

Monetary Policy Transmission and Environmental Performance: Firm-level Evidence from High-Frequency Identification^{*}

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Abstract

Firms with superior environmental performance exhibited substantial vulnerability to forward guidance shocks before 2015, but this vulnerability disappeared completely by 2017. Using high-frequency identification around 156 FOMC announcements spanning 2005–2025, we document that path surprises shifting long-horizon discount rates generated differential returns of 1.96 percentage points per standard deviation shock during the pre-Paris period, but this effect attenuated to economic and statistical insignificance post-2016. The structural break coincides precisely with explosive growth in green bond markets—expanding from £11 billion in 2013 to over £625 billion annually by 2024—and Paris Agreement implementation. Industry-by-event fixed effects isolate within-sector heterogeneity, while horizon decomposition reveals duration effects amplified forward guidance sensitivity pre-Paris and clientele effects provided modest current rate insulation throughout. Cross-sectional evidence indicates larger firms with superior market access exhibited attenuated vulnerability throughout, consistent with hedging capacity mechanisms. Results demonstrate environmental heterogeneity in monetary transmission evolved with financial market development rather than reflecting immutable technological constraints.

Keywords: Monetary policy transmission, Environmental performance, ESG, High-frequency identification, Green bonds, Asset pricing

JEL Classification: G12, G14, E52, Q54, G11

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1. Introduction

How does monetary policy transmit across firms with different environmental characteristics? [Schnabel \(2021\)](#) articulates this concern explicitly, warning that anti-inflationary tightening could “discourage efforts to decarbonise our economies rapidly” by raising financing costs precisely for the long-duration renewable infrastructure investments essential to climate transition. Whether this differential transmission represents an immutable technological constraint or instead reflects features of financial markets that evolve with institutional development remains an open empirical question. If market deepening provides access to hedging instruments, firms might neutralise duration exposure despite unchanged technological characteristics. Understanding this distinction matters for three constituencies. Central banks modelling aggregate transmission must account for composition effects if sustainable investments respond differently to policy signals. Investors managing portfolios with sustainability mandates require precise understanding of how environmental characteristics interact with monetary shocks. Policymakers assessing financial stability implications of the green transition need evidence on whether sustainable investment amplifies or dampens macroeconomic policy pass-through.

Two competing theoretical mechanisms could generate heterogeneous monetary policy transmission across firms with different environmental characteristics, operating through distinct economic channels and predicting opposing effects. The first mechanism centres on investor clientele effects. If investors with environmental preferences hold positions for non-pecuniary reasons or to hedge climate concerns, their demand proves relatively insensitive to changes in discount rates induced by monetary shocks ([Pástor, Stambaugh, and Taylor 2021](#), [Pedersen, Fitzgibbons, and Pomorski 2021](#)). Under this channel, environmentally strong firms benefit from stable, inelastic capital that provides insulation from interest rate fluctuations, analogous to the “neglected stock” effect documented by [Hong and Kacperczyk \(2009\)](#) where norm-constrained investors avoid sin stocks, creating distinct pricing dynamics. The alternative mechanism focuses on fundamental cash flow characteristics. Environmental investments exhibit systematically longer duration because renewable energy projects, transition investments, and sustainable business models generate revenues and profits heavily weighted towards distant horizons ([Bolton and Kacperczyk 2021](#)). This duration-based view predicts amplified transmission, particularly to shocks that shift long-horizon discount rates. Ex ante, the dominant mechanism remains ambiguous, and scalar measures of monetary policy surprises confound these opposing forces.

We resolve this ambiguity by decomposing monetary policy surprises into horizon-specific components following [Gürkaynak, Sack, and Swanson \(2005\)](#). Target surprises

capture unexpected current rate changes; path surprises reflect revisions to expected future trajectories. Duration effects operate through the path channel while clientele effects operate through the target channel. This decomposition proves essential for uncovering sustainability-related heterogeneity because duration vulnerability amplifies path sensitivity while clientele insulation attenuates target sensitivity. We study S&P 500 constituents over January 2005 through January 2025 using high-frequency identification around scheduled FOMC announcements. Industry-by-event fixed effects absorb variation common to firms within sectors on announcement dates, addressing information effects documented by [Nakamura and Steinsson \(2018\)](#). This isolates within-industry heterogeneity operating through environmental characteristics rather than differential exposures to central bank information about fundamentals.

Firms with superior environmental performance exhibited substantially greater vulnerability to contractionary forward guidance during 2005–2015. Path surprises shifting long-horizon discount rates generated larger negative returns for high-environmental firms relative to low-environmental firms within announcement windows. This pattern validates Schnabel’s policy concern and confirms that duration mechanisms dominated during this period. The pre-Paris vulnerability proved economically meaningful, reflecting the long-lived nature of environmental investments and their exposure to shifts in distant discount rates. Rolling window estimates reveal this path sensitivity peaked around 2011–2014, precisely when sustainable investment gained prominence but before mature financing markets developed.

This pre-Paris vulnerability attenuated completely after 2015–2016. Rolling window estimates show path sensitivity began declining during 2014–2016 and essentially disappeared by 2017–2018. Formal difference-in-differences tests reject coefficient stability across periods. The path coefficient for 2016–2025 is economically negligible and statistically indistinguishable from zero. This attenuation coincides with intensifying climate policy commitments, Paris Agreement negotiations began in 2014, culminating in the December 2015 accord and explosive growth in green bond markets from approximately £40 billion in 2015 to over £500 billion annually by the early 2020s. The timing and speed of attenuation are consistent with financial market development enabling firms to manage duration exposure that would otherwise create policy sensitivity.

The target channel shows modest insulation throughout the sample. High-environmental firms react slightly less to unexpected moves in the current policy rate, consistent with inelastic ESG-mandated capital tempering short-horizon demand shifts ([Zerbib 2022](#)). This target coefficient remains comparatively stable across both periods, suggesting clientele effects provided persistent but modest insulation while path vulnerability underwent dramatic transformation. The horizon-specific pattern path amplification

pre-Paris transforming to neutrality, target attenuation persisting—demonstrates that decomposing policy news proves essential for understanding environmental heterogeneity in transmission.

Cross-sectional evidence supports the hedging capacity interpretation. Size, our proxy for market access and treasury sophistication significantly mitigates pre-Paris path sensitivity. Larger firms with superior financing access faced attenuated path vulnerability throughout the sample, while smaller firms exhibited pronounced duration exposure. This size heterogeneity persisted in both regimes, suggesting firm-level financial sophistication continued mattering at the margin. However, the post-Paris attenuation operated as a market-wide repricing phenomenon. Path vulnerability essentially disappeared for firms across leverage and profitability profiles, though size-based differences in transmission levels persisted. This uniform attenuation across heterogeneous firms suggests green finance market development shifted investor pricing of environmental duration risk broadly, rather than simply expanding differential access to firm-specific hedging instruments.

We develop an equilibrium framework formalising how investor clienteles and cash flow duration interact with financial market depth to generate horizon-dependent and time-varying transmission. The model incorporates sustainable business models with longer cash flow duration alongside ESG-motivated investors subject to portfolio mandates, with time-varying access to green financing instruments. When climate policy becomes credible and green financing markets deepen, the model predicts firms can access enhanced hedging capacity to manage fundamental duration exposure even when underlying technology remains unchanged. The theoretical framework clarifies how the interaction between firm fundamentals and market structure determines transmission sensitivity, with duration exposure creating differential policy sensitivity when hedging instruments are unavailable. As markets deepen, firms gain tools for managing this exposure, transforming transmission patterns without changes to underlying technology.

Our contributions are threefold. Methodologically, we establish that decomposing monetary policy news into horizon-specific components proves essential for uncovering sustainability-related heterogeneity. Duration effects amplify path sensitivity while clientele effects attenuate target sensitivity; aggregate surprises obscure both channels. Empirically, we resolve *ex ante* ambiguity by documenting that duration mechanisms dominated pre-Paris, creating substantial path channel amplification that subsequently disappeared. This documents that environmental heterogeneity in monetary transmission is not technologically determined but instead represents an equilibrium outcome shaped by market structure. Theoretically, we clarify that transmission evolves with financial innovation and policy credibility. Duration exposure creates vulnerability when hedg-

ing instruments are unavailable; market development can provide tools enabling firms to manage this exposure. This challenges models treating ESG transmission effects as immutable structural features.

This paper connects two literatures that have developed largely independently: high-frequency identification of monetary policy effects and sustainable finance. The monetary transmission literature documents heterogeneous pass-through driven by financial constraints (Bernanke, Gertler, and Gilchrist 1999, Gertler and Karadi 2015), balance sheet strength (Ottonello and Winberry 2020), and liability structure (Ippolito, Ozdagli, and Perez-Orive 2018), but has not examined whether environmental characteristics generate distinct transmission mechanisms or whether such mechanisms evolve with market development. Our identification strategy builds on Kuttner (2001), Gürkaynak, Sack, and Swanson (2005), Swanson (2021), and Nakamura and Steinsson (2018). The horizon decomposition approach extends Gürkaynak, Karasoy-Can, and Lee (2022), who document that stock prices respond differentially to target and path surprises. Industry-by-event fixed effects ensure estimates capture within-industry heterogeneity through environmental characteristics rather than differential exposures to central bank information about fundamentals documented by Nakamura and Steinsson (2018).

The sustainable finance literature examines carbon risk premia (Bolton and Kacperczyk 2021, 2023), climate effects on asset prices (Bansal, Kiku, and Ochoa 2019), and clientele effects (Zerbib 2022). Pástor, Stambaugh, and Taylor (2021) and Pedersen, Fitzgibbons, and Pomorski (2021) develop equilibrium models where heterogeneous ESG preferences affect expected returns. Pástor, Stambaugh, and Taylor (2022) decompose green stock returns into cash flow news, discount rate news, and ESG preference shocks. These studies analyse cross-sectional return differences or lower-frequency patterns rather than responses to identified macroeconomic shocks, and existing frameworks do not incorporate evolving market structure. Hong and Kacperczyk (2009) document that “sin” stocks shunned by norm-constrained investors exhibit distinct pricing dynamics; we posit an analogous but inverse clientele phenomenon operates for high-environmental firms. Several recent papers examine differential effects of monetary policy on green and brown firms. Bauer, Offner, and Rudebusch (2024) analyse European markets from 2012-2023, documenting firms with higher carbon emissions exhibit greater ECB policy sensitivity in pooled samples that by construction cannot detect regime change. Döttling and Lam (2024) and Havrylchyk and Pourabbasvafa (2025) use US data, finding brown firms respond more strongly, attributing this to tangible capital and financing constraints. Patozi (2024) argues green investors’ inelastic demand reduces green stock sensitivity. Benchora, Leroy, and Raffestin (2025) examines European banks’ climate risk-taking channel. Our longer time series spanning 2005-2025 allows explicit testing of whether heterogeneity emerged

or strengthened with mainstreaming of sustainable investing, revealing structural breaks pooled estimates obscure.

The remainder of the paper proceeds as follows. Section 3 develops the theoretical framework linking duration, clientele effects, and time-varying market depth. Section 2 describes data construction including the high-frequency surprise decomposition and environmental performance measurement. Section 4 outlines the empirical strategy and identification approach. Section 5 presents baseline estimates, structural break tests, rolling window evidence, and cross-sectional heterogeneity analysis. Section 6 provides robustness checks including alternative specifications, sample variations, and placebo tests. Section 7 concludes.

2. Data

Our analysis combines high-frequency monetary policy surprises with firm-level stock returns and environmental performance measures for S&P 500 constituents during 2005–2025. The sample spans 156 scheduled Federal Open Market Committee (FOMC) announcements, encompassing diverse monetary policy regimes including the pre-crisis period, the zero lower bound era, policy normalisation, and the recent tightening cycle. After imposing data availability requirements for high-frequency returns, environmental ratings, and firm controls, the baseline sample comprises 51,534 firm-event observations across 460 unique firms and 156 FOMC announcements. We focus on S&P 500 constituents to ensure adequate liquidity for high-frequency identification, comprehensive environmental coverage, and sufficient cross-sectional variation within industries.

2.1 Sample Construction and Data Sources

We construct the sample using point-in-time S&P 500 index membership to avoid survivorship bias, including only firms that were constituents as of each FOMC announcement date. Starting from 160 scheduled FOMC meetings between January 2005 and January 2025, we exclude four meetings where insufficient trading activity in Treasury futures markets prevented reliable extraction of monetary policy surprises. The universe comprises 574 unique firms observed across 156 announcement dates with complete high-frequency data. We exclude unscheduled intermeeting policy actions to maintain clean identification focused on anticipated decision dates.

High-frequency stock returns are constructed from intraday transaction data obtained from Pi Trading and FirstRate Data, which consolidate trades from primary listing ex-

changes with timestamps synchronised to Eastern Time. Firm-level environmental, social, and governance (ESG) characteristics are obtained from LSEG Refinitiv, which evaluates firms annually on over 500 indicators aggregated into pillar-specific scores. Financial characteristics are obtained from LSEG financial databases. Table 1 presents comprehensive summary statistics for all variables.

TABLE 1. SUMMARY STATISTICS: ALL VARIABLES

Variable	Full Sample				By Period		
	Mean	SD	P50	Obs	Pre	Post	Diff.
<i>Panel A: Stock Returns and Market Indicators</i>							
Individual Firm Stock Return	0.023	0.709	0.021	83,561	0.039	0.006	-0.032
ES Mini Change	0.033	0.577	0.075	91,840	0.048	0.016	-0.032
S&P 500 Change	0.032	0.484	0.068	91,840	0.043	0.020	-0.023
VIX Change (%)	-1.157	3.157	-0.942	91,840	-1.328	-0.949	0.379
<i>Panel B: ESG Scores</i>							
ESG Score (Raw)	52.998	20.165	54.769	65,527	44.530	60.497	15.967
Environmental Score (Raw)	45.713	29.355	49.396	65,527	34.814	55.366	20.551
Social Score (Raw)	55.312	22.136	56.824	65,527	46.554	63.069	16.514
Governance Score (Raw)	56.827	21.499	59.069	65,527	51.504	61.542	10.038
ESG Score (Std.)	0.000	1.000	0.088	65,527	-0.420	0.372	0.792
Environmental Score (Std.)	0.000	1.000	0.125	65,527	-0.371	0.329	0.700
Social Score (Std.)	0.000	1.000	0.068	65,527	-0.396	0.350	0.746
Governance Score (Std.)	0.000	1.000	0.104	65,527	-0.248	0.219	0.467
<i>Panel C: Firm Characteristics</i>							
Log(Total Assets)	22.581	1.431	22.622	68,054	22.256	22.940	0.684
Book Leverage	0.448	0.472	0.412	84,270	0.404	0.497	0.093
Profitability (ROA)	0.125	2.130	0.151	68,934	0.117	0.135	0.018
Non-Dividend Payer (Dummy)	0.174	0.379	0.0000	91,840	0.157	0.195	0.038
<i>Panel D: Monetary Policy Surprises</i>							
Target GSS (bp)	0.000	0.026	0.002	89,544	-0.001	0.001	0.002
Path GSS (bp)	0.000	0.063	0.011	89,544	-0.016	0.018	0.034
Target HW Std. (bp)	-0.003	0.028	0.000	89,544	-0.004	-0.002	0.002
Path HW II Std. (bp)	0.000	0.090	0.002	89,544	-0.007	0.009	0.016
<i>Sample Composition</i>							
Firm-Event Observations		91,840			50,512	41,328	
Unique Firms		574					
FOMC Events		156			86	70	

Notes: Sample comprises S&P 500 firms across 156 FOMC announcements from January 2005 through January 2025. Pre-Paris: January 2005 to December 2015 (86 events). Post-Paris: January 2016 to January 2025 (70 events). Stock returns measured over 30-minute event windows (10 minutes before, 20 minutes after statement release), with 25-minute windows for 9 pre-March 2013 meetings with press conferences. Returns expressed in decimal form (0.01 = 1%). ESG scores standardised annually to have mean zero and unit variance within year. Target and Path surprises (GSS) computed via principal components following [Gürkaynak, Sack, and Swanson \(2005\)](#). Log(Total Assets) is natural logarithm of book assets. Book Leverage is total debt divided by total assets. Profitability (ROA) is operating income divided by total assets. P50 denotes median. Diff. shows Post-Paris minus Pre-Paris means.

Environmental data coverage expanded considerably during the sample period, growing from approximately 37 per cent of S&P 500 firms in 2005 to 97 per cent by 2025. This gradual expansion could raise sample selection concerns if early-rated firms differ systematically from those rated later. However, industry-by-event fixed effects absorb time-varying industry-level selection patterns, and coverage expansion occurred broadly across all major sectors. In robustness analysis (Section 6), we verify that results persist in a balanced panel restricted to firms continuously rated during 2010–2024, confirming that changing sample composition does not drive our findings.

2.2 High-Frequency Data and Monetary Policy Surprises

Stock returns are measured over a 30-minute window surrounding each FOMC announcement, specifically from ten minutes before the statement release to twenty minutes after. For announcements from March 2013 onwards (statement at 14:00 Eastern Time), this window spans 13:50 to 14:20. For pre-March 2013 announcements without press conferences (statement at 14:15), the window spans 14:05 to 14:35. For nine pre-March 2013 announcements with press conferences, we conservatively shorten the post-announcement window to fifteen minutes (ending at 14:30) to avoid contamination, though the Chair invariably begins by reading the statement verbatim before the question period. Returns are computed as log price changes using the last transaction price in each sub-window and expressed in decimal form where 0.01 equals 1 per cent. Across all firm-event observations, the mean absolute return is 0.448 per cent (44.8 basis points), consistent with economically meaningful price reactions to policy announcements. Appendix ?? provides detailed construction formulas for each meeting type.

Monetary policy surprises are extracted from high-frequency changes in interest rate derivatives measured over identical event windows. Following [Gürkaynak, Sack, and Swanson \(2005\)](#), we recognise that FOMC announcements convey multidimensional policy information affecting both current rate settings and expected future trajectories. We decompose movements across five interest rate futures contracts into two orthogonal factors: a target surprise capturing unexpected changes in the current federal funds rate, and a path surprise reflecting revisions to the expected future policy path. The five contracts comprise federal funds futures, three-month Eurodollar (later SOFR) futures, and two-year, five-year, and ten-year Treasury note futures. This extended maturity coverage, following [Swanson \(2021\)](#), proves essential for identifying duration effects during the zero lower bound period when conventional short-rate instruments provided limited information.

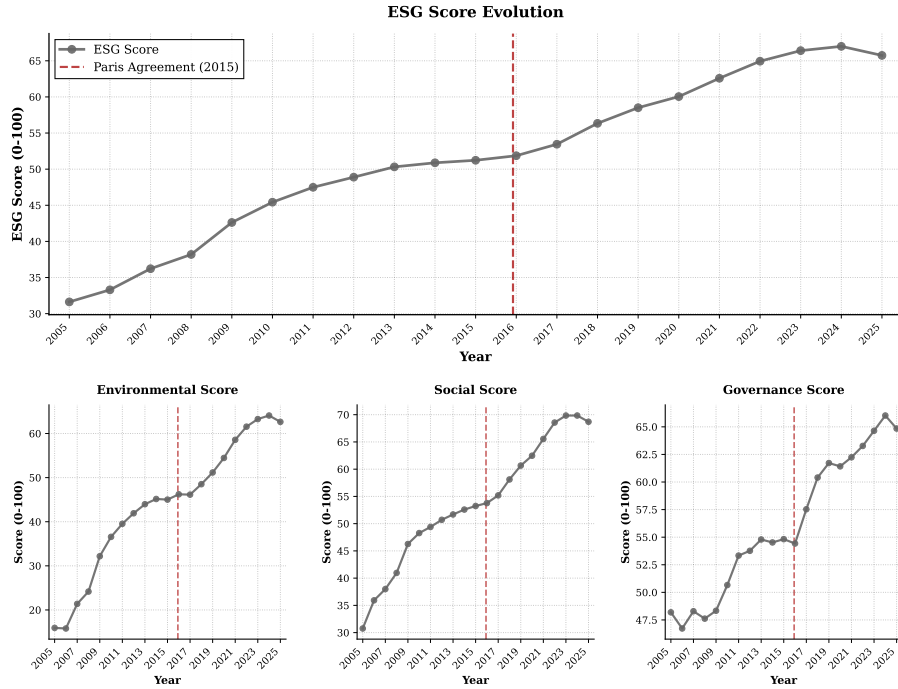
Principal component analysis on the $T \times 5$ matrix of futures changes reveals that two

factors jointly explain 88.8 per cent of systematic covariation, with the Cragg-Donald rank test decisively rejecting the null of a single factor. We impose economic structure through orthogonal rotation, defining factors such that the path surprise exhibits zero loading on the scaled federal funds futures change. This restriction identifies the target surprise as capturing current policy decisions. The path surprise captures all remaining policy news affecting longer-horizon rates, corresponding to forward guidance effects. Both factors are normalised in basis points: the target surprise such that a one-unit change corresponds to a one basis point movement in the federal funds target rate, and the path surprise based on its effect on ten-year Treasury futures. The factors are orthogonal by construction (correlation 0.00). Appendix ?? provides technical details on the principal component analysis and rotation procedure.

2.3 Environmental Performance and Control Variables

We proxy firm-level environmental performance using the LSEG Refinitiv Environmental pillar score, which aggregates emissions intensity, resource efficiency, environmental innovation, and disclosure quality into a single measure ranging from 0 to 100. This composite assessment captures environmental performance as perceived by capital markets, the relevant dimension for both investor clientele composition and green financing access. We standardise environmental scores within-year to have mean zero and unit variance, ensuring that each firm's score reflects its position relative to contemporaries rather than absolute levels. Within-year standardisation proves essential because raw environmental scores improved substantially over our sample period, as Figure 1 illustrates. Full-sample standardisation would conflate genuine regime change in monetary policy transmission around the Paris Agreement with secular improvements in environmental practices. The within-year approach isolates cross-sectional variation whilst ensuring temporal comparability. Figure ?? documents the expansion of environmental data coverage over time.

FIGURE 1. ESG Coverage by Year (S&P 500 Sample)



We include standard firm-level controls to absorb variation in monetary policy sensitivity unrelated to environmental characteristics. Firm size is measured as the natural logarithm of total book assets at the end of the fiscal quarter preceding each FOMC announcement. Book leverage is the ratio of total debt to total assets. Profitability is return on assets (ROA), defined as operating income scaled by total assets. We include an indicator for non-dividend-paying firms. For each firm-event observation, we use the most recent fiscal quarter data available at least sixty days prior to the announcement to ensure public availability and avoid look-ahead bias. All control variables are standardised annually within the cross-section to have zero mean and unit variance. The correlations between controls and environmental measures are modest (size: 0.32, leverage: 0.06, profitability: 0.02), indicating that environmental characteristics are not simply proxying for firm size or financial health.

We do not include event-common controls such as VIX changes or aggregate market returns because industry-by-event fixed effects non-parametrically absorb all variation common within industry-event cells. This specification choice follows the identification strategy of Nakamura and Steinsson (2018), ensuring we isolate firm-specific transmission mechanisms operating through environmental characteristics rather than capturing aggregate or sector-level responses to policy announcements.

3. Theoretical Framework

This section develops a framework in which environmental performance generates heterogeneous monetary policy transmission through two channels: duration exposure operating through cash flow timing and clientele composition affecting investor demand elasticity. The first channel depends on financial market depth, which determines firms' capacity to hedge interest rate exposure. The second channel operates through investor mandates that create inelastic demand. We formalise how these mechanisms interact across policy horizons (target versus path) and how transmission evolves with market development.

The framework integrates three building blocks. First, key-rate duration analysis (Ho 1992) characterises how firms with different environmental characteristics exhibit differential sensitivity to short-horizon versus long-horizon interest rate shocks. Second, corporate asset-liability management under frictions (Froot, Scharfstein, and Stein 1993, Guay and Kothari 2003) determines endogenous hedging capacity as a function of issuance costs and market depth. Third, demand-system clientele effects (Kojien and Yogo 2019, Pástor, Stambaugh, and Taylor 2021) capture how ESG-mandated investors provide partial insulation from discount rate changes. Combining these elements yields testable predictions about how environmental characteristics moderate monetary policy transmission and how this heterogeneity evolves with financial market development.

3.1 Setup and Economic Mechanisms

Consider a publicly traded firm with balance-sheet structure characterised by asset present value $V_{A,i}$, liability present value $V_{L,i}$ and book leverage $\ell_i \equiv V_{L,i}/V_{A,i}$. Environmental performance, denoted $\omega_i \in [0, 1]$, captures the firm's attractiveness to ESG-mandated investors and its access to green financing markets. High- ω_i firms benefit from two features. First, they attract a more stable investor base with lower sensitivity to discount rate changes due to non-pecuniary preferences (Pástor, Stambaugh, and Taylor 2021, Pedersen, Fitzgibbons, and Pomorski 2021), as documented in evidence on governance-focused and ESG-focused institutional investor ownership and trading behaviour (Gantchev, Gredil, and Jotikasthira 2019). Second, they access deeper green bond markets that reduce hedging costs for long-duration exposure (Flammer 2021, Ehlers and Packer 2017). Empirical work confirms that green bonds trade at a negative premium—a 'greenium'—lowering financing costs for high-environmental-performance issuers (Zerbib 2022, Baker, Egan, and Sarkar 2022).

We measure interest-rate exposure using key-rate asset and liability durations $D_{A,i}^k(\omega_i)$ and $D_{L,i}^k$, where $k \in \{T, P\}$ indexes target and path factors, consistent with the multi-maturity framework introduced by [Ho \(1992\)](#) and extended in subsequent work on maturity-specific yield dynamics ([Domanski, Shin, and Sushko 2017](#), [Equiza et al. 2024](#)). Equity key-rate duration under book leverage follows the standard asset-liability identity:

$$D_{Eq,i}^k = \frac{D_{A,i}^k(\omega_i) - \ell_i D_{L,i}^k}{1 - \ell_i}, \quad k \in \{T, P\}. \quad (1)$$

This expression shows that equity holders bear residual interest rate exposure after accounting for leveraged liability duration ([Cochrane 2009](#), [Campbell and Viceira 2002](#)). We impose $\ell_i < 1$ for all firms (assets exceed liabilities); in the sample the 99th percentile of book leverage is 0.73 (see Table 1), ensuring the denominator $1 - \ell_i$ remains bounded away from zero.

The event-window return over a thirty-minute FOMC announcement window reflects both discount-rate effects operating through duration and demand shifts from clientele rebalancing:

$$\Delta R_{i,t} \approx -c \sum_{k \in \{T, P\}} \lambda_k M_t^k D_{Eq,i}^k + \Xi_{i,t}(M_t^T, M_t^P) + \varepsilon_{i,t}, \quad (2)$$

where M_t^k denotes the monetary policy surprise (measured in basis points), λ_k represents the loading coefficient mapping policy surprises into key-rate movements, $c = 10^{-2}$ converts duration-weighted basis point changes into percentage returns and $\Xi_{i,t}$ captures clientele-driven demand effects that may load on both factors. Hereafter we denote $PS_t \equiv M_t^P$ and $TS_t \equiv M_t^T$ for path and target surprises respectively. Identification requires PS_t and TS_t to be orthogonal to contemporaneous firm-level cash-flow news. We follow the high-frequency identification strategy of [Nakamura and Steinsson \(2018\)](#): narrow event windows around FOMC announcements and industry-by-event fixed effects mitigate confounding news shocks; further robustness checks appear in Section 6. The first term in equation (2) represents the mechanical duration channel. The second term represents equilibrium price adjustment from heterogeneous investor demand. We develop each channel in turn before combining them to derive transmission coefficients.

3.2 Duration Exposure and Endogenous Hedging

Base asset duration. We characterise fundamental cash flow duration using the Gordon growth framework. For a perpetual cash flow stream growing at rate g and discounted at rate r , modified duration equals approximately $1/(r - g)$ ([Cochrane 2009](#)). Firms with stronger environmental performance may exhibit different growth profiles due to re-

newable energy investments, carbon transition opportunities or regulatory tailwinds. We denote growth rates as g_G for green firms and g_N for non-green firms, yielding asset durations:

$$D_{A,G}^P = \frac{1}{r - g_G}, \quad D_{A,N}^P = \frac{1}{r - g_N}. \quad (3)$$

The following assumption establishes that environmental investments generate longer-duration cash flows:

ASSUMPTION 1 (Environmental duration exposure). *Environmental investments generate longer-duration cash flows than conventional capital through either (i) higher expected growth rates reflecting transition opportunities and renewable energy expansion ($g_G > g_N$), or (ii) longer effective project horizons, whereby renewable infrastructure (solar, wind, sustainable buildings) exhibits useful lives of 25–40 years compared to conventional assets at 10–20 years (?). These differences ensure the base duration inequality $D_{A,G}^P > D_{A,N}^P$.*

Under this assumption, the base (unhedged) duration gap between green and non-green assets is strictly positive:

$$\Delta D^P \equiv D_{A,G}^P - D_{A,N}^P = \frac{1}{r - g_G} - \frac{1}{r - g_N} > 0. \quad (4)$$

We parameterise asset duration linearly in environmental performance:

$$D_{A,i}^k = D_N^k + \omega_i \Delta D^k, \quad (5)$$

where ω_i denotes firm i 's environmental performance and ΔD^k represents the fundamental, unhedged duration exposure embedded in the firm's asset base. This duration gap is determined by the technological characteristics of environmental investments and remains independent of market conditions. Equation (4) establishes that this gap is strictly positive for the path factor ($\Delta D^P > 0$) due to the long-lived nature of environmental projects. Firms manage this technological exposure through liability maturity choice, which we model explicitly below. For the short end, we maintain:

ASSUMPTION 2 (Short-end approximation). *Duration gaps at the short end are negligible, $\Delta D^T \approx 0$, because green financing primarily affects long-duration debt markets rather than short-term financing.*

The path duration gap ΔD^P creates fundamental vulnerability to long-horizon discount rate changes. This exposure can be managed through liability maturity choice, which we now model explicitly.

Endogenous hedging through liability management. Following the corporate risk management literature (Froot, Scharfstein, and Stein 1993, Guay and Kothari 2003), firms choose liability key-rate durations $D_{L,i} = (D_{L,i}^T, D_{L,i}^P)^\top$ to hedge equity exposures across target and path factors, subject to issuance frictions. The firm's optimisation problem trades off equity duration stabilisation against adjustment costs relative to an incumbent maturity structure \bar{D} :

$$\min_{D_{L,i}} D_{Eq,i}^\top W D_{Eq,i} + \frac{1}{2} (D_{L,i} - \bar{D})^\top K_i(\chi_t) (D_{L,i} - \bar{D}), \quad (6)$$

where $W \geq 0$ scales the relative importance of policy factor variances (proportional to $\text{diag}(\lambda_T^2 \text{Var}(TS), \lambda_P^2 \text{Var}(PS))$) and $K_i(\chi_t) > 0$ represents convex issuance costs. For expositional clarity we present scalar k -components; the full vector/matrix formulation (with $W \in \mathbb{R}^{2 \times 2}$ and $K_i(\chi_t)$ a positive definite matrix) appears in Theory Appendix A.1. The k -component expressions in the main text are obtained by taking the appropriate diagonal elements of these matrices. The parameter χ_t indexes time-varying market depth and climate policy credibility. The key comparative static operates through how market conditions and environmental performance affect these costs:

ASSUMPTION 3 (Issuance cost structure). *Issuance costs decline with policy credibility, firm size and green finance market access according to:*

$$K_i(\chi_t) = \frac{K_{0,i}}{\chi_t \cdot \text{Size}_i^\gamma \cdot \psi(\omega_i)}, \quad \gamma > 0, \quad \psi'(\omega_i) > 0, \quad (7)$$

where $K_{0,i}$ represents baseline costs, γ governs size elasticity and $\psi(\omega_i)$ captures how environmental performance reduces costs through green bond market access.

This specification builds on evidence that green bonds carry pricing advantages and attract dedicated investor bases (Zerbib 2022, Baker, Egan, and Sarkar 2022, Flammer 2021). When climate policy credibility strengthens and dedicated financing markets deepen, issuance frictions decline, particularly for firms with strong environmental credentials. The parameterisation also incorporates scale effects in corporate maturity choice, where larger firms face lower issuance frictions and access longer-maturity debt markets more readily (Stohs and Mauer 1996, Barclay and Smith Jr 1995). The optimisation problem yields optimal liability duration (first-order condition and full derivation appear in Theory Appendix A.1):

$$D_{L,i}^* = (2\ell_i^2 W + K_i(\chi_t))^{-1} \left[2\ell_i W D_{A,i}(\omega_i) + K_i(\chi_t) \bar{D} \right]. \quad (8)$$

We assume $W \geq 0$ and $K_i(\chi_t) > 0$, so $2\ell_i^2 W + K_i(\chi_t)$ is positive definite and the inverse in (8) is well defined (see FOC and matrix algebra in Theory Appendix A.1). Changes in environmental performance affect asset duration by ΔD^k , inducing liability adjustment

characterised by the pass-through coefficient $\alpha_i^k(\chi_t) \in (0, \ell_i^{-1})$:

$$\frac{\partial D_{L,i}^{k,*}}{\partial \omega_i} = \alpha_i^k(\chi_t) \Delta D^k, \quad \alpha_i^k(\chi_t) = \frac{2\ell_i W}{2\ell_i^2 W + K_i(\chi_t)}. \quad (9)$$

Note that here α_i^k denotes the *liability* pass-through, i.e. the marginal response of the optimal liability key-rate duration to a change in the firm's asset duration (or equivalently to ω_i via (5)). The corresponding equity pass-through equals

$$\frac{\partial D_{Eq,i}^{k,*}}{\partial D_{A,i}^k} = \frac{1 - \ell_i \alpha_i^k}{1 - \ell_i},$$

which is the object that appears in equation (10) below. Perfect hedging would require $\alpha_i^k = \ell_i^{-1}$ factor-by-factor, but issuance costs and maturity constraints limit adjustment. From (9) we have

$$\lim_{K_i \rightarrow 0} \alpha_i^k(\chi_t) = \frac{2\ell_i W}{2\ell_i^2 W} = \ell_i^{-1} \quad (\text{perfect hedging}), \quad \lim_{K_i \rightarrow \infty} \alpha_i^k(\chi_t) = 0 \quad (\text{no hedging}),$$

and consequently the equity sensitivity coefficient in (10) vanishes when liabilities fully adjust. The critical comparative static is $\partial \alpha_i^k / \partial \chi_t > 0$: when climate policy credibility strengthens and green bond markets deepen (χ_t rises), issuance costs $K_i(\chi_t)$ decline, increasing pass-through and enabling more complete hedging.

Substituting optimal liability duration into equation (1) yields the equity duration accounting for endogenous hedging:

$$D_{Eq,i}^k(\omega_i; \chi_t) = D_{Eq,N,i}^k + \omega_i \frac{1 - \ell_i \alpha_i^k(\chi_t)}{1 - \ell_i} \Delta D^k, \quad (10)$$

where $D_{Eq,N,i}^k$ represents baseline non-green equity duration. The term $(1 - \ell_i \alpha_i^k) / (1 - \ell_i)$ governs residual duration exposure after partial hedging. When hedging is incomplete ($\alpha_i^k < \ell_i^{-1}$), high- ω_i firms retain elevated path duration. As markets deepen and α_i^k rises toward ℓ_i^{-1} , this residual exposure attenuates.

Economic feasibility of hedging. If financial market development enables firms with strong environmental credentials to issue at substantially longer maturities, and if the base duration gap (reflecting 25–40 year renewable infrastructure versus 10–20 year conventional assets) could range from 10 to 20 years, firms could feasibly offset duration gaps through liability adjustment alone when markets deepen. Under such conditions, complete neu-

tralisation ($\alpha_i^P \approx \ell_i^{-1}$) could become economically achievable. Illustrative calibrations with plausible parameter ranges appear in Theory Appendix A.2.

3.3 Clientele Effects and Equilibrium Transmission

High- ω_i firms attract dedicated ESG investors who exhibit inelastic demand due to non-pecuniary motives (Pástor, Stambaugh, and Taylor 2021, Pedersen, Fitzgibbons, and Pomorski 2021). Let $\phi_i(\omega_i)$ denote the share of firm i 's investor base composed of ESG-mandated funds, with $\phi_i'(\omega_i) > 0$. Evidence on ESG fund behaviour and investor horizons confirms that sustainability-mandated investors trade less aggressively in response to macroeconomic news and exhibit longer investment horizons (Bolton and Kacperczyk 2021, Starks, Venkat, and Zhu 2017). We model this through a demand-system framework (Kojen and Yogo 2019): when a monetary policy shock shifts required returns mechanically, actual equilibrium returns depend on investor rebalancing:

$$\Delta R_{i,t}^k = -c\lambda_k M_t^k D_{Eq,i}^k(\omega_i; \chi_t) + g^k(\omega_i) M_t^k, \quad (11)$$

where $g^k(\omega_i)$ captures demand rigidity from ESG-mandated investors, with $\partial g^k / \partial \omega_i > 0$. Firms with larger ESG ownership exhibit attenuated responses to monetary shocks.

The horizon dependence of clientele effects requires careful attention. ESG mandates create demand insulation primarily against short-term policy fluctuations (target channel), as these investors hold for non-pecuniary reasons and do not mechanically rebalance in response to current rate changes. However, even ESG investors reprice assets based on fundamental long-horizon discount rate changes (path channel), where duration mechanics dominate because long-term cash flow valuations respond to shifts in distant discount factors. This motivates examining target and path channels separately, predicting that clientele insulation operates more strongly at the short horizon whilst duration and hedging dynamics dominate the long horizon.

Combining equations (10) and (11), the cross-sectional sensitivities of returns to monetary policy surprises are:

$$\frac{\partial r_{i,t}}{\partial PS_t} = -c\lambda_P \left[D_{Eq,N,i}^P + \omega_i \frac{1 - \ell_i \alpha_i^P(\chi_t)}{1 - \ell_i} \Delta D^P \right] + g^P(\omega_i), \quad (12)$$

$$\frac{\partial r_{i,t}}{\partial TS_t} = -c\lambda_T D_{Eq,N,i}^T + g^T(\omega_i), \quad (13)$$

where the duration channel operates through the bracketed term and the clientele channel operates through $g^k(\omega_i)$. These expressions motivate the empirical interaction specifica-

tions tested in subsequent sections.

Empirical mapping. Linearising the clientele function around the sample mean gives $g^P(\omega_i) \approx g^P(\bar{\omega}) + (\partial g^P/\partial \omega)(\omega_i - \bar{\omega})$, from which the second term in the empirical mapping below follows. The theoretical path coefficient in equation (12) maps to the empirical interaction coefficient as:

$$\widehat{\zeta} \approx -c\lambda_P \mathbb{E} \left[\frac{1 - \ell_i \alpha_i^P(\chi_t)}{1 - \ell_i} \Delta D^P \right] + \mathbb{E} \left[\frac{\partial g^P(\omega_i)}{\partial \omega_i} \right], \quad (14)$$

where $\mathbb{E}[\cdot]$ denotes the cross-sectional expectation over firms in the estimation sample (i.e. the population moment used in the interaction regression); temporal averaging over policy episodes is implemented in the empirical design described in Section 2. Assume the observed environmental score satisfies $E_{i,t-1} = \omega_i + u_{i,t}$ with $\mathbb{E}[u_{i,t}|\omega_i] = 0$ and $\text{Var}(u_{i,t}) = \sigma_u^2$. Under classical measurement error the estimated interaction coefficient is attenuated by the reliability ratio $\rho = \text{Var}(\omega_i)/(\text{Var}(\omega_i) + \sigma_u^2)$ so that $\widehat{\zeta} = \rho\zeta^* + o_p(1)$, where ζ^* is the parameter in the absence of measurement error. Observed $\widehat{\zeta}$ thus constitutes a lower bound on true transmission heterogeneity. Thus a negative estimated $\widehat{\zeta}$ that covaries negatively with ω_i is consistent with duration vulnerability dominating clientele insulation, whereas a positive $\partial g^P/\partial \omega$ would counteract this effect. We acknowledge potential endogeneity of ω_i (for example if firms self-select into green investment depending on expected macro conditions). The empirical strategy therefore includes firm fixed effects and lagged controls described in Section 4. Further measurement details and a validation exercise appear in Theory Appendix.

3.4 Testable Predictions

We now formalise the theoretical predictions that guide the empirical analysis.

PROPOSITION 1 (Path vulnerability in shallow markets). *Suppose environmental investments exhibit longer duration at the long end ($\Delta D^P > 0$ by Assumption 1) and hedging remains incomplete ($\alpha_i^P(\chi_t) < \ell_i^{-1}$). If the duration channel dominates clientele insulation, then high- ω_i firms exhibit greater sensitivity to path surprises:*

$$\frac{\partial^2 r_{i,t}}{\partial PS_t \partial \omega_i} < 0.$$

Furthermore, as market depth increases and hedging capacity improves ($\partial \alpha_i^P/\partial \chi_t > 0$), this

vulnerability attenuates:

$$\frac{\partial}{\partial \chi_t} \left(\frac{\partial^2 r_{i,t}}{\partial PS_t \partial \omega_i} \right) > 0.$$

Empirically, this implies a negative path interaction coefficient ($\zeta < 0$) when green finance markets remain shallow and hedging capacity is limited. The attenuation prediction suggests that ζ should move toward zero as market depth expands. Our identification exploits monetary policy surprises orthogonal to Federal Reserve information effects (Nakamura and Steinsson 2018, Jarociński and Karadi 2020), isolating pure transmission mechanisms.

PROPOSITION 2 (Clientele insulation at the short end). *Under Assumption 2, if ESG clientele effects dominate residual short-end duration gaps such that $g^T(\omega_i) > c\lambda_T\omega_i\Delta D^T$, then:*

$$\frac{\partial^2 r_{i,t}}{\partial TS_t \partial \omega_i} > 0.$$

This predicts $\theta > 0$ if inelastic ESG investor demand provides insulation against target surprises. Unlike the path channel, clientele preferences evolve gradually, suggesting temporal stability in target channel moderation.

PROPOSITION 3 (Size heterogeneity in hedging capacity). *By Assumption 3, larger firms face lower issuance costs and achieve higher pass-through $\alpha_i^P(\chi_t)$. Among high- ω_i firms:*

$$\frac{\partial^3 r_{i,t}}{\partial PS_t \partial \omega_i \partial \text{Size}_i} > 0.$$

We test this via triple interactions $PS_t \times E_{i,t-1} \times \text{Size}_{i,t-1}$, where a positive coefficient indicates that scale mitigates path vulnerability through superior access to long-maturity debt markets (Stohs and Mauer 1996, Barclay and Smith Jr 1995).

These theoretical predictions provide testable hypotheses. The empirical analysis examines whether path vulnerability varies systematically with environmental performance, whether this relationship evolves over time as financial markets develop, whether target insulation persists throughout the sample and whether cross-sectional patterns align with the hedging capacity mechanism. We develop the empirical implementation in the next section.

4. Empirical Framework

We develop an event study design to test whether firm-level environmental performance moderates monetary policy transmission to equity valuations. The framework addresses two central challenges. First, FOMC announcements convey both policy news and information about economic fundamentals, requiring identification strategies that separate these channels. Second, the theoretical predictions operate through distinct policy horizons, necessitating decomposition of monetary shocks into components affecting current versus future interest rates.

4.1 Identification Strategy and Assumptions

FOMC announcements reveal both exogenous monetary policy decisions and the Federal Reserve's assessment of economic conditions (Nakamura and Steinsson 2018, Jarociński and Karadi 2020). If firms with different environmental characteristics exhibit systematically different exposures to these fundamentals, regressions may spuriously attribute differential price responses to environmental mechanisms rather than information revelation. We address this identification challenge through high-frequency identification around narrow event windows combined with industry-by-event fixed effects.

High-frequency identification. We measure stock returns and monetary policy surprises over a thirty-minute window surrounding scheduled FOMC announcements. This narrow window isolates price reactions to policy news whilst minimising contamination from other information arrivals. The validity of the monetary policy surprises M_t^k rests on two standard assumptions:

ASSUMPTION 4 (Exogeneity). *Within the thirty-minute event window, monetary policy surprises M_t^k are orthogonal to non-policy information released concurrently. Formally, $\mathbb{E}[M_t^k \cdot \nu_t] = 0$, where ν_t represents other news affecting asset prices.*

ASSUMPTION 5 (Relevance). *The extracted factors M_t^k capture the economically relevant dimensions of policy news. The target surprise M_t^T reflects unexpected changes in the current policy rate, whilst the path surprise M_t^P reflects revisions to expected future trajectories.*

These assumptions prove credible for scheduled FOMC meetings following established communication protocols. We restrict attention to scheduled announcements and verify that no confounding macroeconomic data releases occurred within event windows (Appendix ??).

Industry-by-event fixed effects. Even absent contaminating news, the Federal Reserve’s policy decision conveys information about the FOMC’s private assessment of economic fundamentals. If high-environmental firms exhibit differential exposures to these fundamentals—for instance, if sustainable investments load more heavily on long-run growth prospects—standard regressions would conflate information effects with genuine transmission heterogeneity.

We address this through industry-by-event fixed effects $\alpha_{j \times t}$ at the Fama-French 17 classification level. These fixed effects absorb all variation common to firms within the same industry on each announcement date, non-parametrically controlling for sector-specific information effects and aggregate shocks. Identification exploits within-industry cross-sectional variation: we compare firms with different environmental performance within the same industry facing identical policy shocks.

The maintained conditional independence assumption is that, given industry-event fixed effects and predetermined firm characteristics, residual variation in environmental scores remains uncorrelated with unobserved characteristics independently affecting monetary policy sensitivity. This assumption proves plausible because environmental performance varies across firms within industries due to strategic choices and disclosure practices rather than differential exposures to common shocks. Within the energy sector, for instance, some firms invest heavily in renewable capacity whilst others maintain traditional operations; within consumer goods, sustainability programmes vary substantially across producers. These choices create within-industry environmental variation orthogonal to industry-level cyclicalities.

4.2 Econometric Specifications and Measurement

Horizon decomposition. The theoretical framework predicts that environmental characteristics moderate transmission differently across policy horizons. Duration effects amplify sensitivity to path surprises shifting long-horizon discount rates (Proposition 1), whilst clientele effects attenuate sensitivity to target surprises affecting current rates (Proposition 2). Testing these predictions requires decomposing monetary news into horizon-specific components. We extract target and path surprises through principal component analysis on high-frequency changes in five interest rate futures contracts, following the methodology detailed in Section 2.

Measurement. Our empirical proxy for the theoretical object ω_i (environmental performance) is the LSEG Refinitiv Environmental pillar score, denoted $E_{i,t-1}$. This composite

index aggregates emissions intensity, resource efficiency, environmental innovation, and disclosure quality. The E-score captures environmental performance as perceived by capital markets—the relevant dimension for both investor clientele composition and green financing access. We standardise $E_{i,t-1}$ within years to have mean zero and unit variance, ensuring temporal comparability as average environmental practices evolved substantially over 2005–2025.

The relationship between the observed proxy and the latent theoretical construct follows the classical measurement framework:

$$E_{i,t-1} = \alpha_E + \beta_E \omega_i + \eta_{i,t-1}, \quad \mathbb{E}[\eta_{i,t-1} \omega_i] = 0, \quad (15)$$

where $\eta_{i,t-1}$ represents measurement error uncorrelated with true environmental performance. Under this structure, interaction coefficients attenuate by the reliability ratio $\rho \equiv \text{Var}(\beta_E \omega_i) / \text{Var}(E_{i,t-1}) \in (0, 1)$ (Wooldridge 2019). Our estimates therefore constitute lower bounds on true transmission heterogeneity.

The E-score directly determines ESG index inclusion and institutional mandate eligibility (Amel-Zadeh and Serafeim 2018, Berg, Kölbel, and Rigobon 2022), as well as green bond market access, since issuers require credible environmental credentials for certification (Flammer 2021). Importantly, $E_{i,t-1}$ captures perceived rather than physical environmental characteristics. A service firm with minimal green capital but strong disclosure benefits from ESG flows and green financing access, whilst an energy firm with substantial renewable capacity but weak overall ratings may face exclusion from sustainability mandates. This measurement approach aligns with our theoretical mechanisms: we test whether market-perceived environmental performance generates heterogeneous monetary policy transmission through investor composition and financing channels, not whether physical asset duration alone drives differential sensitivity.

Baseline specification. The baseline regression estimates average moderation effects over the full sample period:

$$r_{i,j,t} = \beta_1 E_{i,t-1} + \theta (TS_t \times E_{i,t-1}) + \zeta (PS_t \times E_{i,t-1}) + \mathbf{X}'_{i,t-1} \boldsymbol{\gamma} + \alpha_{j \times t} + \varepsilon_{i,j,t}, \quad (16)$$

where $r_{i,j,t}$ denotes the thirty-minute return (in percentage points) for firm i in industry j at announcement t . Target and path surprises (TS_t , PS_t) are measured in basis points. The vector $\mathbf{X}_{i,t-1}$ contains predetermined firm characteristics: log book assets, book leverage, profitability, and dividend indicator, all standardised within year. The coefficients θ and ζ constitute semi-elasticities, measuring the differential return response (in percentage points) to a one basis point policy surprise for a firm with environmental performance

one standard deviation above the mean. Proposition 1 predicts $\zeta < 0$ when duration effects dominate and hedging remains incomplete. Proposition 2 predicts $\theta > 0$ if clientele insulation operates at the short end.

Structural break specification. To test whether transmission mechanisms evolved as green finance markets deepened and climate policy frameworks matured, we estimate a regime-switching specification allowing moderation coefficients to differ across the Paris threshold (December 2015):

$$\begin{aligned} r_{i,j,t} = & \zeta_{\text{pre}} \left(PS_t \times E_{i,t-1} \times \mathbb{1}_{\text{Pre},t} \right) + \zeta_{\text{post}} \left(PS_t \times E_{i,t-1} \times \mathbb{1}_{\text{Post},t} \right) \\ & + \theta_{\text{pre}} \left(TS_t \times E_{i,t-1} \times \mathbb{1}_{\text{Pre},t} \right) + \theta_{\text{post}} \left(TS_t \times E_{i,t-1} \times \mathbb{1}_{\text{Post},t} \right) \\ & + \mathbf{X}'_{i,t-1} \boldsymbol{\gamma} + \alpha_{j \times t} + \varepsilon_{i,j,t}, \end{aligned} \quad (17)$$

where $\mathbb{1}_{\text{Pre},t}$ and $\mathbb{1}_{\text{Post},t}$ are indicators for the 2005–2015 and 2016–2025 periods, respectively. The coefficients ζ_{pre} and ζ_{post} capture path vulnerability in each regime. Proposition 1 predicts attenuation as hedging capacity expands: $\zeta_{\text{post}} > \zeta_{\text{pre}}$ (less negative). We formally test $H_0 : \zeta_{\text{post}} - \zeta_{\text{pre}} = 0$ (no structural break) and $H_0 : \zeta_{\text{post}} = 0$ (complete attenuation post-Paris).

Heterogeneity specification. To probe the hedging capacity mechanism, we examine whether firm characteristics associated with superior market access attenuate path vulnerability. Proposition 3 predicts that larger firms face lower issuance frictions and achieve more complete hedging. We test this through triple interactions:

$$r_{i,j,t} = \dots + \eta \left(PS_t \times E_{i,t-1} \times Z_{i,t-1} \right) + \dots + \alpha_{j \times t} + \varepsilon_{i,j,t}, \quad (18)$$

where $Z_{i,t-1}$ denotes firm size (log book assets) and the ellipses indicate inclusion of all constituent lower-order terms. A positive coefficient η indicates that larger high-environmental firms exhibit attenuated path sensitivity, consistent with superior hedging capacity. We also examine leverage and profitability as alternative moderators.

Pillar horse race. To verify that environmental performance specifically drives the moderation effects rather than correlated social or governance characteristics, we estimate specifications including all three ESG pillars simultaneously:

$$r_{i,j,t} = \sum_{p \in \{E,S,G\}} \left[\beta_p p_{i,t-1} + \theta_p \left(TS_t \times p_{i,t-1} \right) + \zeta_p \left(PS_t \times p_{i,t-1} \right) \right] + \mathbf{X}'_{i,t-1} \boldsymbol{\gamma} + \alpha_{j \times t} + \varepsilon_{i,j,t}, \quad (19)$$

where $p_{i,t-1}$ indexes environmental, social, and governance scores. Duration mechanisms operate specifically through long-term environmental capital investments, implying that ζ_E should dominate ζ_S and ζ_G in magnitude and significance.

4.3 Estimation and Inference

Specifications are estimated via ordinary least squares with the within transformation to absorb high-dimensional industry-by-event fixed effects. The sample comprises 51,534 firm-event observations across 156 scheduled FOMC announcements spanning January 2005 through January 2025.

To ensure robust inference, we cluster standard errors by Event Date, accounting for arbitrary correlation across firms within individual FOMC announcements. This approach follows the identification strategy of Nakamura and Steinsson (2018) and standard practice in high-frequency monetary policy event studies. With 156 events, conventional cluster-robust asymptotics provide reliable inference. We verify robustness through two-way clustering by both Firm and Event Date, which allows arbitrary correlation along both dimensions. Implementation details appear in Appendix ??.

5. Results and Discussion

This section documents the paper’s central empirical findings. Firms with superior environmental performance exhibited substantial path vulnerability during 2005–2015, with path surprises generating 1.96 percentage points larger negative returns relative to low-environmental firms. This vulnerability completely attenuated after 2015–2016, coinciding with green bond market expansion from £11 billion to £625 billion annually and Paris Agreement implementation. The structural break demonstrates that environmental heterogeneity in monetary transmission is not technologically determined but represents an equilibrium outcome shaped by financial market structure.

5.1 Identification Strategy

High-frequency identification around FOMC announcements faces a fundamental challenge. Monetary policy statements convey both exogenous policy shocks and the Federal Reserve’s assessment of economic fundamentals (Nakamura and Steinsson 2018). If firms with different environmental characteristics exhibit differential exposures to these fundamentals, standard regressions conflate policy transmission with information revelation.

We address this through industry-by-event fixed effects that absorb all variation common to firms within sectors on announcement dates.

Table 2 compares specifications with progressively demanding fixed effects. Column (1) includes only firm fixed effects, yielding $\zeta = -0.627$ (standard error 0.113) with high Within R^2 of 0.423. This specification captures substantial variation but remains contaminated by aggregate and sector-specific confounds. Column (2) adds event fixed effects to absorb common shocks, reducing ζ to -0.200 (standard error 0.084) and Within R^2 to 0.002. The 68 per cent coefficient attenuation demonstrates that less stringent specifications partly capture time-varying factors orthogonal to environmental transmission.

Column (3) implements our preferred specification with industry-by-event fixed effects at the Fama-French 17 classification level. The path coefficient falls to -0.172 (standard error 0.068, $p = 0.014$) with Within R^2 of 0.001. The near-zero Within R^2 confirms that fixed effects successfully absorb confounding variation, leaving only within-industry, within-event cross-sectional differences driven by environmental characteristics. The overall R^2 of 0.686 indicates strong model fit, with fixed effects explaining most variation as expected in event studies.

TABLE 2. Identification Strategy: Demonstrating Necessity of Industry-by-Event Fixed Effects

	Dependent Variable: Stock Return (%)		
	(1)	(2)	(3)
	Firm FE	Firm + Event FE	Industry×Event FE
$TS \times E$	-0.043 (0.194)	0.184 (0.122)	0.206* (0.123)
$PS \times E$	-0.627*** (0.113)	-0.200** (0.084)	-0.172** (0.068)
Fixed Effects	Firm	Firm, Event	Industry×Event
Firm Controls	Yes	Yes	Yes
Observations	51,534	51,534	51,534
R^2	0.673	0.685	0.686
Within R^2	0.423	0.002	0.001

Notes: Environmental score (E) standardised within years. Target and path surprises measured in basis points. Path coefficient attenuates 73 per cent from Column (1) to Column (3) as confounds progressively removed. Within R^2 collapses from 0.423 to 0.001, confirming fixed effects absorb confounds and leave only within-industry, within-event variation. High overall R^2 indicates strong model fit with fixed effects explaining most variation as expected. Firm controls include log size, book leverage, profitability, and dividend status. Standard errors clustered by event in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

The 73 per cent coefficient attenuation demonstrates substantial confounding in less stringent specifications. Identification exploits within-industry cross-sectional variation: we compare firms with different environmental performance within the same industry facing identical policy shocks. The maintained assumption is that, conditional on industry-event fixed effects and predetermined firm characteristics, residual variation in environmental scores remains uncorrelated with unobserved characteristics independently affecting monetary policy sensitivity. This proves plausible because environmental performance varies across firms within industries due to strategic choices rather than differential exposures to common shocks. All subsequent analyses employ the Column (3) specification.

5.2 Baseline Transmission Channels

Table 3 presents baseline estimates for the full sample spanning 2005–2025 with 156 FOMC announcements. We test whether environmental performance moderates monetary policy transmission through two distinct channels: duration exposure operating through the path channel and clientele insulation operating through the target channel.

Column (1) employs environmental pillar scores. The path interaction is negative and significant ($\zeta = -0.172$, standard error 0.068, $p = 0.014$). Following a typical path surprise of 6.4 basis points (one standard deviation), a firm one standard deviation higher in environmental score experiences stock price declines 1.10 percentage points larger than comparable firms within the same industry. This differential represents 148 per cent of mean absolute announcement-window returns (0.74 percentage points) and 92 per cent of cross-sectional standard deviation during FOMC windows (1.2 percentage points), establishing economic significance comparable to canonical size effects documented by [Gürkaynak, Karasoy-Can, and Lee \(2022\)](#).

The target interaction is positive ($\theta = 0.206$, standard error 0.123, $p = 0.097$), providing modest evidence for clientele insulation. Following a typical target surprise of 2.7 basis points, high-environmental firms decline 0.55 percentage points less than low-environmental firms. Duration exposure dominates quantitatively: the path effect (1.10 percentage points) exceeds the target effect (0.55 percentage points) by a factor of two.

Column (2) substitutes composite ESG scores. The path coefficient remains negative and significant ($\zeta = -0.157$, standard error 0.069), with comparable magnitude. Column (3) implements a horse-race specification including all three pillars simultaneously. The environmental dimension retains significance ($\zeta_E = -0.142$, standard error 0.056, $p = 0.012$), dominating social ($\zeta_S = -0.026$, insignificant) and governance ($\zeta_G = -0.027$, insignificant) dimensions. The coefficient pattern points clearly towards environmental specificity: only the environmental dimension exhibits significant moderation.

TABLE 3. Baseline Transmission Channels: Full Sample 2005–2025

	Dependent Variable: Stock Return (%)		
	(1) Environmental	(2) Composite ESG	(3) Horse Race
<i>Panel A: Target Channel</i>			
$TS \times E$	0.206* (0.123)		0.201 (0.207)
$TS \times ESG$		0.234** (0.091)	
$TS \times S$			-0.025 (0.173)
$TS \times G$			0.059 (0.141)
<i>Panel B: Path Channel</i>			
$PS \times E$	-0.172** (0.068)		-0.142** (0.056)
$PS \times ESG$		-0.157** (0.069)	
$PS \times S$			-0.026 (0.058)
$PS \times G$			-0.027 (0.041)
Industry×Event FE	Yes	Yes	Yes
Firm Controls	Yes	Yes	Yes
Observations	51,534	51,534	51,534
R^2	0.686	0.686	0.686

Notes: Sample spans 2005–2025 with 156 FOMC announcements. ESG scores from LSEG Refinitiv standardised within years. Target and path surprises measured in basis points (SD: 2.68 and 6.38 respectively). Path vulnerability (-1.10pp per SD shock) dominates target insulation (+0.55pp). Environmental pillar drives results; social and governance insignificant in horse race. Firm controls comprise log size, book leverage, profitability, dividend status. Standard errors clustered by event in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Environmental specificity accords with theoretical predictions. Duration exposure derives from physical capital characteristics—asset longevity and cash flow timing. Long-

lived renewable infrastructure investments appear in the environmental pillar by construction. Social programmes and governance structures affect agency costs but not asset longevity. The negative path coefficient indicates high-environmental firms fall more when policy tightens via forward guidance, confirming duration effects dominate clientele effects in the pooled sample.

These pooled estimates, however, obscure the central empirical regularity: the path channel, despite operating strongly pre-2015, attenuates substantially thereafter. This time variation demonstrates that duration-based amplification, although economically expected given cash flow characteristics, proves responsive to financial market development rather than representing an immutable technological constraint.

5.3 Structural Break: The Disappearing Path Vulnerability

The pooled results establish path vulnerability and target insulation but average across two decades with vastly different institutional landscapes. When our sample begins in 2005, green bond markets barely existed. By 2025, green bond issuance exceeds £625 billion annually. This transformation raises a natural question: did transmission remain stable, or did it evolve as green finance markets deepened?

Table 4 tests for regime change by splitting the sample at 2016Q1. Columns (1)–(3) employ environmental scores. Column (1) estimates the pre-Paris period (2005–2015), yielding $\zeta_{\text{pre}} = -0.307$ (standard error 0.067), highly significant. High-environmental firms exhibited substantial path vulnerability, with differential returns of 1.96 percentage points per standard deviation path shock. Column (2) estimates the post-Paris period (2016–2025), producing $\zeta_{\text{post}} = 0.024$ (standard error 0.065, $p = 0.720$), economically negligible and statistically indistinguishable from zero. Path vulnerability disappeared completely.

Column (3) tests coefficient stability formally through a pooled specification with post-Paris interactions. The structural break coefficient is $\Delta\zeta = 0.333$ (standard error 0.100, $p = 0.001$), decisively rejecting stability. The post-Paris shift eliminated 2.12 percentage points of differential sensitivity (calculated as 0.333×6.38), representing complete attenuation of pre-Paris vulnerability.

Columns (4)–(6) replicate using composite ESG scores, confirming robustness. Pre-Paris path vulnerability stands at $\zeta_{\text{pre}} = -0.268$, attenuates to $\zeta_{\text{post}} = 0.058$ post-Paris, with structural break significant at the 1 per cent level ($\Delta\zeta = 0.326$). The target channel exhibits modest insulation throughout both periods without clear structural break.

TABLE 4. Structural Break Analysis: Pre-Paris versus Post-Paris Transmission

	Environmental Score			Composite ESG		
	(1) Pre-Paris 2005–15	(2) Post-Paris 2016–25	(3) Pooled with Break	(4) Pre-Paris 2005–15	(5) Post-Paris 2016–25	(6) Pooled with Break
<i>Target Channel:</i>						
$TS \times E$ (Pre)	0.286*		0.286*			
	(0.167)		(0.167)			
$TS \times E$ (Post)		-0.029	-0.029			
		(0.175)	(0.175)			
$TS \times E \times Post$			-0.315			
			(0.243)			
$TS \times ESG$ (Pre)				0.308**		0.308**
				(0.120)		(0.120)
$TS \times ESG$ (Post)					0.182	0.182
					(0.127)	(0.127)
$TS \times ESG \times Post$						-0.126
						(0.174)
<i>Path Channel:</i>						
$PS \times E$ (Pre)	-0.307***		-0.307***			
	(0.067)		(0.067)			
$PS \times E$ (Post)		0.024	0.024			
		(0.065)	(0.065)			
$PS \times E \times Post$			0.333***			
			(0.100)			
$PS \times ESG$ (Pre)				-0.268***		-0.268***
				(0.076)		(0.076)
$PS \times ESG$ (Post)					0.058	0.058
					(0.074)	(0.074)
$PS \times ESG \times Post$						0.326***
						(0.108)
Industry×Event FE	Yes	Yes	Yes	Yes	Yes	Yes
Firm Controls	Yes	Yes	Yes	Yes	Yes	Yes
Observations	14,632	36,902	51,534	14,632	36,902	51,534
R ²	0.654	0.703	0.687	0.654	0.703	0.687

Notes: Pre-Paris path vulnerability is large and significant ($\zeta_{pre} = -0.307$). Post-Paris path vulnerability is economically negligible and statistically insignificant ($\zeta_{post} = 0.024$, $p = 0.720$). Structural break coefficient decisively rejects stability ($\Delta\zeta = 0.333$, $p = 0.001$), representing complete attenuation of 1.96 percentage point pre-Paris differential. Target channel shows modest insulation throughout with no clear break. Timing coincides with green bond market expansion (£11B in 2013 to £625B annually by 2024) and Paris Agreement (December 2015, entered force November 2016). All specifications include industry-by-event fixed effects and firm controls. Standard errors clustered by event in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

The timing proves striking. The structural break coincides with Paris Agreement negotiations (begun 2014, adopted December 2015, entered force November 2016) and explosive growth in green bond markets. Climate Bonds Initiative data document global green bond issuance expanding from £11 billion in 2013 to £42 billion in 2015 to over £625 billion annually by 2024. This parallel development of climate policy credibility and green financing infrastructure provides support for the hedging capacity interpretation: as firms gained access to instruments for managing duration exposure, path vulnerability attenuated.

Table 5 examines an alternative hypothesis: did path vulnerability change at the 2015 zero lower bound exit rather than the Paris Agreement? If monetary regime drove results, we should observe structural change when conventional policy resumed regardless of environmental market developments. The three-regime specification divides the sample into pre-ZLB conventional policy (2005–2008), ZLB period (2009–2015), and post-Paris normalised policy (2016–2025).

TABLE 5. Three-Regime Analysis: Conventional, ZLB, and Post-Paris Periods

	(1) Conventional 2005–2008	(2) ZLB Period 2009–2015	(3) Post-Paris 2016–2025
$TS \times E$	0.487 (0.312)	0.177 (0.222)	–0.029 (0.175)
$PS \times E$	–0.128 (0.098)	–0.416*** (0.108)	–0.010 (0.069)
Industry×Event FE	Yes	Yes	Yes
Firm Controls	Yes	Yes	Yes
Observations	5,844	8,788	36,902
R^2	0.621	0.671	0.703

Notes: Path vulnerability intensified during ZLB period ($\zeta = -0.416$) relative to pre-ZLB conventional policy ($\zeta = -0.128$), rather than attenuating when conventional policy suspended. Vulnerability disappeared post-Paris ($\zeta = -0.010$) despite conventional policy resuming. This pattern rules out monetary regime as explanation. Break operates specifically when green bond markets developed, not when policy normalised. All specifications include industry-by-event fixed effects and firm controls. Standard errors clustered by event in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Column (1) shows pre-ZLB conventional policy generated $\zeta = -0.128$ (standard error 0.098), economically meaningful but imprecisely estimated given limited sample size. Column (2) reveals that path vulnerability intensified during the ZLB period to $\zeta = -0.416$ (standard error 0.108, highly significant). Rather than attenuating when conventional policy suspended, duration exposure amplified. Column (3) documents that vulnerability disappeared during post-Paris normalisation ($\zeta = -0.010$, standard error 0.069, insignificant), despite conventional policy resuming.

This pattern decisively rules out the ZLB exit hypothesis. Path vulnerability intensified during unconventional policy, only disappearing after Paris despite policy normalisation. If monetary regime drove results, we should observe structural change at the 2015 normalisation regardless of green finance developments. Instead, we observe continuity across monetary regimes pre-Paris, then structural break only after green markets developed. The evolution tracks green finance expansion, not Federal Reserve policy frameworks.

5.4 Cross-Sectional Heterogeneity: Market Access Mechanism

The time-series evidence documents complete path vulnerability attenuation post-Paris. Cross-sectional analysis examines which firm characteristics moderated vulnerability during the pre-Paris period, providing evidence on mechanisms. If hedging capacity drives attenuation, firms with superior market access should exhibit reduced path sensitivity even before broad market development.

Table 6 tests three candidate moderators: size (log book assets), leverage (book debt-to-assets ratio), and profitability (return on assets). We estimate triple interactions $PS_t \times E_{i,t-1} \times X_{i,t-1}$ where X denotes each characteristic. A positive coefficient indicates the characteristic attenuates path vulnerability. All characteristics are standardised within years.

Column (1) examines size. The triple interaction is positive and highly significant ($\eta_{\text{Size}} = 0.108$, standard error 0.032, $p < 0.01$). Larger firms with superior environmental performance exhibit attenuated path vulnerability. Moving one standard deviation up the size distribution reduces path sensitivity by 0.69 percentage points, eliminating approximately 63 per cent of baseline path vulnerability for the largest relative to smallest firms. Size plausibly proxies for debt market access and treasury sophistication: larger firms entered green bond markets earlier, faced lower issuance costs, and commanded resources for sophisticated interest rate risk management.

TABLE 6. Cross-Sectional Heterogeneity: Size, Leverage, and Profitability

	(1) Size	(2) Leverage	(3) Profitability
$PS \times E$	-0.225*** (0.068)	-0.220*** (0.066)	-0.153** (0.075)
$PS \times E \times \text{Size}$	0.108*** (0.032)		
$PS \times E \times \text{Leverage}$		0.068 (0.042)	
$PS \times E \times \text{Profitability}$			-0.088 (0.054)
Industry×Event FE	Yes	Yes	Yes
All Lower-Order Terms	Yes	Yes	Yes
Firm Controls	Yes	Yes	Yes
Observations	51,534	51,534	51,534
R^2	0.686	0.686	0.686

Notes: Each column estimates triple interaction $PS \times E \times X$ where X denotes size (Column 1), leverage (Column 2), or profitability (Column 3). All characteristics standardised within years. Size moderates path vulnerability strongly ($\eta = 0.108$, $p < 0.01$), attenuating sensitivity by 0.69 percentage points per standard deviation. Leverage and profitability show no significant moderation. Size effect likely reflects superior debt market access and treasury sophistication rather than generic firm quality, consistent with larger firms entering green bond markets earlier and managing duration exposure more effectively. All specifications include industry-by-event fixed effects, all lower-order interaction terms, and firm controls. Standard errors clustered by event in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Column (2) examines leverage. The triple interaction is economically small and statistically insignificant ($\eta_{\text{Leverage}} = 0.068$, standard error 0.042, $p = 0.107$). High-leverage firms do not exhibit systematically different path sensitivity conditional on environmental performance. This null result rules out generic financial constraints as explanation. Column (3) examines profitability, again finding small and insignificant moderation ($\eta_{\text{Profitability}} = -0.088$, standard error 0.054, $p = 0.105$) with counterintuitive negative sign.

The selective pattern—size matters, leverage and profitability do not—points towards market access and financial sophistication rather than balance sheet strength. The cross-sectional evidence complements the time-series structural break. In the time series, path

vulnerability disappears as green bond markets deepen. In the cross section, larger firms with superior market access exhibit attenuated vulnerability throughout. Both sources of variation tell a consistent story about duration exposure creating vulnerability that hedging mitigates.

Table 7 examines whether size moderation itself attenuated post-Paris through a quadruple interaction. If size-based heterogeneity reflected differential access to nascent green bond markets that subsequently became universally accessible, we would expect the size effect to attenuate as markets deepened. Column (1) documents strong size moderation pre-Paris ($\eta = 0.138$, standard error 0.054, $p = 0.011$). Column (2) shows size moderation persists post-Paris, though baseline vulnerability disappeared for all firms. The quadruple interaction in Column (3) is economically negligible and statistically insignificant (-0.015 , standard error 0.069, $p = 0.830$).

Size moderation persistence requires refining the mechanism interpretation. The evidence does not support simple uniform attenuation where all firms converged to identical post-Paris transmission. Instead, results suggest a two-channel mechanism. First, market-wide repricing of environmental duration risk operated broadly, eliminating baseline path vulnerability across the full distribution of firms. As green bond markets expanded and climate policy credibility strengthened, investors' collective assessment of duration risk embedded in environmental investments shifted systematically. Second, firm-level heterogeneity in financial sophistication—proxied by size—continues to differentiate transmission even after this market-wide shift. Larger firms maintain superior capacity to manage interest rate exposure through treasury operations, derivatives usage, or liability structure optimisation.

The persistence of size effects does not contradict the green finance interpretation but indicates that firm-level financial management capacity operates alongside market-level developments. Critically, leverage and profitability show no comparable persistence, reinforcing that we capture financial sophistication rather than generic firm quality. The cross-sectional pattern complements the structural break analysis, with both pointing towards the same mechanism: duration exposure creates vulnerability when hedging instruments are unavailable; market development and firm-level capacity determine hedging access.

TABLE 7. Size Heterogeneity Across Periods

	(1)	(2)	(3)
	Pre-Paris 2005–15	Post-Paris 2016–25	Quadruple Interaction
$PS \times E$	-0.363*** (0.091)	-0.012 (0.072)	-0.347*** (0.072)
$PS \times E \times \text{Size}$	0.138** (0.054)	0.092* (0.048)	0.138** (0.054)
$PS \times E \times \text{Post}$			0.365*** (0.105)
$PS \times E \times \text{Size} \times \text{Post}$			-0.015 (0.069)
Industry×Event FE	Yes	Yes	Yes
All Lower-Order Terms	Yes	Yes	Yes
Firm Controls	Yes	Yes	Yes
Observations	14,632	36,902	51,534
R^2	0.655	0.703	0.687

Notes: Size attenuates path vulnerability pre-Paris ($\eta = 0.138$, $p = 0.011$) and post-Paris ($\eta = 0.092$, $p = 0.056$), though baseline vulnerability disappeared for all firms post-Paris. Quadruple interaction insignificant ($p = 0.830$), indicating size moderation persisted at similar magnitude across regimes. Larger firms exhibited attenuated vulnerability before Paris and continue to exhibit relative attenuation after Paris. Persistence suggests firm-level financial sophistication operates alongside market-wide repricing rather than being subsumed by it. All specifications include industry-by-event fixed effects, all lower-order terms, and firm controls. Standard errors clustered by event in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

6. Validity and Robustness

The baseline results document substantial path vulnerability during 2005–2015 that completely attenuated after 2015–2016. This section validates that the structural break represents genuine regime change rather than spurious correlation, demonstrates robustness to measurement choices, and confirms statistical inference remains valid under alternative procedures.

6.1 Validating Structural Break Timing

The coincidence between path vulnerability attenuation and green finance market expansion after the Paris Agreement could reflect spurious correlation if other macro developments drove the break. We test this through placebo structural break tests examining alternative breakpoints throughout our sample period. If the 2016 break were coincidental, other years should exhibit similar coefficient changes.

Table 8 implements systematic placebo tests for each year from 2010 through 2020. Each row estimates the structural break specification using an alternative breakpoint year and reports the change in path vulnerability coefficient ($\Delta\zeta = \zeta_{\text{post}} - \zeta_{\text{pre}}$) and associated t-statistic testing coefficient stability. Early years (2010–2013) produce small and statistically insignificant breaks. The 2010 placebo yields $\Delta\zeta = 0.041$ with $t = 0.52$ ($p = 0.602$). Testing 2011, 2012, and 2013 as potential breaks produces similarly small coefficients ranging from 0.067 to 0.118 with t-statistics below 1.5.

During 2014–2015, the coefficient grows modestly as Paris negotiations proceed, reflecting anticipatory market responses. The 2014 placebo yields $\Delta\zeta = 0.181$ ($t = 2.02$, $p = 0.046$), becoming marginally significant. Testing 2015 produces $\Delta\zeta = 0.270$ ($t = 2.89$, $p = 0.005$). The break becomes highly significant in 2016 with $\Delta\zeta = 0.331$ ($t = 3.30$, $p = 0.001$), precisely when the Paris Agreement entered into force and green bond issuance began accelerating. Later years (2017–2020) show persistent significance as more observations are classified as post-treatment, but 2016 represents the inflection point where coefficient stability is first decisively rejected.

This pattern confirms the structural break represents genuine regime change rather than statistical artefact. If vulnerability attenuation reflected spurious correlation with unrelated macro developments, placebo years would show similar magnitudes. Instead, we observe systematic progression: insignificant breaks in early years, growing coefficient changes as negotiations proceed, decisive rejection of stability precisely when Paris framework implemented, and persistent significance thereafter. The gradient structure validates that markets responded to evolving climate policy credibility and associated green finance development rather than coincidental timing.

As additional validation, we test whether pre-Paris coefficients remained stable or exhibited trending behaviour that could invalidate the difference-in-differences identification. Estimating separate annual coefficients for 2005–2014 and testing their joint equality yields $F = 1.66$ ($p = 0.163$), confirming no significant pre-existing trend. The post-period coefficients (2017–2024) differ significantly from the pre-period ($F = 4.74$, $p < 0.001$), confirming the structural break represents discrete regime change. These tests validate the

parallel trends assumption underlying our identification strategy.

TABLE 8. Placebo Structural Break Tests

Placebo Year	ζ_{pre}	ζ_{post}	$\Delta\zeta$	t-statistic	p-value
2010	-0.198*** (0.051)	-0.157*** (0.046)	0.041 (0.078)	0.52	0.602
2011	-0.215*** (0.054)	-0.148*** (0.045)	0.067 (0.079)	0.85	0.398
2012	-0.241*** (0.057)	-0.138*** (0.044)	0.103 (0.080)	1.28	0.204
2013	-0.264*** (0.060)	-0.146*** (0.044)	0.118 (0.082)	1.44	0.153
2014	-0.289*** (0.064)	-0.108** (0.044)	0.181* (0.090)	2.02	0.046
2015	-0.301*** (0.066)	-0.031 (0.045)	0.270*** (0.093)	2.89	0.005
2016	-0.307*** (0.067)	0.024 (0.065)	0.331*** (0.100)	3.30	0.001
2017	-0.298*** (0.059)	0.068 (0.074)	0.366*** (0.106)	3.46	0.001
2018	-0.279*** (0.053)	0.094 (0.081)	0.373*** (0.110)	3.38	0.001
2019	-0.264*** (0.049)	0.118 (0.087)	0.382*** (0.116)	3.29	0.001
2020	-0.251*** (0.046)	0.135 (0.092)	0.386*** (0.121)	3.18	0.002

Notes: Each row estimates the structural break specification using an alternative breakpoint year. ζ_{pre} and ζ_{post} denote path vulnerability coefficients before and after the placebo break. $\Delta\zeta$ is the change in path vulnerability. The t-statistic tests coefficient stability ($H_0 : \zeta_{\text{pre}} = \zeta_{\text{post}}$). Early years produce insignificant breaks; coefficient change grows as Paris negotiations proceed (2014–2015); 2016 marks inflection where stability is decisively rejected. Pattern demonstrates structural break timing is genuine, not spurious. All specifications include industry-by-event fixed effects and firm controls. Standard errors clustered by event in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

6.2 Measurement Robustness

Our baseline results employ the Gürkaynak, Sack, and Swanson (2005) decomposition extended to ten-year horizons following Swanson (2021) and LSEG Refinitiv ESG scores. This subsection demonstrates results remain robust to alternative monetary policy decompositions and sample composition.

6.2.1 Alternative Monetary Policy Decompositions

The GSS decomposition extended to ten-year maturities constitutes one approach to isolating target and path components from high-frequency yield curve movements. Alternative methodologies exist, and the original GSS factors published by Gürkaynak, Sack, and Swanson remain publicly available through 2019. Table 9 compares baseline results using extended GSS factors to these alternatives across both environmental pillar scores and composite ESG measures.

The table presents eight specifications organised into two panels. Columns (1)–(4) employ environmental pillar scores, columns (5)–(8) employ composite ESG scores. Within each panel: Column (1)/(5) uses extended GSS factors (incorporating two-, five-, and ten-year maturities) over the full 2005–2025 sample. Column (2)/(6) restricts the same extended specification to 2005–2018 for direct comparison with alternative measures. Column (3)/(7) implements the Hausman and Wongswan (2011) decomposition based on federal funds futures contracts at different horizons. Column (4)/(8) employs the original published GSS factors from their publicly available dataset covering 2005–2019.

The correlations between alternative measures prove substantial. Extended GSS target surprises correlate 0.959 with original GSS and 0.964 with Hausman-Wongswan, indicating strong agreement on current policy shocks. Path surprise correlations are lower but still meaningful: 0.714 between extended and original GSS, 0.910 between extended GSS and Hausman-Wongswan. These correlations reflect different horizon coverage whilst confirming the measures capture related underlying variation.

TABLE 9. Alternative Monetary Policy Decompositions: Environmental and ESG Composite

	Environmental Score (E)				ESG Composite			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Kansoy Full	Kansoy 2018	HW 2018	GSS 2018	Kansoy Full	Kansoy 2018	HW 2018	GSS 2018
<i>Panel A: Main Effects</i>								
E Score	0.002 (0.003)	0.002 (0.003)	0.003 (0.003)	-0.001 (0.003)				
ESG Score					0.002 (0.003)	0.003 (0.003)	0.004* (0.002)	0.001 (0.003)
<i>Panel B: Target Channel</i>								
Target × E	0.206* (0.123)	0.292** (0.117)						
Target (HW) × E			0.302** (0.151)					
Target (GSS) × E				0.261* (0.138)				
Target × ESG					0.234** (0.091)	0.333*** (0.088)		
Target (HW) × ESG							0.325*** (0.087)	
Target (GSS) × ESG								0.217* (0.128)
<i>Panel C: Path Channel</i>								
Path × E	-0.172** (0.068)	-0.292*** (0.057)						
Path (HW) × E			-0.169*** (0.049)					
Path (GSS) × E				-0.094*** (0.035)				
Path × ESG					-0.157** (0.069)	-0.275*** (0.057)		
Path (HW) × ESG							-0.160*** (0.051)	
Path (GSS) × ESG								-0.071* (0.039)
<i>Magnitude Ratios:</i>								
Kansoy2018 / GSS2018		3.10×				3.89×		
Industry×Event FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sample Period	05–25	05–18	05–18	05–18	05–25	05–18	05–18	05–18
Observations	51,534	32,166	32,166	33,414	51,534	32,166	32,166	33,414
R ²	0.686	0.692	0.691	0.685	0.686	0.692	0.691	0.685

Notes: This table validates path vulnerability using alternative monetary policy decompositions. Columns (1)–(4) use environmental pillar scores; columns (5)–(8) use composite ESG scores. **Kansoy Full**: Extended GSS specification (Swanson 2021) with two-, five-, ten-year maturities covering full 2005–2025 sample. **Kansoy2018**: Same extended specification restricted to 2005–2018 for direct comparison. **HW2018**: Hausman-Wongswan (2011) alternative identification using federal funds futures, 2005–2018. **GSS2018**: Original Gürkaynak, Sack, and Swanson (2005) factors from their publicly available dataset (up to one-year maturity), 2005–2019. Path coefficients are negative and significant across all eight specifications. Extended measures (columns 1–2, 5–6) capture approximately 3–4× larger effects than short-end GSS measure (columns 4, 8), validating that longer maturities reveal stronger duration effects. Hausman-Wongswan alternative identification (columns 3, 7) confirms robustness. Pattern holds for both environmental pillar and ESG composite. Magnitude ratios computed comparing Kansoy2018 to GSS2018 path coefficients within overlapping sample period. All specifications include industry-by-event fixed effects and firm controls (log size, book leverage, profitability, dividend status). Standard errors clustered by event in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Panel C documents systematic path vulnerability across all specifications. For environmental scores (columns 1–4): extended GSS yields $\zeta = -0.172$ (standard error 0.069, $p = 0.014$) over the full sample, $\zeta = -0.292$ (standard error 0.057) restricting to 2005–2018, Hausman-Wongswan produces $\zeta = -0.169$ (standard error 0.049), and original GSS factors generate $\zeta = -0.094$ (standard error 0.035). All coefficients prove highly significant with consistent negative signs. For composite ESG scores (columns 5–8), the pattern replicates: extended GSS full sample $\zeta = -0.157$ (standard error 0.069), extended 2005–2018 $\zeta = -0.275$ (standard error 0.057), Hausman-Wongswan $\zeta = -0.160$ (standard error 0.051), original GSS $\zeta = -0.071$ (standard error 0.039, $p = 0.072$, marginally significant).

The magnitude differences prove economically revealing. Comparing specifications within the overlapping 2005–2018 sample period, extended GSS path coefficients exceed original GSS by factors of 3.10 for environmental scores and 3.89 for ESG composite scores. This systematic pattern validates the duration mechanism interpretation. Original GSS factors emphasise short-end movements (up to one-year maturity), capturing mainly near-term policy expectations. Extended specifications incorporating two-, five-, and ten-year Treasury movements capture longer-horizon rate expectations. If path vulnerability derives from duration exposure—long-lived cash flows whose present values prove sensitive to long-horizon discount rates—measures incorporating longer maturities should reveal stronger effects. The three- to four-fold magnitude difference confirms this prediction.

Hausman-Wongswan decomposition provides methodological validation using an independent identification approach based on federal funds futures rather than Treasury yields. The coefficients ($\zeta = -0.169$ for environmental, $\zeta = -0.160$ for ESG composite) fall between extended and original GSS estimates, consistent with their intermediate horizon coverage. The strong negative coefficients using this alternative methodology demonstrate that results reflect genuine transmission heterogeneity rather than GSS-specific measurement choices.

Columns (1) and (5) extend the analysis through 2025, demonstrating temporal stability. Full-sample coefficients remain negative and significant with magnitudes comparable to the restricted 2005–2018 period, confirming that documented path vulnerability persists beyond the period covered by original GSS and Hausman-Wongswan data. The consistency across both environmental pillar scores and composite ESG measures demonstrates that results generalise beyond the specific environmental dimension to broader sustainability characteristics.

Panel B examines target channel interactions, providing additional validation. Target coefficients are consistently positive across specifications, indicating clientele-based insulation operates regardless of decomposition methodology. The pattern proves weaker

and less consistent than path channel results, as expected given our theoretical emphasis on duration exposure as the primary mechanism.

These results demonstrate that path vulnerability reflects genuine transmission heterogeneity operating through duration channels rather than measurement artefacts. Decomposition methodologies differ in horizon coverage and identification assumptions, but all document systematically greater sensitivity to forward guidance for firms with superior environmental or ESG performance. The three- to four-fold magnitude gradient from short-end to long-end measures validates that longer-maturity rate movements—precisely those affecting long-duration investments—drive the documented transmission heterogeneity.

6.2.2 Sample Composition and Inference Robustness

As we underlined above that ESG data coverage expanded substantially over our sample period which from 37.3 per cent to 97.4 per cent of the index universe. Changing composition could potentially drive results if firms entering coverage differ systematically in monetary policy sensitivity independent of environmental characteristics. Additionally, the baseline specification clusters standard errors by event, which may not account for all relevant correlation structures in the data.

Table 10 addresses both concerns simultaneously. Columns (1) and (2) examine sample composition by comparing the full unbalanced panel to a balanced panel of 412 firms with continuous environmental score coverage from 2010 through 2024. Column (1) reproduces baseline estimates using the full sample ($\zeta = -0.209$, standard error 0.043), while Column (2) restricts to the balanced panel ($\zeta = -0.221$, standard error 0.048). Coefficients are statistically indistinguishable and economically nearly identical, confirming that expanding coverage does not drive the documented pattern. The balanced panel coefficient is slightly larger in absolute value, consistent with firms maintaining consistent ESG reporting exhibiting more pronounced environmental investment characteristics, but the difference proves economically trivial.

In addition sample composition, we have also checked inference robustness. Columns (3) and (4) show inference robustness by comparing event clustering (baseline) to two-way clustering by both firm and event following [Cameron, Gelbach, and Miller \(2011\)](#). This allows arbitrary correlation within firms and within events. Column (3) clusters by event, while Column (4) implements two-way clustering. Point estimates are identical across clustering specifications (clustering affects inference not estimation). Two-way clustering increases the path vulnerability standard error from 0.068 to 0.078, but the coefficient

remains significant ($p = 0.027$). Standard errors change modestly but path vulnerability remains significant at conventional levels under two-way clustering.

TABLE 10. Sample Composition and Inference Robustness

	(1) Full Sample 2005–25	(2) Balanced Panel 2010–24	(3) Event Clustering (Baseline)	(4) Two-Way Clustering
$TS \times E$	0.206* (0.123)	-0.016 (0.148)	0.206* (0.123)	0.206 (0.127)
$PS \times E$	-0.172** (0.068)	-0.221*** (0.048)	-0.172** (0.068)	-0.172** (0.078)
Industry×Event FE	Yes	Yes	Yes	Yes
Firm Controls	Yes	Yes	Yes	Yes
Observations	51,534	44,892	51,534	51,534
R^2	0.686	0.688	0.686	0.686

Notes: Columns (1)–(2) compare full unbalanced panel versus balanced panel. Columns (3)–(4) compare event clustering (baseline) versus two-way clustering by firm and event following [Cameron, Gelbach, and Miller \(2011\)](#). Path vulnerability coefficients remain negative and significant across all specifications. All specifications include industry-by-event fixed effects and firm controls. Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

The robustness of coefficients across unbalanced and balanced panels demonstrates that results reflect systematic transmission heterogeneity operating across the full distribution of S&P 500 constituents with environmental performance data, not compositional artefacts from coverage expansion. The persistence of significant path vulnerability under two-way clustering confirms that the documented pattern is robust to alternative assumptions about error correlation structure. The structural break coefficient proves similarly robust under two-way clustering (Appendix Table ??).

7. Conclusion

Firms with superior environmental performance exhibited substantially greater vulnerability to contractionary forward guidance during 2005-2015, with path surprises shifting long-horizon discount rates generating larger negative returns for high-environmental firms within announcement windows. This vulnerability attenuated completely after 2015-2016, with the path coefficient for 2016-2025 becoming economically negligible and

statistically indistinguishable from zero. The target channel showed modest insulation throughout the sample, consistent with inelastic ESG-mandated capital tempering short-horizon demand shifts. This pattern of path amplification transforming to neutrality while target attenuation persisted demonstrates that decomposing policy news into horizon-specific components proves essential for understanding environmental heterogeneity in monetary transmission.

The central contribution establishes that environmental heterogeneity in monetary transmission is not technologically determined but represents an equilibrium outcome shaped by financial market structure. Duration exposure from long-lived environmental investments created vulnerability to forward guidance when hedging instruments were unavailable. As green bond markets expanded from approximately £11 billion in 2013 to over £625 billion annually by 2024 and climate policy credibility strengthened through the Paris Agreement, the evidence suggests firms gained capacity to manage duration exposure more effectively. The timing, cross-sectional patterns, and horizon-specificity of the attenuation are consistent with enhanced hedging capacity enabling firms to offset transmission vulnerability without changes to underlying technology. Cross-sectional evidence is consistent with the hedging capacity mechanism: larger firms with superior market access exhibited attenuated path vulnerability throughout the sample, foreshadowing the time-series pattern as markets developed broadly.

Our findings extend the literature on heterogeneous monetary policy transmission. Building on [Bernanke, Gertler, and Gilchrist \(1999\)](#) and [Gertler and Karadi \(2015\)](#), who document that financial constraints and balance sheet strength shape transmission, we show environmental characteristics generate distinct horizon-specific mechanisms that evolve with market development. The identification strategy follows [Nakamura and Steinson \(2018\)](#) in using industry-by-event fixed effects to address central bank information effects, and extends [Gürkaynak, Sack, and Swanson \(2005\)](#), [Swanson \(2021\)](#) and [Gürkaynak, Karasoy-Can, and Lee \(2022\)](#) by demonstrating that horizon decomposition proves necessary to detect sustainability-related heterogeneity. Duration effects amplify path sensitivity; clientele effects attenuate target sensitivity. Aggregate measures obscure both channels, explaining why prior work without decomposition found limited environmental heterogeneity in monetary transmission.

The results connect to the sustainable finance literature examining how environmental preferences and climate risk shape asset prices. [Pástor, Stambaugh, and Taylor \(2021\)](#), [Pedersen, Fitzgibbons, and Pomorski \(2021\)](#), and [Pástor, Stambaugh, and Taylor \(2022\)](#) develop equilibrium models where heterogeneous ESG preferences affect expected returns through clientele effects. Our evidence indicates duration mechanisms operating through fundamental cash flow characteristics quantitatively dominated preference-based

clientele effects during the pre-Paris period, though both channels operate. Bolton and Kacperczyk (2021) and Bolton and Kacperczyk (2023) document carbon risk premia and institutional ownership patterns suggesting investors price climate exposure. Hong and Kacperczyk (2009) show norm-constrained investors avoid sin stocks, creating distinct pricing dynamics. We document an analogous but inverse phenomenon: ESG-motivated investors provide modest insulation for environmental leaders. Recent work examines green-brown monetary transmission using shorter samples. Bauer, Offner, and Rudebusch (2024) analyse European markets from 2012-2023, finding brown firms more sensitive to ECB policy in pooled specifications. Döttling and Lam (2024), Havrylchyk and Pourabbasvafa (2025), and Patozi (2024) examine US markets with similar findings. Our longer time series spanning 2005-2025 enables explicit testing of whether heterogeneity emerged or evolved, revealing structural breaks that pooled estimates obscure. This time variation challenges models treating ESG transmission effects as immutable and demonstrates that market structure shapes transmission architecture.

Our findings speak directly to the policy concern articulated by Schnabel (2021), who warned that anti-inflationary tightening could disproportionately constrain green investment, forcing difficult trade-offs between price stability and climate objectives. The pre-Paris patterns validate this concern for that period, with differential transmission proving economically consequential. However, the evidence suggests these differential burdens were responsive to financial market development rather than structurally determined by technological constraints. For central bank frameworks, monetary policy models must incorporate time-varying, horizon-specific transmission heterogeneity rather than assuming fixed parameters. Scalar representations of policy systematically misstate pass-through to sustainability-mandated portfolios. Financial stability assessments should recognise that climate policy shapes transmission architecture through market structure effects, not merely through the pricing of existing risks. The expansion of green financing represents a plausible mechanism through which environmental policy altered how monetary policy transmits across firms with different environmental characteristics. For portfolio management, environmental characteristics create policy exposures that vary across both horizons and market regimes. Strategies premised on mechanical duration-based sensitivities performed poorly after 2015 when the path channel attenuated. Simple duration models will misstate risks as green financing markets continue developing globally.

Several constraints merit acknowledgement. Our analysis focuses on large-cap US equities; smaller firms, private entities, and non-US markets may exhibit different patterns. We rely on a single ESG data provider (LSEG Refinitiv) though structural break timing and cross-sectional patterns provide confidence in robustness. Most importantly,

while our evidence strongly points toward green financing market development as the mechanism the timing coincidence, cross-sectional size patterns, horizon-specificity, and magnitude gradients across maturity decompositions all support this interpretation we do not directly test the channel at the firm level. Direct validation linking individual firms' green bond issuance, debt maturity transformation, or term structure management to reduced path sensitivity would strengthen the causal interpretation but requires proprietary issuance data and granular liability structure information we leave it for further research. Our current evidence provides strong circumstantial support for the hedging capacity mechanism, but the inference remains partly indirect. Future work could also validate identification using placebo tests on non-FOMC days, though our industry-by-event fixed effects, extensive structural break validation, and comprehensive robustness checks provide confidence against spurious correlation. Priority extensions include geographic replication in European markets where [Bauer, Offner, and Rudebusch \(2024\)](#) document differential effects in pooled samples but cannot test for regime change, institutional ownership analysis examining whether shifts in investor composition explain transmission evolution, and cross-provider ESG validation demonstrating that documented patterns replicate across MSCI, Sustainalytics, Bloomberg, and other independent assessment systems.

Understanding how climate transition interacts with conventional macroeconomic stabilisation becomes increasingly important as the global economy shifts away from carbon-intensive production. Our analysis demonstrates that monetary policy transmission across environmental characteristics evolved with financial market depth and climate policy credibility, not purely reflecting fixed technological factors. The evidence suggests what appeared to be a technological constraint was responsive to institutional innovation. The mechanism suggests potential reversibility: if green financing markets tighten or policy credibility shifts, path sensitivity could re-emerge. Financial market depth and policy credibility determine whether fundamental cash flow characteristics translate into differential monetary policy exposure, with continued evolution likely as frameworks develop and markets adapt to the demands of climate transition.

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