trading and non-trading segments, we uncover heterogeneity that is masked in the aggregate close-to-open measure. Second, we introduce a time-resolved cross-sectional measure of overnight price discovery that allows us to trace when information becomes incorporated into prices. This design provides a simple and transparent framework to discriminate between competing narratives of international information transmission and opening-auction price formation. Third, our findings connect the overnight anomaly to market frictions. The documented sign split and liquidity-dependent reversal highlight the role of transaction costs and thin depth in shaping off-hours

prices, thereby linking asset-pricing patterns in overnight returns to the institutional features of extended-hours trading.

The remainder of the paper proceeds as follows. Section 2 describes the institutional organization of pre- and after-market trading. Section 3 introduces the data and formally defines the return decomposition underlying our analysis. Section 4 documents extended-hours trading activity and liquidity patterns. Section 5 presents the overnight return decomposition results and analyzes the relation between dark and pre-market returns as a function of liquidity. Section 6 traces the timing of price discovery using the cross-sectional $R^2(\tau)$ path. Section 7 concludes.

2. Organization of pre- and after-markets

Extended-hours trading operates under materially different institutional conditions than the regular session. During regular trading hours (09:30-16:00 ET), the U.S. regulatory framework requires trading centers to protect the best displayed quotations across venues.[1] Although Rule 611 of Regulation National Market System formally remains in effect outside regular trading hours, protected quotations are far less prevalent and intermarket price competition is substantially reduced, so that effective trade-through protection is considerably weaker during extended-hours trading (FINRA, 2014a, 2024). During extended hours, trading is fragmented across venues and cross-venue price protection is weaker because markets are not linked in the same way as during regular trading hours (U.S. Securities and Exchange Commission, 2011; FINRA, 2024). In addition, on exchanges that operate a designated market maker model, continuous quoting obligations are defined for the core trading session (09:30–16:00 ET); outside these hours, such obligations are

[1] During regular trading hours (09:30–16:00 ET), Rule 611 of Regulation NMS (Order Protection Rule) prohibits trade-throughs of protected automated quotations in NMS stocks, thereby requiring trading centers to execute orders at the national best bid or offer when such quotations are accessible (U.S. Securities and Exchange Commission, 2008).

typically not in force, and liquidity provision is more discretionary (NYSE, 2021a; U.S. Securities and Exchange Commission, 2011). As a result, prices formed between the close and the next open arise in comparatively thin and weakly protected markets. Returns within the night period may therefore reflect not only information revelation but also compensation for supplying immediacy when liquidity is scarce (Berkman et al., 2012; Cui and Gozluklu, 2019; Eaton et al., 2025).

This institutional environment motivates our decomposition of the overnight window into transaction-silent dark intervals and actively traded after- and pre-market segments. We next define the corresponding trading phases and return measures that underlie our empirical design.

3. Data and variable construction

Our baseline universe consists of S&P 500 constituents from October 2008 through December 2023. Index membership is updated on a daily basis to avoid survivorship and look-ahead bias. We use one-minute trade bars from Algoseek as transaction prices. The data cover the regular session as well as extended-hours trading (16:00-20:00 and 04:00-09:30 ET).[2] We account for corporate actions (e.g., stock splits and dividends) using LSEG Datastream's adjustment factors and total return series. Furthermore, we exclude odd-lot trades (i.e., trades with fewer than 100 shares). Consistent with the institutional environment described in Section 2, we base our analysis on executed transaction prices rather than quotes.[3] Transaction prices therefore provide the relevant basis for measuring phase-specific returns and trading costs.

In Figure 1 we partition each 24-hour trading day into four non-overlapping phases. The regular market runs from 09:30 to 16:00 (New York time). The after-market runs from 16:00 to 20:00.

[2]Algoseek minute bars are constructed from the consolidated SIP (CTA/UTP) feed and report one-minute aggregates (prices, volume, and trade counts). We use the NoFINRA bars, which exclude FINRA TRF prints, so that our extended-hours measures reflect on-exchange (lit) executions rather than off-exchange trades subsequently reported to FINRA.

[3]Displayed quotes outside regular trading hours are not uniformly protected or directly comparable across venues (U.S. Securities and Exchange Commission, 2005; FINRA, 2014a,b, 2024).

The pre-market session runs from 04:00 to 09:30. The remaining interval, 20:00 to 04:00, is labeled the *dark* period, reflecting the absence of exchange trading activity for most securities.

- Insert Figure 1 here -

Let $P_{i,t}^{\mathrm{A,last}}$ denote the last transaction price for stock i in the after-market session on calendar day t, and let $P_{i,t+1}^{\mathrm{P,first}}$ denote the first transaction price in the pre-market session on day $t{+}1$. We use these as close/open proxies for extended-hours measurement. Following Figure 2, we define:

- Insert Figure 2 here -

$$r_{i,t}^{\mathrm{after}} = \ln\left(\frac{P_{i,t}^{\mathrm{A,last}}}{P_{i,t}^{\mathrm{reg,close}}}\right), \tag{1}$$

$$r_{i,t}^{\mathrm{dark}} = \ln\left(\frac{P_{i,t+1}^{\mathrm{P,first}}}{P_{i,t}^{\mathrm{A,last}}}\right), \tag{2}$$

$$r_{i,t+1}^{\mathrm{pre}} = \ln\left(\frac{P_{i,t+1}^{\mathrm{reg,open}}}{P_{i,t+1}^{\mathrm{P,first}}}\right), \tag{3}$$

where $P_{i,t}^{\mathrm{reg,close}}$ is the regular-session close and $P_{i,t+1}^{\mathrm{reg,open}}$ is the first regular-session trade (09:30). The standard close-to-open overnight return is then

$$r_{i,t+1}^{\mathrm{ON}} = \ln\left(\frac{P_{i,t+1}^{\mathrm{reg,open}}}{P_{i,t}^{\mathrm{reg,close}}}\right) = r_{i,t}^{\mathrm{after}} + r_{i,t}^{\mathrm{dark}} + r_{i,t+1}^{\mathrm{pre}}. \tag{4}$$

Throughout, returns are computed in log form. In the empirical sections that follow, we report both time-series averages and cross-sectional patterns using these phase-specific components.

With these definitions in place, we can first quantify how thin markets are outside the regular session.

4. Extended-hours Liquidity and Trading Activity

We begin by characterizing the liquidity and participation environment in extended-hours trading. Although extended-hours price formation has become economically relevant, systematic evidence on the timing and intensity of participation across these sessions remains limited. Extended-hours trading is economically meaningful but thin: participation is intermittent and highly concentrated near the boundaries of regular trading, so the overnight window combines brief periods of activity with long transaction-silent intervals. We first document the incidence of trading during extended hours. Table 1 reports off-hours coverage of trading activity across coarse after-market and pre-market time bins. Many stock-nights exhibit no trading outside regular hours. On average, 61.3% of stocks register at least one after-market trade per night and 51.3% at least one pre-market trade. Only 22.7% (25.4% in the last five years) trade in both sessions within the same overnight interval. Conditional on trading occurring, activity is disproportionately concentrated in bins close to the regular session rather than evenly spread across extended hours.

- Insert Table 1 here -

We next examine the intensity of trading conditional on session activity. Table 2 reports dollar volume, the number of trades, and average trade size across fixed time bins. Trading activity is low in levels and highly uneven within the session: both dollar volume and trade counts rise sharply as 09:30 approaches, whereas early pre-market bins exhibit substantially less activity. This steep time-of-day gradient suggests that the cost of immediacy (and price impact) is likely higher early in the pre-market and declines as liquidity and competition build toward the open. A salient after-market feature is the first post-close bin (16:01-16:10), where mean trade notional is about \$10 million. Because our NoFINRA bars exclude TRF prints, this spike is most plausibly driven by large on-exchange executions tied to the closing auction and the immediately following post-close

matching window (Nasdaq, Inc., 2023, 2024; NYSE, 2021b). Participation is thin outside regular hours (Barclay and Hendershott, 2003; U.S. Securities and Exchange Commission, 2011; FINRA, 2024). As a result, a small number of such large prints mechanically inflates average trade size; mean notional then declines sharply toward 20:00 and converges to pre-market levels.

- Insert Table 2 here -

Figure 3 plots average extended-hours volume and reveals a pronounced concentration in narrow time intervals. After-market activity is front-loaded, with elevated volume immediately after 16:00 ET that then declines sharply. In the pre-market, volume is sparse before 07:00 ET and rises stepwise thereafter, with pronounced spikes around 07:00 and 08:00 ET, consistent with broker access windows that channel retail participation into discrete start times (NYSE, 2023; U.S. Securities and Exchange Commission, 2011). A further spike at 08:30 ET aligns with scheduled U.S. macroeconomic releases and coincides with a temporary increase in trading intensity (Andersen et al., 2007; U.S. Bureau of Labor Statistics, 2023). Volume increases sharply up to 09:29. Taken together with Tables 1 and 2, extended-hours prices are formed in a market characterized by (i) long transaction-silent stretches and (ii) trading clustered near regular-session boundaries.

- Insert Figure 3 here -

This evidence implies that extended-hours price formation occurs in a thin and highly time-varying liquidity environment. In such a setting, the first transaction after a transaction-silent interval may embed a liquidity compensation rather than pure information.

We now quantify how this institutional environment shapes the structure of close-to-open returns by decomposing the overnight return into its after-market, dark, and pre-market components and analyzing how these segments interact.

5. Overnight Return Decomposition

We begin by decomposing the close-to-open return into the after-market, dark, and pre-market components defined in Section 3. Figure 4 reports the cumulative contribution of each segment to overall overnight performance.

Two patterns stand out in both the equal-weighted and value-weighted portfolios. First, the after-market component is economically meaningful, indicating that a nontrivial fraction of overnight returns accrues immediately after the regular-session close. Second, and more strikingly, the dark and pre-market components display a persistent sign split: On average, dark returns are positive, while pre-market returns are negative. The two series diverge systematically, implying that economically meaningful overnight price changes are formed in segments that partially offset each other.

In point-estimate terms, the average dark return is approximately +5 bps per day, whereas the average pre-market return is approximately −5 bps per day. Table 3 complements the graphical evidence by summarizing average returns across return components. The magnitude and persistence of the sign split are difficult to attribute to information shocks. Instead, they are consistent with a liquidity compensation. When trading resumes after a transaction-silent interval, liquidity providers face elevated inventory and adverse-selection risk and therefore require wider spreads in extended hours (Cui and Gozluklu, 2019; Eaton et al., 2025; FINRA, 2014a; U.S. Securities and Exchange Commission, 2011). If the first pre-market trade is buyer-initiated, the execution price embeds a liquidity premium, generating a positive measured dark return even absent new fundamental information. As liquidity and participation increase toward the open, this liquidity premium is partially unwound, producing a negative average pre-market return. This mechanism predicts that the dark–pre-market offset should be strongest when pre-market liquidity is thin.

To test this prediction, we sort stock-days into quintiles based on pre-market dollar volume and examine how the relation between dark and subsequent pre-market returns varies with liquidity. Figure 5 reports this relation separately by quintile.

- Insert Figure 5 here -

The negative association between pre-market and dark returns is strongest when pre-market dollar volume is low and attenuates as pre-market volume increases, consistent with the idea that deeper pre-market trading mitigates price pressure and subsequent reversion. The slope of the dark–pre-market relation is steeply negative in the lowest liquidity quintile: large positive (negative) dark returns are followed by pronounced negative (positive) pre-market moves, implying near-complete offset by the open. In contrast, in the highest-volume quintile the slope is close to zero. When liquidity is ample, the first pre-market print tends to occur near the last after-market price, and subsequent price changes fluctuate around that level rather than reversing a prior liquidity premium.

Overall, the decomposition and liquidity-sorting evidence show that pre-market trading both reverses liquidity-induced overshoots and contributes materially to overall overnight price formation. This raises a complementary question central to our competing hypotheses: At what clock times does cross-sectional variation in close-to-open returns become observable in transaction prices?

6. Timing of Price Discovery

We trace the timing of overnight price discovery by measuring how the cross-sectional explanatory power of cumulative close-to-τ returns for the corresponding overnight return evolves over extended hours. Our identification exploits the mapping between clock time and trading environments. Competing narratives imply sharply different patterns for the evolution of cross-sectional

explanatory power over the extended-hours window. The first narrative is an international-markets channel. Under this view, U.S. overnight returns primarily reflect information revealed in foreign markets while U.S. equities are closed. Using near-24-hour E-mini S&P 500 futures, Bondarenko and Muravyev (2023) document that average night returns concentrate around the European open (23:30 -03:30 ET), suggesting that international trading drives off-hours U.S. price adjustment. If this mechanism dominates at the stock level, explanatory power should exhibit a discrete increase at the first trade after 04:00 AM, rather than accumulate gradually over the pre-market window.

H1 (International-markets channel): *Overnight returns are mainly driven by price discovery in international markets that are open while U.S. equity markets are closed.*

The second narrative is an opening-auction channel. Here, overnight returns arise from order imbalances and limited depth at the regular-session open. Berkman et al. (2012) argue that measured overnight returns largely reflect inflated opening prices linked to retail demand. Consistent with this mechanism, Lou et al. (2019) provide evidence consistent with retail-like (small) trades clustering near the open (09:30), while institutional (large) trades are more concentrated near the close. If opening-auction imbalances are the primary driver, cross-sectional variation in overnight returns should remain largely unreflected in pre-market transaction prices and materialize predominantly at the opening auction, implying a discrete increase in explanatory power at 09:30.

H2 (Opening-auction channel): *Overnight returns are driven by price formation frictions at the regular-session open, in particular order imbalances at 09:30.*

The two hypotheses generate distinct predictions for the time path of cross-sectional explanatory power. If international trading drives overnight price formation, explanatory power should jump discretely at 04:00. If trading starts later, the jump should occur at the first pre-market trade,

reflecting the incorporation of information revealed in European markets. If instead overnight returns are primarily driven by opening-auction imbalances, explanatory power should exhibit a discrete increase at the regular-session open. To discriminate between these narratives, we construct a time-resolved cross-sectional explanatory-power measure. For each trading day t and cutoff time τ within extended hours, we compute the cumulative return from the regular-session close to τ. We then estimate a daily cross-sectional regression of the full close-to-open return on this cumulative return and record the associated $R^2(\tau)$. Averaging $R^2(\tau)$ across days yields the mean explanatory-power path over time. By construction, $R^2(09{:}30) = 1$.

Figure 8 shows that the mean $R^2(\tau)$ rises gradually throughout the pre-market rather than exhibiting a discrete jump either at the first pre-market trade or at the regular-session open (09:30). No individual time interval accounts for a disproportionate share of the eventual cross-sectional variation. Instead, explanatory power accumulates smoothly as trading activity and liquidity intensify toward the regular-session open. This pattern is difficult to reconcile with a discrete international-news mechanism. If stock-level overnight returns were primarily driven by information revealed at specific foreign market opens, we would expect step-like increases in $R^2(\tau)$ aligned with those clock times, with the increases occurring primarily at the first pre-market trades. Likewise, the data reject a pure opening-auction mechanism: explanatory power is already substantial prior to 09:30. Conditioning on the timing of the first observed pre-market trade further sharpens this interpretation. Securities that begin trading earlier in the pre-market exhibit an earlier and smoother rise in explanatory power. The timing of observability thus shifts with participation and liquidity, consistent with information being incorporated gradually as trading resumes, rather than materializing at a single point in time.

The evidence rejects both a purely international-news mechanism and a purely opening-auction mechanism. Overnight returns do not appear to be driven by discrete information arrivals during

specific foreign-market trading hours, nor do they materialize predominantly in a single adjustment at 09:30. Instead, the timing evidence points to a gradual valuation mechanism operating through extended-hours trading. Price formation unfolds continuously as trading resumes and liquidity deepens toward the open, implying that cross-sectional differences in overnight returns become observable sequentially rather than at a single clock time. The smooth rise in $R^2(\tau)$ is consistent with a gradual increase in investors' willingness to pay higher prices for a given level of earnings. Our sample (October 2008-2023) spans a period of pronounced multiple expansion, including large increases in the price-earnings ratio. In such a regime, variation in close-to-open returns plausibly reflects ongoing reassessments of discount rates and risk premia. Consistent with this interpretation, $R^2(\tau)$ rises smoothly as participation broadens and depth builds toward the open, indicating that valuation changes become observable in transaction prices as trading resumes.

7. Conclusion

This paper revisits overnight returns by decomposing the close-to-open window into distinct trading environments and tracing when cross-sectional variation in overnight returns becomes reflected in transaction prices. First, the conventional overnight return masks a systematic sign split between the dark and the pre-market segments. On average, dark returns are positive, whereas pre-market returns are negative. This "scissor-like" pattern is consistent with a liquidity compensation in thin extended-hours markets: the first transaction after a trading-silent interval embeds a cost-of-immediacy component that partially reverses when participation and depth increase at the regular-session. Second, this reversal is strongly state-dependent. The negative relation between dark and subsequent pre-market returns is most pronounced when pre-market volume is low and attenuates monotonically as pre-market liquidity increases. Third, price discovery is pulled forward into the pre-market. The cross-sectional explanatory power of cumulative close-to-τ re-

turns for the corresponding overnight return rises smoothly throughout the pre-market window. If overnight returns primarily reflected information revealed during foreign-market trading hours while U.S. markets are closed, explanatory power should increase discretely when pre-market trading resumes at 04:00, or at the first pre-market print when trading starts later. Likewise, if overnight returns were primarily shaped by opening-auction imbalances, explanatory power should exhibit a dominant jump at 09:30. Neither pattern is present in the data. This evidence rejects both a purely international-markets mechanism and a purely opening-auction mechanism: cross-sectional variation in overnight returns becomes observable gradually rather than materializing at a single clock time. Taken together, these findings point to a valuation mechanism operating in a thin and time-varying liquidity environment. Overnight returns reflect valuation adjustments that become impounded into transaction prices as and when trades occur. During our sample period (October 2008-December 2023), which coincides with substantial expansion in aggregate price-earnings multiples, variation in discount rates and risk premia was economically important. Such valuation changes are unlikely to be incorporated in a single coordinated event. Instead, they are gradually revealed through trading as participation broadens toward the regular-session open. Our results suggest that the overnight return is not a single informational object but rather the equilibrium outcome of price formation across heterogeneous trading regimes.

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Table 1: Off-hours trading coverage and time-bin activity: full sample versus last five years

This table reports stock-day statistics for trading activity outside regular hours. The left block covers the full sample (October 2008-December 2023) and the right block reports the last five years (January 2019-December 2023). Off-hours trading comprises pre-market transactions between 04:00 and 09:29 and after-hours transactions between 16:01 and 20:00 ET. Panel A reports coverage and the number of trade-active one-minute intervals outside the regular session. The first rows report the fraction of stock-days with at least one pre-market trade, at least one after-market trade and at least one trade in both sessions during the same overnight interval. The remaining rows report the number of one-minute intervals with at least one trade per stock-day, reported for all stock-days and conditional on activity in the respective off-hours session. Panel B reports the share of active pre-market and active after-market stock-days with at least one active minute in the respective time-of-day interval. Entries report cross-sectional means and standard deviations of indicator variables. N denotes the number of stock-day observations.

	2008-10-01 to 2023-12-31			2019-01-01 to 2023-12-31		
Variable	N	Mean	SD	N	Mean	SD
Panel A: Coverage and trading minutes outside the regular session						
Share of stock-days with at least one pre-market trade	1,835,257	0.513	0.500	608,772	0.594	0.491
Share of stock-days with at least one after-hours trade	1,120,857	0.613	0.487	415,541	0.544	0.498
Share of stock-days with at least one trade in both the pre-market and the after-hours (same night)	1,835,257	0.227	0.419	608,772	0.254	0.435
Pre-market minutes with trades per stock-day (all days)	1,835,257	6.738	21.661	608,772	9.700	29.116
Pre-market minutes with trades per active stock-day	942,176	13.124	28.811	361,766	16.324	36.311
After-hours minutes with trades per stock-day (all days)	1,120,857	7.516	20.584	415,541	8.748	24.506
After-hours minutes with trades per active stock-day	686,971	12.263	25.161	225,881	16.093	31.409
Panel B: Trading activity across pre- and after-hours time bins (≥ 1 active minute)						
Share of active pre-market days with at least one trade in 04:00–06:59	942,176	0.214	0.410	361,766	0.336	0.472
Share of active pre-market days with at least one trade in 07:00–07:59	942,176	0.352	0.478	361,766	0.506	0.500
Share of active pre-market days with at least one trade in 08:00–08:59	942,176	0.599	0.490	361,766	0.586	0.493
Share of active pre-market days with at least one trade in 09:00–09:29	942,176	0.840	0.367	361,766	0.839	0.368
Share of active pre-market days with at least one trade at 09:29	942,176	0.540	0.498	361,766	0.579	0.494
Share of active after-hours days with at least one trade at 16:01	686,971	0.323	0.468	225,881	0.202	0.402
Share of active after-hours days with at least one trade in 16:01–16:10	686,971	0.802	0.398	225,881	0.720	0.449
Share of active after-hours days with at least one trade in 16:11–16:45	686,971	0.648	0.477	225,881	0.665	0.472
Share of active after-hours days with at least one trade in 16:46–19:45	686,971	0.743	0.437	225,881	0.842	0.364
Share of active after-hours days with at least one trade in 19:46–20:00	686,971	0.264	0.441	225,881	0.345	0.475

Table 2: Pre- and after-market trading volume, number of trades, and dollar trade size by fixed time bins

This table reports stock-day cross-sectional statistics for (i) dollar trading volume, (ii) number of trades, and (iii) dollar trade size (USD per trade) across fixed pre-market and after-market time bins over October 2008-December 2023. Pre-market rows report activity between 04:00 and 09:29 ET, with the 09:30 minute reported separately. After-market rows report activity between 16:01 and 20:00 ET on calendar day $t-1$, aligned to stock-day t; the 16:00 minute is reported separately. Entries report cross-sectional means and standard deviations across stock-days. N denotes the number of non-missing stock-day observations.

Variable	N	Mean	SD
Panel A: Pre- and after-market trading volume (USD)			
Pre-market total volume (USD)	984,264	1,992,595.739	17,967,932.211
04:00-06:59 volume (USD)	984,264	136,432.511	2,249,129.640
07:00-07:59 volume (USD)	984,264	339,538.040	4,111,205.664
08:00-08:59 volume (USD)	984,264	788,360.932	7,971,895.647
09:00-09:29 volume (USD)	984,264	728,264.256	5,886,299.091
09:30 volume (USD)	984,264	7,279,335.530	26,656,488.599
16:00 volume (USD)	1,471,019	17,662,506.700	72,981,651.804
After-market total volume (USD)	1,471,019	11,855,224.780	59,024,372.327
16:01-16:10 volume (USD)	1,471,019	11,043,652.410	54,115,853.998
16:11-16:45 volume (USD)	1,471,019	366,277.902	12,474,491.983
16:46-19:45 volume (USD)	1,471,019	417,480.292	11,277,103.177
19:46-20:00 volume (USD)	1,471,019	27,814.176	414,105.127
Panel B: Pre- and after-market number of trades			
Pre-market total number of trades	984,264	96.361	835.658
04:00-06:59 number of trades	984,264	5.021	66.229
07:00-07:59 number of trades	984,264	12.965	150.799
08:00-08:59 number of trades	984,264	40.168	419.560
09:00-09:29 number of trades	984,264	38.207	317.334
09:30 number of trades	984,264	108.543	250.290
16:00 number of trades	1,471,019	122.235	188.197
After-market total number of trades	1,471,019	34.198	577.432
16:01-16:10 number of trades	1,471,019	6.756	118.433
16:11-16:45 number of trades	1,471,019	11.775	248.539
16:46-19:45 number of trades	1,471,019	14.703	278.480
19:46-20:00 number of trades	1,471,019	0.964	9.462
Panel C: Pre- and after-market dollar trade size (USD per trade)			
Pre-market total dollar trade size (USD per trade)	672,009	19,441.408	140,942.721
04:00-06:59 dollar trade size (USD per trade)	128,972	22,431.199	39,443.153
07:00-07:59 dollar trade size (USD per trade)	244,029	22,395.086	40,172.357
08:00-08:59 dollar trade size (USD per trade)	447,470	19,859.448	84,733.286
09:00-09:29 dollar trade size (USD per trade)	610,861	19,790.676	160,947.316
09:30 dollar trade size (USD per trade)	984,264	196,527.502	914,714.977
16:00 dollar trade size (USD per trade)	1,471,019	9,311,427.812	32,670,255.271
After-market total dollar trade size (USD per trade)	1,471,019	5,911,523.942	13,261,976.925
16:01-16:10 dollar trade size (USD per trade)	1,224,488	9,996,042.659	20,818,471.935
16:11-16:45 dollar trade size (USD per trade)	507,541	61,959.998	3,101,736.630
16:46-19:45 dollar trade size (USD per trade)	586,031	22,417.377	181,044.416
19:46-20:00 dollar trade size (USD per trade)	192,649	21,393.833	42,737.130

Table 3: Segment-level returns across trading sessions

This table reports cross-sectional distributional statistics for stock-day returns across trading segments over October 2008-December 2023. Returns are expressed in basis points and computed as log price changes over the corresponding segment. The pre-market return is measured from the first pre-market trade to the regular-session open (04:00–09:30 ET), the after-market return from the regular-session close to the last after-market trade (16:00–20:00 ET), and the regular-session return from 09:30 to 16:00 ET. The overnight return is the standard close-to-open return. The dark return is the return from the last observed after-market transaction price to the first observed pre-market transaction price on the following trading day; in the baseline case, this is the return from the last after-market trade on day $t-1$ to the first pre-market trade on day t. The rows "Dark return with no after-market," "Dark return with no pre-market," and "Dark return with no after- & no pre-market" report the corresponding return when one or both surrounding extended-hours segments are missing. If the after-market has no trades, the regular-session close is used as the last observed price; if the pre-market has no trades, the regular-session open is used as the first observed price; if both are missing, the dark return reduces to the standard overnight return. N denotes the number of non-missing stock-day observations. Means, standard deviations, and percentiles are computed across stock-days.

Variable	N	Mean	SD	5%	25%	Median	75%	95%
Total return (bps)	1,871,895	3.21	244.81	-317.17	-87.27	6.60	98.84	309.56
Regular session return (bps)	1,871,895	1.24	191.39	-267.77	-79.10	3.68	84.63	259.99
Overnight return (bps)	1,871,895	1.97	152.86	-164.33	-39.02	4.17	46.87	158.94
After-market return (bps)	1,423,367	0.92	92.25	-52.66	-4.17	0.00	5.78	56.54
Dark return (bps)	762,341	5.02	301.26	-164.31	-36.43	4.34	50.14	167.67
Dark return with no after-market (bps)	187,204	5.12	165.88	-141.38	-34.11	3.68	47.84	146.93
Dark return with no pre-market (bps)	661,029	2.34	125.28	-123.94	-32.37	3.60	39.55	121.33
Dark return with no after- & no pre-market (bps)	261,333	2.71	76.03	-106.98	-30.28	3.42	37.73	108.58
Pre-market return (bps)	949,536	-4.91	270.68	-162.19	-42.74	-2.01	35.75	141.73

Figure 1: Trading phases and the overnight window.

This figure shows the partition of the trading day into the regular session (09:30-16:00 ET), the after-market session (16:00-20:00 ET), a transaction-silent dark interval (20:00-04:00 ET), and the pre-market session (04:00-09:30 ET). The overnight window extends from the regular-session close to the next regular-session open and comprises after-market trading, the dark interval, and pre-market trading.

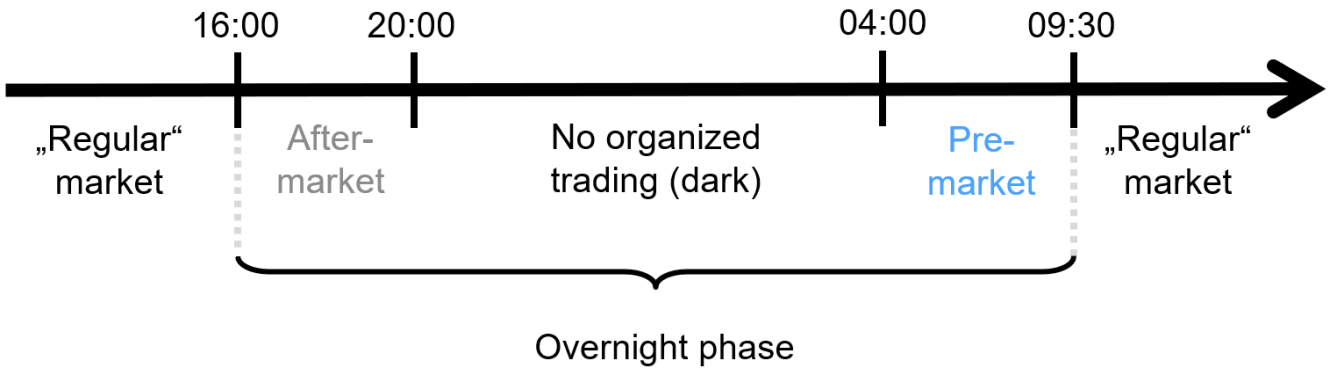

Figure 2: Return decomposition across after-market, dark, and pre-market segments.

This figure illustrates the decomposition of the close-to-open (overnight) return into three components. The after-market return runs from the regular-session close (16:00 ET) to the last after-market transaction price. The dark return is the return from the last after-market trade to the first pre-market trade across the transaction-silent interval. The pre-market return runs from the first pre-market trade to the regular-session open (09:30 ET).

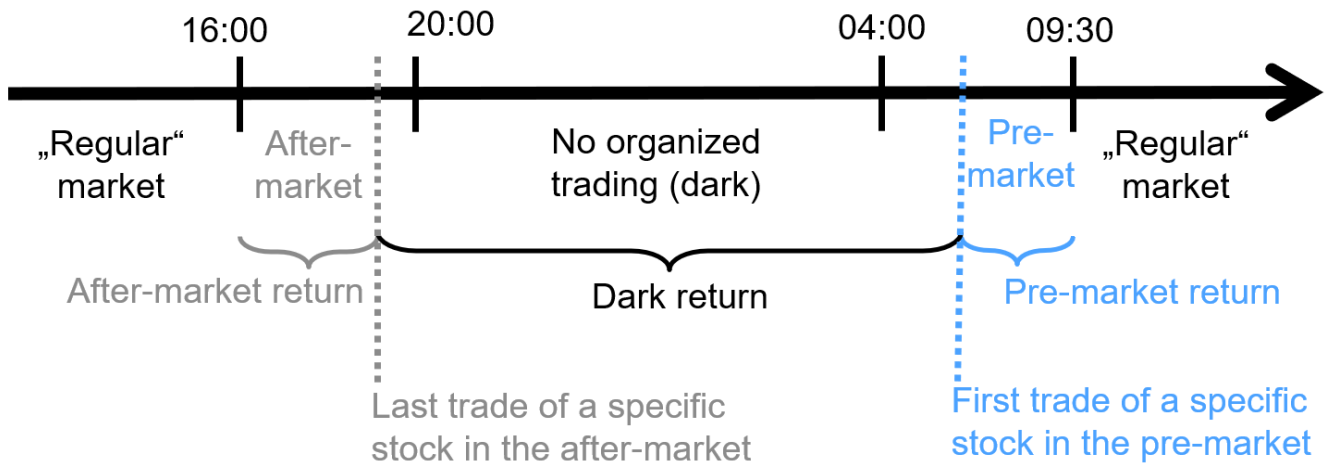

Figure 3: Aggregate one-minute trading volume during after-market and pre-market sessions.

This figure plots aggregate dollar trading volume at the one-minute frequency during after-market trading (16:01–20:00 ET) and pre-market trading (04:00–09:29 ET). For each minute, dollar volume is first summed across all sample stocks and then averaged across trading days. The left column reports the full sample (October 1, 2008-December 31, 2023) and the right column the last five years (January 1, 2019-December 31, 2023). The top panels correspond to the after-market session and the bottom panels to the pre-market session.

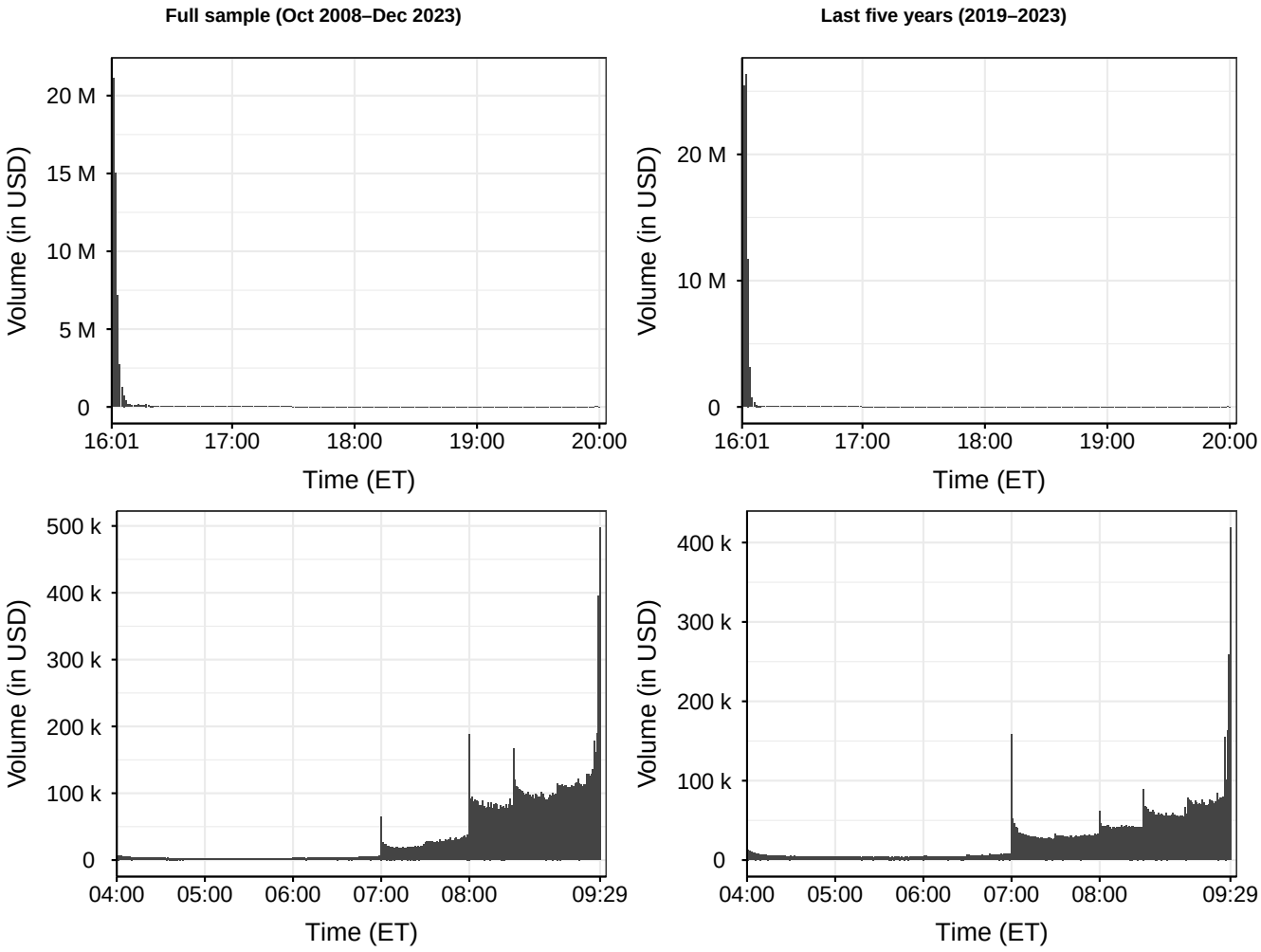

Figure 4: Day and night returns for equal-weighted and value-weighted portfolios.

This figure plots cumulative log returns for U.S. equities over the period October 1, 2008-December 31, 2023. The left column reports an equal-weighted portfolio of all sample stocks, and the right column the corresponding value-weighted portfolio. The top row shows cumulative log returns during the regular trading session ("Day"), the overnight period ("Night"), and the full 24-hour period ("Total"). The bottom row decomposes overnight returns into the pre-market ("Pre", 04:00-09:29), after-market ("After", 16:01–20:00), and dark-period ("Dark") components. All series are cumulative log returns (not expressed in percent).

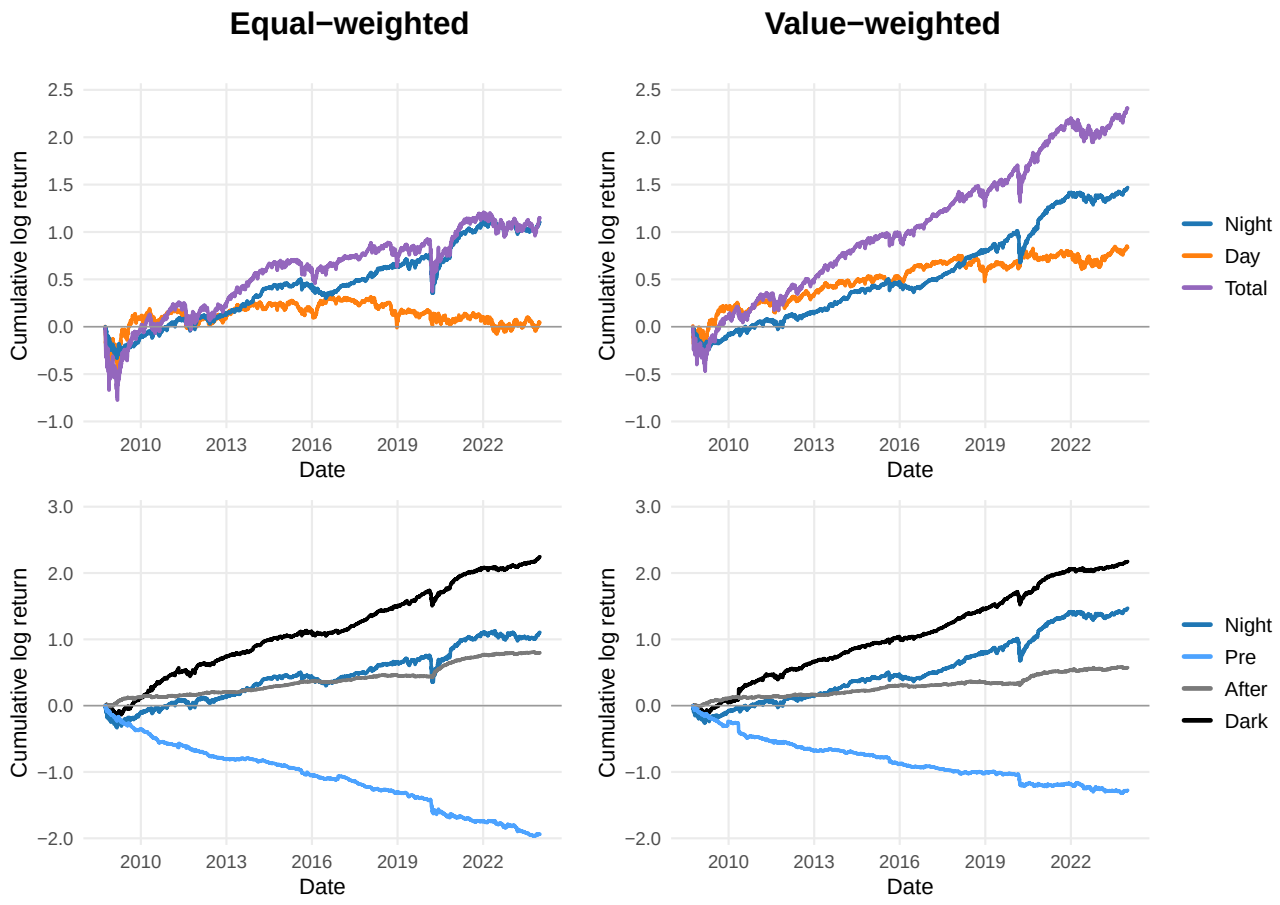

Figure 5: Dark returns and subsequent pre-market returns by pre-market volume.

This figure plots the relation between the dark return, $r_{dark,t} = \ln(P_t^{P,first}/P_{t-1}^{A,last})$, and the subsequent pre-market return, $r_{pre,t} = \ln(P_{open,t}/P_{pre,t})$. The top-left panel reports the full sample of S&P 500 stock-days over the sample period. The remaining panels report the same relation separately for quintiles Q_1–Q_5 of the cross-sectional distribution of pre-market dollar volume, from the lowest to the highest pre-market volume days. Each dot represents one stock-day observation, and the solid line shows the fitted OLS relation within the respective subsample. Observations with $|r_{dark,t}| \geq 20\%$ or $|r_{pre,t}| \geq 20\%$ are excluded.

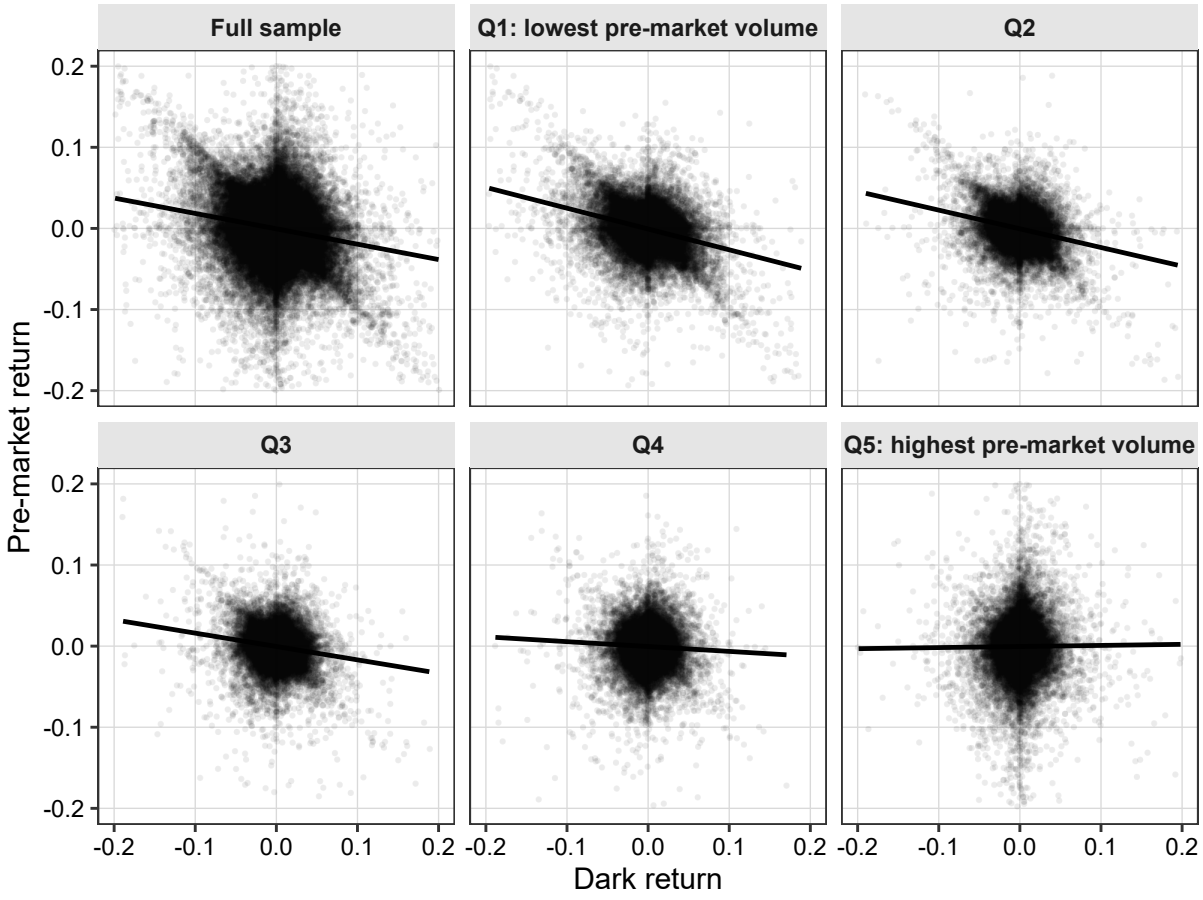

Figure 6: H1: International-markets channel (schematic).

This schematic depicts the hypothesis that overnight price discovery in U.S. equities is driven by information revealed during foreign market trading hours. Under this view, the cross-sectional explanatory power of cumulative close-to-τ returns for the full close-to-open return should increase discretely when pre-market trading resumes at 04:00 or at the first trade thereafter if trading starts later, rather than rising smoothly throughout the pre-market window.

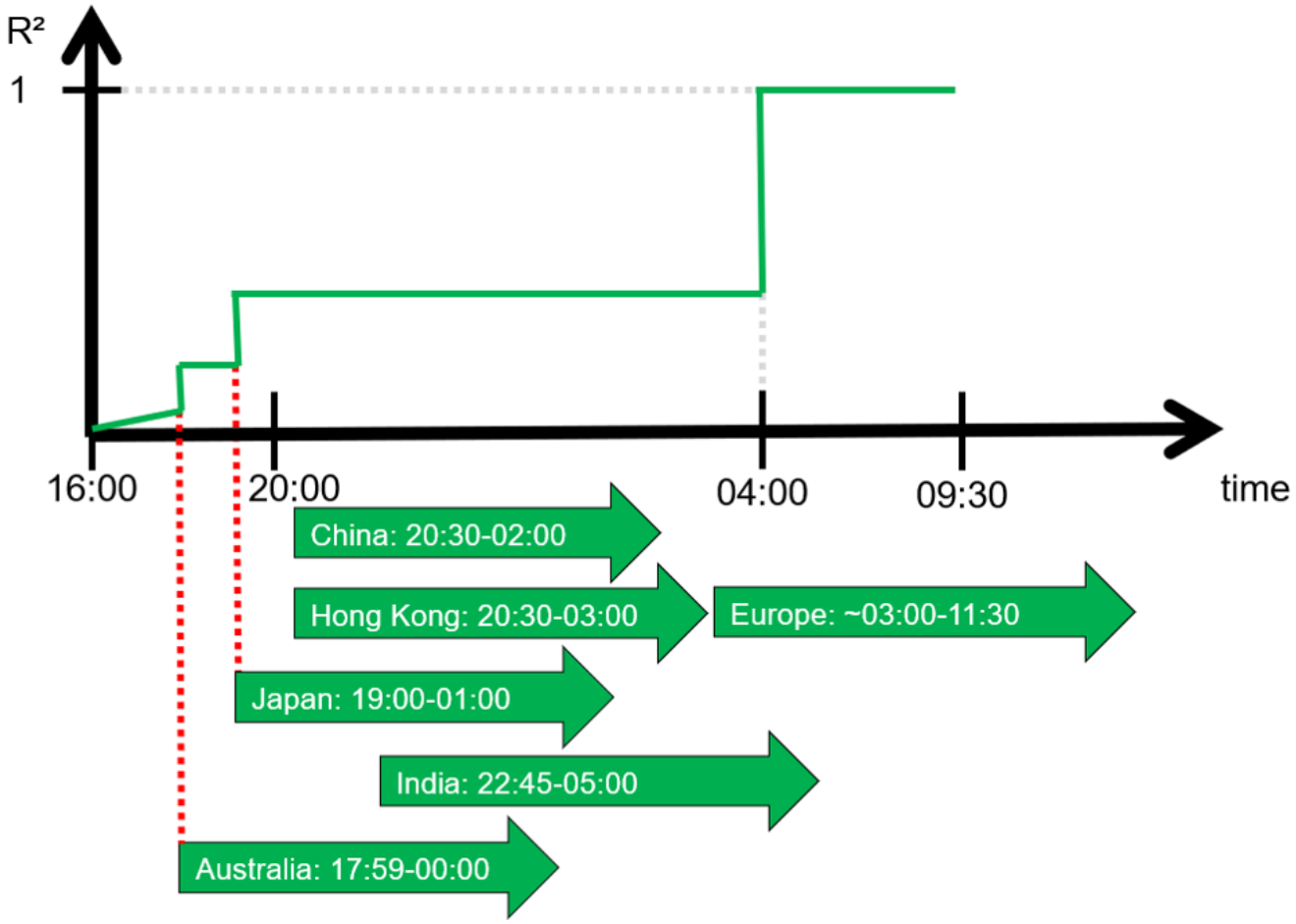

Figure 7: H2: Opening-auction channel (schematic).

This schematic illustrates the hypothesis that most overnight price discovery is not reflected in transaction prices until the regular-session open. Under this view, cumulative close-to-τ returns should explain little of the full close-to-open return throughout extended hours, and cross-sectional explanatory power should increase discretely at 09:30 when the opening auction occurs and regular-session liquidity and participation return.

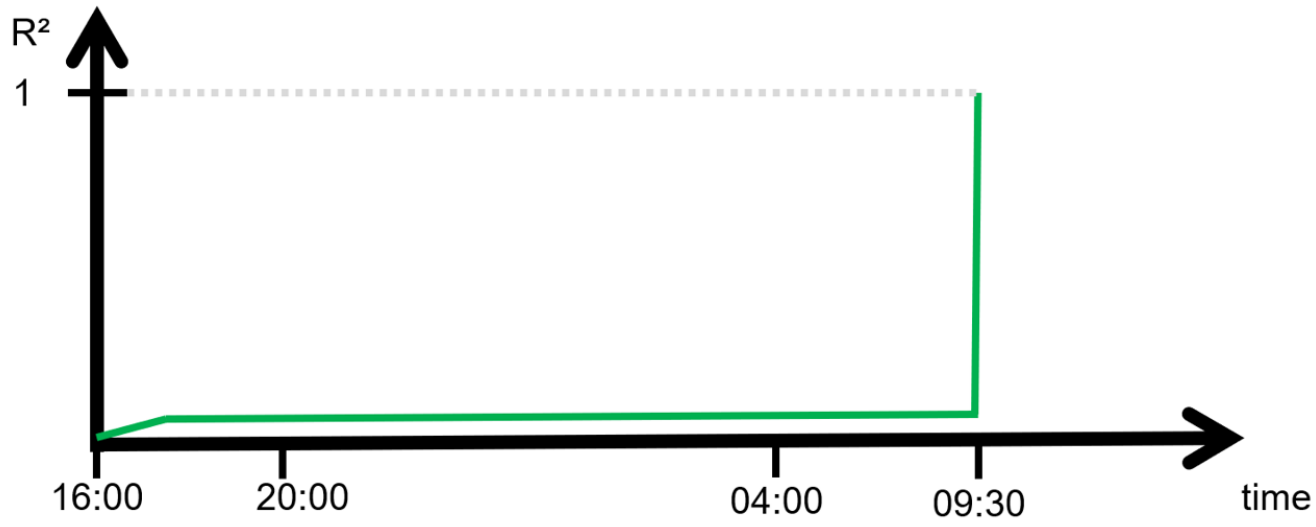

Figure 8: Cross-sectional R^2 paths over the overnight window with mid-interval dark knots.

This figure plots the evolution of cross-sectional explanatory power over the overnight window. For each day t and stock i, the overnight return is defined as $r_{night,i,t} = \ln(P_{open,i,t}/P_{close,i,t-1})$. For each clock-time horizon $\tau \in \{16{:}10, 16{:}45, 19{:}45, 20{:}00, 06{:}59, 07{:}59, 08{:}59, 09{:}29, 09{:}30\}$, we estimate a daily cross-sectional regression of the overnight return on the cumulative return from the regular-session close to time τ: $r_{night,i,t} = \alpha_t(\tau) + \beta_t(\tau)\, r_{close\to\tau,i,t} + \varepsilon_{i,t}(\tau)$. The figure reports the mean daily $R^2(\tau)$ across days. Lines correspond to groups of stocks defined by the time of the first observed pre-market trade. Because the residual unobserved overnight move (the dark component) becomes observable at different times across these groups, the figure does not place a separate dark tick on the x-axis. Instead, a mid-interval knot, indicated by a dashed vertical guide, marks the point at which the dark component becomes observable for the respective group. Shaded bands report the interquartile range of the daily cross-sectional $R^2(\tau)$.