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Green Stocks and Monetary Policy Shocks: Evidence from Europe*

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Abstract

Policymakers and researchers worry that the low-carbon transition may be inadvertently delayed by higher global interest rates. To examine whether green investment is especially sensitive to interest rate increases, we consider the effect of unanticipated monetary policy changes on the equity prices of green and brown European firms. We find that brown firms, measured in terms of carbon emission levels or intensities, are more negatively affected than green firms by tighter monetary policy. This heterogeneity is robust to different monetary policy surprises, emission measures, econometric methods, and sample periods, and it is not explained by other firm characteristics. This evidence suggests that higher interest rates may not skew investment away from a sustainable transition.

Keywords: monetary transmission, carbon premium, ESG, climate finance
JEL Classifications: E52, G14, Q54, Q58

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1 Introduction

Consumer prices accelerated surprisingly quickly in many countries in 2021 and 2022, and central banks responded by pushing up short-term interest rates at the fastest pace in decades, from levels near zero to around 5% or more. While this global monetary tightening appears to have been successful in fostering a return toward price stability, higher interest rates may also inadvertently slowed the transition to a low-carbon economy. Given the urgent need for a green transition to forestall further climate change, such potential adverse side effects raise serious concerns. Specifically, observers have worried that the increase in the cost of capital resulting from tighter monetary policy would significantly and disproportionately reduce investment in new renewable and green projects. For example, Schnabel (2023) highlighted concerns in Europe that the latest monetary policy tightening "may discourage efforts to decarbonize our economies rapidly." She noted the competitive disadvantage of building renewable energy facilities at high interest rates. Intuitively, the substantial initial financing costs of renewable energy infrastructure together with minimal future fuel costs result in long-duration cash flow investments that should be particularly sensitive to interest rates. Indeed, research has highlighted the relevance of financing conditions for the production of renewable energy and identified the level of interest rates an important determinant of the cost of generating clean electricity; see Egli et al. (2018), Schmidt et al. (2019), and the references therein. Thus, the sharp rise in interest rates in recent years may have reduced investments in clean energy production and slowed decarbonization efforts (Monnet and van 't Klooster, 2023; Aguila and Wullweber, 2024).

Of course, a monetary tightening will likely slow business investment of all types. The key open empirical question is whether a monetary tightening has disproportionate effects on green investment, technologies, and businesses. Does monetary policy have heterogeneous effects so that low-carbon "green" companies are more sensitive to interest rates than higher-carbon "brown" firms? In this case, a tighter stance of monetary policy may unduly slow the green transition. In this paper, we investigate this issue and find little supporting evidence in financial markets for such adverse effects from tighter monetary policy. Instead, the equity prices of brown firms appear to be more sensitive to interest rate surprises than those of low-carbon, green firms.

Our empirical approach is an event-study analysis of the firm-level stock market responses to monetary policy actions by the European Central Bank (ECB). As in much recent empirical monetary research, we focus on high-frequency monetary policy surprises, that is, the changes in interest rates over narrow intraday windows around the Governing Council's policy announcements. Because these surprises are exogenous with respect to changes in asset prices around the policy announcements, they can identify the causal effects of monetary policy actions on financial markets and macroeconomic outcomes.[1] We consider several different measures of ECB monetary policy surprises in our analysis. We combine these data with firm-level environmental measures, stock prices, and financial accounting data for euro area firms. Our baseline measure of greenness is emission intensity, calculated as the ratio of carbon emissions to sales, an indicator that is widely used in climate finance to differentiate green and brown stocks (e.g., Bauer et al., 2022; Huij et al., 2024). Alternatively, we measure the greenness of firms using other emission intensity measures, emission levels, and indicators based on ESG (environmental, social, and governance) data.

The central result of our panel regressions is that ECB policy surprises have greater effects on brown stocks, that is, stocks of firms with high emissions and emission intensities. This result is robust to using a range of different regression specifications and sample choices as well as different measures of monetary policy surprises and different emission-based measures of greenness (although we do not find systematic firm-level differences based on ESG indicators). Regressions that control for sector-by-time fixed effects yield similar estimates as our baseline regressions, which implies that the within-industry green/brown heterogeneity in interest rate sensitivity is similar to the across-industry heterogeneity. In addition to the event-study panel regressions, we also employ tools from empirical asset pricing: We form green and brown portfolios based on lagged emission intensities that investors could have constructed in real-time. The results show that brown portfolios reacted relatively more strongly to monetary policy. For example, after an ECB tightening announcement, brown-minus-green spread portfolios tend to loose substantial value. For the past few years of monetary tightening we document that the largest recent hawkish policy surprises resulted in substantial underperformance of brown stocks, in line with our overall evidence. Overall, our evidence strongly suggests that tighter monetary policy hurts high-carbon companies and brown stocks significantly more than low-emission companies and green stocks.

The firm-level impact of monetary policy has been shown to depend significantly on firm characteristics such as leverage, age, size, and liquidity, among others.[2] Existing studies have focused exclusively on the United States, and there is no established evidence of the heterogeneous effects of ECB monetary policy on the stock prices or investment behavior of European companies, at least to the best of our knowledge. To fill this gap, we consider a range of commonly used firm characteristics, and document how they affect the sensitivity of

[1]Classic empirical studies using monetary policy surprises include Rudebusch (1998), Kuttner (2001), Bernanke and Kuttner (2005) and Gürkaynak et al. (2005). For recent work and an in-depth discussion of this high-frequency identification, see Bauer and Swanson (2023a).

[2]See, for example, Ozdagli (2018), Ozdagli and Velikov (2020), Ottonello and Winberry (2020), Cloyne et al. (2023), Jeenas (2023), Döttling and Ratnovski (2023), and Jungherr et al. (2024).

stock prices to ECB policy surprises. Consistent with the industry-level results of Bernanke and Kuttner (2005) for the U.S., we find that stocks with higher market betas exhibit a stronger sensitivity than low-beta stocks. We also find an important role for the book-to-market ratio, leverage, profitability and age, broadly consistent with U.S. evidence.

Green and brown stocks show certain systematic differences regarding their business characteristics. For example, high-carbon firms tend to have higher leverage, lower profitability, and more tangible capital, which are all attributes typically associated with a greater sensitivity to monetary policy. This firm-level variation naturally raises the question whether the differential response of green and brown stocks that we document is a separate dimension of heterogeneity, or instead is simply a reflection of other differences between brown and green firms. To answer this question, we estimate regressions that include interactions of the ECB policy surprise with both carbon intensity as well as with various other firm characteristics, either individually or jointly. Controlling for other characteristics has essentially no impact on our estimates of the green-brown heterogeneity, which indicates that it is indeed the greenness of a firm that plays a significant independent role for the stock price sensitivity to monetary policy.

Several other recent studies have examined the differential impact of monetary policy interest rate shocks on the equity prices of brown and green firms, including Döttling and Lam (2024), Havrylchyk and Pourabbasvafa (2023), Patozi (2024), and Benchora et al. (2023). These all use an event study research strategy to investigate the heterogeneous effects of Federal Reserve monetary policy announcements on the equity prices of U.S. green and brown firms. The four papers broadly arrive at a similar conclusion that higher-carbon brown firms tend to have a stronger equity price responses to monetary policy shocks than lower-carbon green firms. Our results for Europe are qualitatively and quantitatively consistent with these earlier results for the United States. By contrast, despite using similar event study methods, Fornari and Gross (2024) find that green firms are as sensitive to monetary policy as brown firms in the United States and more sensitive in the euro area. The difference between their findings and other work largely stems from their particular classification of brown firms, which includes all firms that do not report emissions data and is binary, ignoring shades of green and brown. Fornaro et al. (2024) classify green U.S. firms using data on green patents, and find that investment by these firms declines more strongly in response to monetary contractions than for other firms, which leads the authors to conclude that "higher interest rates and tighter credit conditions could slow down [...] progress toward climate sustainability goals." Clearly, the empirical findings about differential effects of monetary policy strongly depend on the type of green-brown firm classification, which underscores the importance of further research in this area.

Across all of the studies, there is little agreement as to the relevant causal mechanisms and interpretations for the differential sensitivity of green and brown stocks to monetary policy. We distinguish four broad possible channels. In a "credit channel" explanation, brown firms are more reliant on external financing; therefore, their stock prices are more sensitive to changes in interest rates. However, according to our European results, differences in firm characteristics capturing the importance of external finance, including the share of tangible capital, do not help explain the green/brown policy response heterogeneity, in contrast to the findings of Havrylchyk and Pourabbasvafa (2023) and Döttling and Lam (2024) based on U.S. data. Two other channels relate to the existence of a carbon premium, that is, the higher expected returns for brown stocks. If there is a sizable carbon risk premium in brown stocks, then their stronger response could arise from the effects of monetary policy on the quantity of transition risk (Benchora et al., 2023) or more broadly on risk appetite and prices of risk via a "risk-taking channel of monetary policy" (Bauer et al., 2023).[3] Similarly, if the carbon premium also reflects green investor preferences—a carbon aversion premium—that could also reduce the sensitivity of green stocks to monetary policy shocks (Benchora et al., 2023; Patozi, 2024). While the climate finance has not reached a consensus on the existence of a carbon premium (Bauer et al., 2022; Atilgan et al., 2023; Zhang, 2024), recent evidence by Pastor et al. (2022) and Eskildsen et al. (2024) for higher expected returns of brown stocks provides some indirect support for these two channels. Finally, brown stocks may be more sensitive to monetary policy via a "demand channel" if the high-carbon firms face demand for their products that is more responsive to interest rate changes. It is well known that some industries, including durable goods and housing, are more cyclical and interest rate sensitive than others (e.g. Petersen and Strongin, 1996), and such differences between green and brown industries—together with within-industry differences in interest rate sensitivity of demand—may help explain differences in the heterogeneous policy response of green and brown stocks. However, for all of these potential explanation, much more work is needed to sharpen both the evidence and our theoretical understanding of their role in explaining differences in green and brown stock price sensitivities.

Most earlier work in this area focuses solely on the U.S. experience, and our examination of the green/brown heterogeneity of European equity pricing with respect to ECB monetary policy shocks provides an important investigative expansion along several dimensions. First, while it was the monetary tightening of 2022 and 2023 that motivated concerns about the impact of higher interest rates on low-carbon investment, the U.S. studies generally have

[3] In important related work, Altavilla et al. (2024) examine the effects of ECB monetary policy shocks on climate risk in bank lending and uncover a climate risk-taking channel for monetary policy, so an unexpected monetary tightening raises the climate risk premium charged to high-emission firms.

samples that end before this crucial episode. Our data sample extends to include that tightening and the associated relevant empirical evidence.

Even more importantly, it is in Europe that concerns about the impact of higher interest rates on the green transition have been most salient (Schnabel, 2023). U.S. policymakers have not expressed the same level of urgency or even agreement on this issue as European policymakers.[4] The relative lack of clarity about a U.S. green transition path must affect investors' perceptions and pricing of climate equity risk. For example, a green transition in the United States may be plagued by so much policy uncertainty that investors view changes in the Federal Reserve policy rate as a second-order determinant to green/brown valuations. Our European analysis can better link relevant empirical evidence with the widespread and high-level discourse on the connections between monetary policy and the green transition. In this way, our evidence speaks to the question whether tighter monetary policy and higher interest rates may have slowed the path to carbon neutrality by adversely influencing firms' investment decisions, capital replacement, and sustainability efforts.

There are a variety of other differences between the U.S. and European economies that can inform our understanding of green/brown monetary policy heterogeneity. For example, relative to the United States, the euro area has a different set of climate policies—with a greater skew towards carbon taxes than subsidies–that may interact differently with higher interest rates and monetary policy more generally. In addition, the euro area may also have a greater share of investors with preferences for low-carbon firms given the divisive and politicized views of sustainable investing in the United States, and Patozi (2024) argues that such green investors are less likely to substitute away from green stocks following a contractionary monetary policy shock. Finally, the different sectoral distribution of the European economy provides a useful check on the U.S. results. Havrylchyk and Pourabbasvafa (2023) suggests that a key driver of the U.S. green/brown differential reaction to Fed policy shocks is the outsize reaction of the oil and gas mining and production sectors. This reaction may however partly reflect the sizable interest rate sensitivity of fossil fuel prices and consumer demand, a mechanism that is only tangentially related to the impact of interest rates on the green transition. In Europe, where fossil fuel production is a much smaller share of total output, this confounding effect is greatly reduced. In sum, the European experience provides a new and substantially different empirical sandbox to explore the outstanding issues and discrepancies in earlier research.

In terms of the climate finance literature, our paper makes five empirical contributions.

[4]The United States is a notable outlier among developed nations in having weak legal, social, and political commitments to a green transition. For example, the United States is the only country to ever have withdrawn for a time from the Paris Agreement on Climate Change.

First, we document that in the euro area, stocks of high-carbon firms are more sensitive to monetary policy surprises. Second, we provide new results on the heterogeneous effects of the ECB's monetary policy on euro area stocks, which show an important role for firms' leverage, profitability, and book-to-market multiples. Importantly, none of these other firm characteristics account for the heterogeneous impact of monetary policy on green and brown firms. Third, our closer investigation of the recent monetary tightening episode suggests that green European firms were not disproportionately affected by the ECB's rate hikes, alleviating concerns about a negative impact on the ongoing green transition. Fourth, we contribute to the discussion of possible channels for differential brown/green effects of monetary policy. Finally, we show that our results hold even if we narrow our focus to just the energy industry and compare the differential monetary policy effects on renewable and fossil fuel equity indexes.

Our paper is most closely related to the four U.S. studies cited above on the effects of Fed monetary policy surprises on green and brown stocks. Other empirical work in climate finance has used event studies to estimate the differential effects on green and brown stocks of climate and fiscal policies (Bauer et al., 2024b) or election outcomes that shift probabilities of future policies (Ramelli et al., 2021). Separately, a burgeoning macro-climate literature investigates the interactions of monetary policy and climate policies, or the effects of green monetary policies, using general equilibrium models. Ferrari and Nispi Landi (2024, 2023) study green QE—purchases of low-carbon assets by central banks—and find that in the euro area, it likely has a negligible impact on carbon emissions. Both Diluiso et al. (2021) and Dafermos et al. (2018) conclude that green QE for financial stability can reduce climate-induced financial instability. Benmir and Roman (2020) consider interactions of carbon policy and quantitative easing policies. Our paper contributes new empirical evidence on the climate-relevant consequences of monetary policy decisions. Finally, our work is part of the broader climate finance literature on the pricing of green and brown stocks. This literature is large and growing quickly, see Bolton and Kacperczyk (2021), Pastor et al. (2022), Bauer et al. (2022), Aswani et al. (2024), Ardia et al. (2023), Huij et al. (2024), Eskildsen et al. (2024), and Bauer et al. (2024a), among many others.

The paper is structured as follows: Section 2 explains our different data sources and presents summary statistics. Section 3 shows the main results and various robustness checks. Section 4 considers the role of other firm characteristics for explaining the observed heterogeneity in the responsiveness of European firms to monetary policy. Section 5 discusses the possible channels and explanations for the documented green-brown heterogeneity. Section 6 considers the narrower question about whether interest rates disproportionately affect the renewable energy sector. Section 7 concludes.

2 Data

2.1 Firm-level data

Our firm-level data are from the ESG and Datastream databases of LSEG Data & Analytics. The ESG database is quite comprehensive and currently includes firms that together account for more than 90% of the global stock market capitalization.[5] From this database, we include all euro-area publicly traded firms.[6] While coverage in the ESG database begins in 2002, the availability of emissions data in the early years is quite sparse; therefore, we use emissions data beginning in January 2010. Our sample ends in October 2023.

We consider a range of measures of firm-level greenness. First, we use measures of the carbon emissions of a firm, specifically, the sum of scope 1 (direct) and scope 2 (indirect) total greenhouse gas (GHG) emissions in tons of total CO_2 equivalents. Following other climate finance studies, we leave out scope 3 emissions, because these indirect emissions from upstream and downstream activities of the reporting firm are very large in magnitude and particularly difficult to estimate.[7] We focus on emission intensity as our preferred measure of greenness, calculated as the ratio of emissions and total revenues. This measure is widely used in empirical work in climate finance (e.g., Bauer et al., 2022; Benchora et al., 2023; Havrylchyk and Pourabbasvafa, 2023). As an alternative measure of emission intensity, we scale emissions by a firm's market capitalization. We also consider the (log) level of emissions, which Bolton and Kacperczyk (2021, 2023) found to be an important determinant of stock returns. For all of these greenness measures, the underlying carbon emissions of some firms are estimates from the data provider that are imputed based on other firm-level data. The inclusion of estimated emissions can be problematic in some empirical applications (Aswani et al., 2024) but not others (Bauer et al., 2022). To ensure that our results are robust to this issue, we also consider alternative samples that are limited to only the observations when firms actually reported emissions, excluding vendor-based estimates.

Second, we consider the environmental ratings that constitute ESG scores. Although these ratings have some disadvantages, including discrepancies across data providers (Billio et al., 2021) and ex post revisions (Berg et al., 2021), they are often used in climate finance research. Indeed, in some applications, certain ESG scores seem to appropriately capture climate transition risk (Pastor et al., 2022; Bauer et al., 2024b). We use two types of scores:

[5] For more information on this ESG database, see `https://www.lseg.com/en/data-analytics/financial-data/company-data/esg-data`. It was formerly called the Refinitiv ESG database and, still earlier, the ASSET4 database.

[6] Our results are robust to excluding firms in the financial and utilities industries, as in Ozdagli and Velikov (2020) and Döttling and Lam (2024).

[7] See, for example, Kruse et al. (2020), Bauer et al. (2022) and Huij et al. (2024).

"E scores" are the broader environmental scores that incorporate metrics from three different categories: emissions, innovation, and resource use. "Emission scores" are the category score for metrics in the emission category. These scores are between 0 (a poor environmental rating) and 100 (a very green firm), and they are constructed by comparing firms to their industry peers.

We winsorize the variables that are based on emissions, as well as all of the accounting variables described below, at the one-percent level. Panel A of Table 1 shows summary statistics for the firm-by-year panel of greenness measures.

For financial market data, we extract daily returns and annual accounting data from LSEG Datastream and Worldscope. To create our baseline sample of firms, we filter out stocks that are not common equity or primary equity quotations. We also remove securities with prices lower than $1 and securities whose name fields indicate non-common equity affiliation.[8] Our final sample contains 916 companies. Firm-level controls include size (proxied by the log of market capitalization), market-to-book equity, profitability (measured as return on assets), book leverage, sales growth, investment (calculated as capital expenditure divided by total assets), and log of net property, plant, and equipment. The daily stock returns are close-to-close returns adjusted for buybacks and stock splits. Panels B and C of Table 1 show summary statistics of our firm-level controls and the daily stock returns.

Our empirical approach tries to ensure that the differential green/brown equity returns in our event-study analysis could have actually been achieved by investors using publicly available information. Therefore, we account for publication lags of firm-level accounting and ESG data. While accounting data are usually released within three to six months after the end of the reporting year, ESG data—including emissions—are often not made public until up to nine months after the reporting year (Bauer et al., 2022; Ardia et al., 2023). To conservatively account for this information lag, we impose a twelve-month publication lag, which is best illustrated with an example: Most accounting data for 2020 would have be published in the second quarter of 2021, much of the emissions data were not published until fall 2021. We use accounting and emissions data for 2020 for the observations with ECB announcements and stock returns from January to December 2022.[9]

[8]These filters are common practice in the empirical asset pricing literature. For a more detailed description, see Bauer et al. (2022).

[9]In additional analysis, we have verified that a six month publication lag, as used in Bauer et al. (2022) and many other empirical asset pricing studies, leads to similar results.

Table 1: Summary Statistics

	Mean	SD	Min	q25	Median	q75	Max	Obs.
(A) Environmental performance								
Emissions/sales	0.30	1.91	−3.02	0.01	0.03	0.12	107.71	5,949
Emissions/market cap	0.61	3.39	0.00	0.01	0.03	0.17	108.48	5,966
Log emissions	11.56	2.92	−4.76	9.57	11.49	13.54	19.09	5,957
E score	56.49	26.98	0.00	37.29	60.76	79.14	98.94	5,965
Emission score	61.82	30.30	0.00	40.62	69.15	88.10	99.89	6,156
(B) Firm-level controls								
Size	21.01	1.90	15.16	19.65	20.97	22.31	28.23	10,271
Book/market	0.95	3.05	0.00	0.34	0.59	1.01	116.73	10,271
Leverage	0.25	0.17	0.00	0.12	0.24	0.36	3.71	10,075
Profitability	0.10	2.06	−172.76	0.00	0.02	0.09	12.99	9,379
Rev. growth	0.64	3.07	−12.75	−1.37	0.47	2.61	16.61	9,340
Investment	0.04	0.04	0.00	0.02	0.03	0.06	0.68	10,102
Log PP&E	19.28	2.57	8.17	17.64	19.37	21.10	26.05	8,765
Liquidity	0.14	0.15	−0.03	0.05	0.10	0.17	3.89	10,042
Tangibility	0.75	0.33	−5.62	0.60	0.86	0.97	12.78	5,976
Beta	0.98	0.45	−0.23	0.66	0.96	1.28	2.59	10,221
Cash flow	0.06	0.61	−0.96	0.02	0.05	0.09	60.61	10,242
Age	17.80	16.65	−13.00	7.00	15.00	23.00	117.00	10,066
(C) Firm-level stock returns (%)								
Daily return	0.04	2.62	−36.03	−0.92	0.00	1.11	91.49	81,980
(D) High-frequency monetary policy surprises (bps)								
3-months OIS	0.34	2.21	−5.60	−0.17	0.00	0.50	10.35	107
1-Year OIS	0.05	3.37	−14.92	−0.65	−0.12	1.07	10.66	107
PC	0.05	3.61	−12.75	−0.93	−0.15	1.37	12.42	107
Target	0.08	2.07	−6.26	−0.44	−0.30	0.15	11.08	107
FG	0.35	2.01	−4.05	−0.64	0.11	0.67	10.33	107
KTW	0.34	2.21	−5.60	−0.17	0.00	0.50	10.35	67
JK	0.69	4.34	−7.36	−1.37	0.54	2.25	18.72	107

Summary statistics for firm-level variables and monetary policy surprises. Environmental measures are described in the text. Size is log of market capitalization in millions USD, market leverage is total debt divided by by total assets, profitability is return on assets, investment is capital expenditure divided by total assets. Variables based on emissions, and all firm-level controls, are winsorized at the one-percent level. Monetary policy surprises are the 30-minute changes in the three-month OIS rate around the monetary policy announcement. Returns are daily calculated using close to close prices. Sample for panels A and B is a year-by-firm panel from 2010 to 2021 (except for the variable Age which differs by announcement); panels C (announcement-by-firm panel) and D (time series) use 107 ECB announcements from January 2012 to October 2023.

2.2 ECB monetary policy surprises

To estimate the causal effects of the ECB's monetary policy changes on green and brown stocks requires a measure of exogenous policy changes. Following a long tradition in empirical monetary economics, going back to Kuttner (2001) and Gürkaynak et al. (2005), we use high-frequency changes in interest rates around monetary policy announcements, which reflect new information about the current stance and future course of monetary policy.[10]

For the ECB, a detailed high-frequency database of asset price changes around monetary policy announcements is available online: the Euro Area Monetary Policy Event-Study Database, described in Altavilla et al. (2019). To account for the specific way the ECB releases information about its monetary policy actions, which differs from the Fed's monetary policy announcements, this database contains asset price changes over three different intraday windows: the press release window, the press-conference window, and the total monetary event window, which includes both the press release and the President's press conference. Based on changes in different interest rates over the different event windows, a number of policy surprise measures can be constructed.

Our baseline measure is the change in the one-year overnight index swap (OIS) rate over the entire monetary event window, which includes the effects of both the press release and the subsequent press conference on financial markets.[11] The change in the one-year OIS rate captures the revision in the average expected future policy rate over the next year.[12] The one-year maturity corresponds to the horizon of monetary policy expectations typically considered in the literature on high-frequency monetary policy surprises. For example, Gürkaynak et al. (2005), Nakamura and Steinsson (2018) and Bauer and Swanson (2023a) use money market futures up to the four-quarter-ahead Eurodollar futures contract. This measure also has the advantage of being straightforward to calculate without requiring additional assumptions. We also consider the change in the three-month OIS rate over the monetary event window, following Krusell et al. (2023). A relatively short interest rate maturity is often used in this context, going back to Kuttner (2001) who used the spot-month fed funds futures contract, while Gertler and Karadi (2015) and others use the three-month-ahead fed funds futures contract. However, short-term interest rates in the Euro area were constrained by the effective lower bound on nominal interest rates for a substantial part of our sample period. During this time, monetary policy events mainly affected interest rates

[10] See Bauer and Swanson (2023a) for a recent discussion of the practical considerations and caveats of using high-frequency monetary policy surprises.

[11] Specifically, this is the change in the median OIS quote from around 13:30—before the press release—to the median quote at around 15:45—after the press conference.

[12] Change in risk premia may also contribute to changes in term rates, but their contribution to near-term rate changes at high frequencies is likely to be minor (Piazzesi and Swanson, 2008).

and financial markets via forward guidance, which is a strong reason to extend the monetary policy surprise measure to longer maturities.

To consider longer-term rates beyond the one-year OIS rate, we follow the common practice to construct monetary policy surprises by combining changes in different interest rates; see Gürkaynak et al. (2005), Nakamura and Steinsson (2018), Altavilla et al. (2019), and many others. Specifically, we use the first principal component of changes in the seven OIS rates considered by Altavilla et al. (2019), with maturities of one, three, and six months, and one, two, five and ten years. We again take the change over the monetary event window to capture as much of the new information about the ECB's policy as possible. This surprise is then scaled to have a unit effect (i.e., a principal component loading of one) on the one-year OIS rate. We call this measure "PC" for principal component.

For better comparability with existing results, we also analyze the effects of the "Target" and "Forward Guidance" surprise of Altavilla et al. (2019). Both are based on principal components of the changes in the seven OIS rates mentioned above. The Target surprise uses changes over the press release window, and is constructed in a way to load most strongly on short-term rates changes, in order to capture surprise changes in the target rate similar to the target factor of Gürkaynak et al. (2005) for the Federal Reserve. The Forward Guidance surprise is based on changes in OIS rates around the press conference window, and is closely related to the OIS rates with intermediate maturities that are most strongly affected by ECB guidance about the future path of policy rates. For both of these surprises, Altavilla et al. (2019) have documented significantly negative effects on the European stock market, and we will investigate the heterogeneity of these effects.

One concern about interest rate changes around monetary policy announcements is that they might be driven not only by monetary policy news, but also by signals about the central bank's economic outlook that could directly affect expectations. These non-monetary "information effects" might confound empirical analysis that relies on high-frequency surprises, because they would have opposite effects on asset prices and macroeconomic variables than monetary policy shocks. Information effects therefore received considerable attention in the monetary economics literature; see Campbell et al. (2012) and Nakamura and Steinsson (2018), among many others.[13] Several studies, including Jarociński and Karadi (2020) and Miranda-Agrippino and Ricco (2021) have proposed new measures of monetary policy surprises that are constructed in ways to mitigate or even eliminate the confounding impact of information effects. The simplest approach, the "poor man's proxy" of monetary shocks

[13] Recent work by Bauer and Swanson (2023b,a) has argued that some of the evidence for information effects may in fact be due to a different channel that arises from incomplete information about the central bank's reaction function. Their evidence supports the view that the Fed's announcements mainly provide new information about the course of monetary policy, and not about the Fed's own economic outlook.

from Jarociński and Karadi (2020), is to exclude from the sample of central bank announcements those observations when the aggregate stock market moved in the same direction as the interest-rate surprise. Krusell, Thürwächter and Weiss (2023) use this approach to identify ECB announcements around which the change in the three-month OIS rate most likely captures a monetary shock, and we consider this "KTW" surprise in our robustness analysis. An alternative approach uses a Bayesian VAR to decompose each high-frequency surprise into monetary policy and information shocks. Jarociński and Karadi (2020) provide the resulting shock series for the ECB, and we include this "JK" series in our analysis.[14]

Summary statistics for all seven monetary policy surprises are presented in panel D of Table 1. The firm-level emissions data starts in 2010, and due to the publication lag described above, we begin our sample of stock returns and monetary policy surprises in 2012. In total, our sample contains 107 ECB announcements from January 2012 to October 2023.

3 Effects of monetary policy on green and brown stocks

We begin our investigation of the effects of ECB policy surprises on green and brown stocks using the following baseline panel regression:

$$r_{it} = \beta_1 \, mps_t + \beta_2 \, mps_t \, g_{it} + \beta_3 \, g_{it} + \gamma' X_{it} + \alpha_i + \varepsilon_{it}, \tag{1}$$

where r_{it} is the stock return of firm i (measured in percent) on ECB announcement day t. The monetary policy surprise, mps_t, is the intraday percentage point change in the one-year OIS rate around the policy event, as described above. The coefficient β_1 is expected to be negative given the conventional evidence that the overall stock market tends to decline in value following a positive monetary policy surprise (e.g., Altavilla et al., 2019; Gürkaynak et al., 2005). Firm-level greenness, g_{it}, is measured using emissions intensity—so that high values of g_{it} correspond to brown stocks—and standardized to have unit standard deviation for ease of interpretation. The coefficient β_2 captures how differing levels of greenness will alter the sensitivity of firm-level returns to mps_t. Therefore, if β_1 is negative, a negative β_2 implies that brown stocks have a stronger negative reaction to policy surprises than green stocks. Following earlier studies, we also include other firm-level controls in X_{it}: size, market-to-book equity, leverage, profitability, sales growth, investment, and the logarithm of

[14] Specifically, we use the "MP_median" series from Marek Jarocinski's website, see https://github.com/marekjarocinski/jkshocks_update_ecb_202310. This measure results from a decomposition of the surprise that is the first PC of OIS changes with maturities of one, three, six, and twelve months over the monetary event window, based on the Euro Area Monetary Policy Event-Study Database.

Table 2: Effects of ECB policy surprises on green and brown stocks

	(1)	(2)	(3)	(4)	(5)
mps	-9.87^{*}	-9.87^{*}			
	(5.39)	(5.42)			
$mps \times g$		-2.02^{***}	-2.07^{***}	-2.22^{***}	-2.13^{***}
		(0.57)	(0.22)	(0.32)	(0.31)
g	0.17^{***}	0.15^{***}	0.14^{***}	0.14^{***}	0.15^{***}
	(0.04)	(0.03)	(0.03)	(0.03)	(0.03)
Firm FE	Y	Y	Y	Y	Y
Time FE	N	N	Y	N	N
Industry-by-time FE	N	N	N	Y	N
Country-by-time FE	N	N	N	N	Y
Observations	30,504	30,504	30,504	30,504	30,504
Adjusted R^2	0.04	0.04	0.35	0.37	0.37

Estimates for panel regression (1) and alternative specifications. The dependent variable is the daily stock return of each firm on the day of an ECB announcement. Monetary policy surprises, mps, are intraday changes in the one-year OIS rate. The greenness measure, g, is emission intensity, calculated as scope 1+2 GHG emissions divided by total revenue, measured two years before the announcement date t, and standardized to have a unit standard deviation. Additional controls include size, market-to-book equity, leverage, profitability, sales growth, investment, and log PP&E. Industry-by-time fixed effects are constructed using the two-digit SIC industry classification. The sample period from January 2012 to October 2023 includes 107 ECB announcements. Standard errors in parentheses are two-way clustered by firm and announcement, and ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

"properties, plants and equipment" (PP&E).[15] As explained above in Section 2.1, we use a twelve-month publication lag for firm-level controls and the greeneness measure, so X_{it} and g_{it} correspond to the calendar year two years before the ECB announcement t.

Table 2 reports the estimation results. The first column includes only mps_t but no interaction term in order to establish the average response of stock prices to ECB policy surprises. The estimate of β_1 implies that the announcement of a one percentage point positive (hawkish) monetary policy surprise would cause stock prices to decline on average by 9.87 percent. The standard deviation of the policy surprise is about three basis points (see Table 1), so a one-standard-deviation surprise corresponds to a decline of stock prices by about 0.3 percent, a magnitude that is broadly in line with the estimates Altavilla et al. (2019) obtained for European stock market indices.

The second column Table 2 shows estimates for the regression with an interaction effect between the policy surprise mps_t and the firm's emission intensity, corresponding to the

[15]These controls are largely the same as those used in Döttling and Lam (2024). Size is the log of the firm's market cap. Leverage is the ratio of total debt to total assets. Profitability is the ratio of gross profits to total assets. Investment is the ratio of capital expenditure to total assets.

specification in equation (1). The interaction coefficient is negative and strongly statistically significant, meaning that brown stocks with higher emissions intensity g_{it} respond more negatively to positive interest rate surprises than green stocks.

The remaining columns of Table 2 show estimates for specifications that add time fixed effects, sector-by-time, or country-by-time fixed effects. Because these fixed effects allow for a different stock market return on each ECB announcement day, mps_t drops out from the regression. The specification

$$r_{it} = \beta_2\, mps_t\, g_{it} + \beta_3\, g_{it} + \gamma' X_{it} + \alpha_i + \alpha_{st} + \varepsilon_{it}, \tag{2}$$

with firm fixed effects α_i and sector-by-time fixed effects α_{st} is particularly common in the literature on heterogeneous stock market effects of monetary policy (e.g. Patozi, 2024), and these estimates are in column (4). The statistical significance of the estimates of β_2 remains high, and the magnitude of the coefficient largely unchanged, across all fixed effects specifications.

The difference in sensitivities between green and brown firms is quantitatively meaningful. To understand the magnitudes, consider the response of green and brown firms to a one unit contractionary monetary policy surprise, that is, a one percentage point increase in the one-year OIS rate around the ECB monetary policy event. Using the estimates from column (4), a brown firm with emission intensity one standard deviation above average would experience, on average, a decline in its stock price of 12.1 percent. This decline is materially larger than the predicted decline for a green firm with emission intensity one standard deviation below average, which is 7.6 percent.

The heterogeneity of the effects of monetary policy on green and brown stocks could in principle be different within and across industries. For example, it could be the case that stocks in brown, high-carbon industries were more strongly affected by monetary policy than those in green industries, while within industries, green and brown stocks exhibited similar effects. Table 2 shows that this is not the case. The estimates in column (4) include industry-by-time fixed effects that capture all of the cross-industry heterogeneity in the effects of mps_t on stock returns, so the interaction coefficient β_2 captures the residual within-industry heterogeneity in this specification. This β_2 estimate is almost identical to the one in column (3), where we do not account for industries. The results therefore suggest that the within-industry and across-industry differences in monetary policy sensitivities are very similar.

To further investigate the heterogeneous response of green and brown firms to monetary policy, we sort our firms into five portfolios based on their emission intensity, and estimate a panel regression separately in each quintile of firms. This grouping approach, which follows

Table 3: Effects of ECB policy surprises on green and brown portfolios

(A) Quintiles for emission intensity					
	Q1 (green)	Q2	Q3	Q4	Q5 (brown)
mps	-9.98^{**}	-7.60	-10.20^{**}	-9.73^{**}	-11.16^{**}
	(4.97)	(4.88)	(5.15)	(4.94)	(4.94)
Observations	4,292	5,850	6,886	6,979	6,497
Adjusted R^2	0.05	0.04	0.05	0.03	0.04

(B) Response of brown-minus-green portfolios						
	Equal-weighted			Value-weighted		
mps	-0.97	-2.98^{*}	-3.32^{**}	-4.14	-6.27	-8.69^{*}
	(1.40)	(1.71)	(1.58)	(3.64)	(5.15)	(4.98)
Observations	107	107	107	107	107	107
R^2	0.01	0.04	0.21	0.04	0.07	0.35
Double-sorted	N	Y	Y	N	Y	Y
Year FE	N	N	Y	N	N	Y
Month FE	N	N	Y	N	N	Y

Event-study regressions for stock returns around ECB announcements, using firm portfolios based on emission intensity. Panel (A) shows the estimated coefficient on the monetary policy surprise, *mps*, in separate panel regressions for each quintile of firms sorted by emission intensity. Controls include size, market-to-book equity, leverage, profitability, sales growth, investment, and log PP&E. We use firm fixed effects and standard errors that are clustered both at the firm and announcement level. Panel (B) reports results for time series regressions of portfolio returns on the monetary policy surprise, with brown-minus-green portfolios formed using the top and bottom quintile of the firm distribution based on emission intensity. We use white standard errors, reported in parentheses. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively. The sample period from January 2012 to October 2023 includes 107 ECB announcements.

Cloyne et al. (2023) and subsequent work, has the advantage that it does not restrict the heterogeneity to be linear, instead allowing each group of stocks to exhibit a different policy response.[16] The top panel of Table 3 shows the estimation results for each quintile of firms. The regressions include firm fixed effects as well as all the firm-level controls used in Table 2. The sensitivity of brown firms, in the top quintile, is higher than the sensitivity of other firms. The sensitivity increases with quintiles, but not linearly so, which underscores the importance of obtaining group-specific estimates of policy sensitivity.

A related approach uses portfolio returns in time series regressions. We form brown-minus-green (BMG) portfolios using the differences in returns between the top and bottom quintile portfolios—using either equal-weighted or value-weighted returns. The BMG returns on days with ECB announcements are then regressed on the monetary policy surprise. An

[16] Patozi (2024) and Döttling and Lam (2024) also employ this method to estimate the heterogeneous response of green and brown stocks in the U.S. to Fed policy surprises, although they sort stocks based on E scores and emission levels, respectively.

advantage of this portfolio approach, based on a long tradition in empirical asset pricing, is that investors could have formed these portfolios in real time and obtained exposure to green and brown firms in a similar fashion.[17]

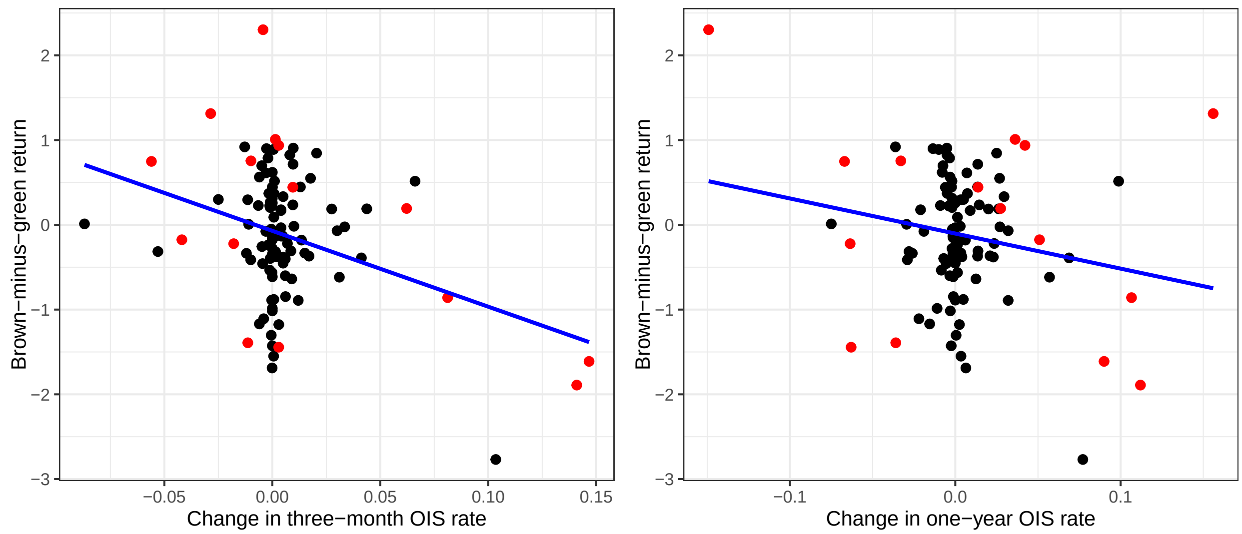
The bottom panel of Table 3 shows the estimation results. In the simple time series regression, the coefficient on mps_t is negative but not statistically significant at conventional significance levels for either equal-weighted or value-weighted portfolios. The magnitude of the response is substantially higher for the value-weighted portfolio, suggesting that large firms play an outsized role in explaining the differential response. Following common practice to account for the impact of size in this context, we also double-sort first by size and then by greenness (Döttling and Lam, 2024). In this case, the return for the green portfolio, for example, is the average of the returns for portfolios with large green firms and small green firms. This double-sorting actually increases the magnitude of the estimated response of both equal-weighted and value-weighted BMG portfolio, and in the former case, the coefficient becomes marginally significant. Adding year and month fixed effects further increases the magnitudes of the coefficients, which are now significant at the 5-percent and 10-percent levels, respectively. Overall, the negative response of the BMG return to the policy surprise shows that brown stocks exhibit a stronger response to monetary policy than green stocks.

To better understand the differential response of brown and green portfolios to ECB policy surprises, Figure 1 shows a regression of the BMG return (the difference between the top and bottom quintiles of value-weighted portfolio returns) on the monetary policy surprise. The left-hand panel defines the policy shock using high-frequency changes in the three-month OIS rate and the right-hand panel uses the one-year OIS rate, as in our baseline estimates. Both scatter plots show a negative correlation; that is, monetary policy tightening shocks lead to a greater decline for brown stocks compared with green ones. In addition, in Figure 1 the ECB announcements for the most recent monetary tightening in 2022 and 2023 are shown in red. These latest observations fit in well with the stock market response over the full sample. Most notably, the three most hawkish surprises in the lower-right area of the left-hand plot—corresponding to the ECB announcements in March 2020, July 2022, and March 2023—led to particularly strong brown underperformance.

Our baseline results use carbon emission intensity as the measure of a firm's greenness, but for robustness, we consider a variety of other measures used in the climate finance literature. For example, there are different ways to scale emissions to calculate emission intensity. Our baseline measure normalizes by firm-level revenue, like many other studies, but emission intensity is also sometimes calculated using market capitalization or other measures of firm

[17] For recent work in climate finance using the portfolio approach, see Bauer et al. (2022) and the references therein.

Figure 1: Reaction of brown-minus-green portfolio to ECB surprises



The figure plots the BMG portfolio return—the difference between the top and bottom quintile value-weighted portfolios sorted by emission intensity—against the monetary policy surprise on ECB announcement days. Surprises are calculated as intraday changes in the three-month or one-year OIS rate around the monetary policy announcements. ECB announcements in 2022 and 2023 are shown in red. The sample period from January 2012 to October 2023 includes 107 ECB announcements.

size (Ilhan et al., 2021; Bauer et al., 2024b). Furthermore, several empirical studies use the *unscaled* level of CO_2 emissions to characterize greenness.[18] Accordingly, the top panel of Table 4 reports estimates of the interaction of ECB policy surprises with greenness, with the latter defined as (1) the ratio of emissions to sales (our baseline result also reported in Table 2), (2) the ratio of emissions to market cap, or (3) the (log) level of scope 1+2 emissions. The regression specification is equation (2), which includes firm and industry-by-time fixed effects. Across all three emission-based measures, we find that the estimated effect is consistently negative and statistically significant.

A related issue for any greenness measure based on emissions or emissions intensity is that a non-negligible number of firms actually do not report CO_2 emissions. For many of these firms, data providers impute emissions based on other firm-level data. Some researchers have suggested that such imputations may be problematic for certain types of analysis and use samples with only firms that actually report emissions (Aswani et al., 2024; Bauer et al., 2022). In light of this critique, Panel B of Table 4 shows estimates for the same three emission-based metrics but only using those observations when firms have actually reported

[18] Bolton and Kacperczyk (2021) estimate a large carbon premium for the level of emissions but not for emission intensity, and argue the former is a better measure, while (Aswani et al., 2024) disagree. Döttling and Lam (2024) use the level of emissions to investigate the heterogeneous response to Fed policy surprises.

Table 4: Estimated effects of monetary policy surprises on different greenness measures

	Emissions/sales	Emissions/market cap	Log emissions
(A) All emissions (estimated and reported)			
$mps \times g$	-2.22^{***}	-1.08^{***}	-1.45^{**}
	(0.32)	(0.05)	(0.64)
Observations	30,504	30,504	30,504
Adjusted R^2	0.37	0.37	0.37
(B) Only reported emissions	Emissions/sales	Emissions/market cap	Log emissions
$mps \times g$	-0.03	-1.02^{***}	-1.5^{***}
	(0.22)	(0.38)	(0.59)
Observations	23,928	23,928	23,928
Adjusted R^2	0.41	0.38	0.41
(C) Scores	Emission score	E score	
$mps \times g$	-0.9	-1.24	
	(0.66)	(0.78)	
Observations	31,720	30,497	
Adjusted R^2	0.38	0.34	

Results of regression (2) of daily returns on monetary policy surprises interacted with alternative measures of greenness, g. Controls include size, market-to-book equity, leverage, profitability, sales growth, investment, and log PP&E, and we include firm and time-by-industry fixed effects. The sample period from January 2012 to October 2023 includes 107 ECB announcements. We use two-way clustered standard errors at the firm level and the ECB announcement date level. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

their (scope 1 and 2) emissions. For the case of reported emissions divided by sales, the interaction coefficient is insignificant, but for the other two metrics there is no appreciable difference from limiting the sample in this way.

As a final alternative approach to distinguish green and brown stocks, we consider the environmental scores and emissions scores that underlie the proprietary ESG ratings often used by financial analysts. This approach has been employed in empirical climate finance studies of the stock market; see, for example, Pastor et al. (2022) and Patozi (2024). But these ESG ratings have several shortcomings, including the fact that they are judgmental and can be quite inconsistent across different data providers. In addition, ESG ratings can get revised in subsequent data releases, meaning that the results of empirical studies using revised data may not be based on the same information available to investors at the time.[19]

[19] For more discussion of the discussion of the problems with ESG ratings, see Berg et al. (2022), Berg et al. (2021), and Billio et al. (2021).

Results for emission scores and E (environmental) scores are shown in panel C of Table 4. In contrast to the emission-based measures, we do not find a statistically significantly different response of stocks that are classified as green and brown based on these scores. Overall, the estimated heterogeneity of the effects of monetary policy does not seem to be too sensitive to the exact measure of greenness, as long as it is based on carbon emissions instead of the scores from ESG data providers.

Table 5: Estimated effects of different monetary policy surprises on emission intensity

	Simple changes		Principal components			No info. effects	
	OIS 3m	OIS 1y	PC	Target	FG	KTW	JK
(A) Firm fixed effects							
mps	-6.16	-9.87^{*}	-10.3	-4.57	-11.15^{***}	-39.04	-24.67^{**}
	(10.7)	(5.42)	(6.61)	(10.77)	(4.17)	(26.05)	(11.24)
$mps \times g$	-1.76^{***}	-2.02^{***}	-1.67^{**}	-1.10^{***}	-0.45	-7.36^{***}	-2.94^{***}
	(0.23)	(0.57)	(0.66)	(0.20)	(0.83)	(1.89)	(0.75)
Adjusted R^2	0.01	0.04	0.04	0.01	0.02	0.14	0.15
(B) Industry-by-time fixed effects							
$mps \times g$	-1.76^{***}	-2.22^{***}	-1.82^{***}	-1.13^{***}	-0.78^{*}	-6.81^{***}	-3.14^{***}
	(0.23)	(0.32)	(0.25)	(0.17)	(0.46)	(1.89)	(0.65)
Observations	30,504	30,504	30,504	30,504	30,504	18,977	30,504
Adjusted R^2	0.37	0.37	0.37	0.37	0.37	0.44	0.37

Regressions of daily stock returns on emission intensity interacted with alternative monetary policy surprises (described in the text). Controls include size, market-to-book ratio, leverage, profitability, sales growth, investment, log PP&E, and emission intensity. In the top panel, we include only firm fixed effects, as in equation (1) and column (2) of Table 2. In the bottom panel, we include firm and industry-by-time fixed effects, as in column (4) of Table 2. Industry-by-time fixed effects are constructed using the two-digit SIC industry classification. The sample period from January 2012 to October 2023 includes 107 ECB announcements. Standard errors clustered at firm and announcement level are reported in parentheses. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

We also consider robustness to the different ECB monetary policy surprises described in Section 2.2. Table 5 shows results for two different regression specifications: The top panel reports estimates of equation (1) (corresponding to column (2) of Table 2), which include only firm fixed effects. To narrow down to within-industry heterogeneity, the bottom panel shows estimates for regressions that include industry-by-time fixed effects (corresponding to column (4) of Table 2).

The first two columns of Table 5 show results for simple changes in OIS rates, for the three-month and one-year maturities. The former has less of an impact on the stock market than the one-year rate, our baseline measure, but it also leads to a strongly significant negative interaction coefficient. The next three columns report results for monetary policy surprises constructed as principal components of OIS rate changes. The interaction coefficients are all negative, and generally statistically significant. The only exception is the case of the forward guidance (FG) surprise of Altavilla et al. (2019) that uses the event window around press conferences. This surprise has a strong effect on the stock market, but only a marginally significant (bottom panel) or insignificant (top panel) interaction effect. Apparently, the green-brown heterogeneity is much stronger when the stock market response is measured with respect to the ECB surprise over the entire monetary event window. The last two columns use the policy surprise measures of Krusell et al. (2023) (KTW) and Jarociński and Karadi (2020) (JK) that are constructed to avoid contamination with information effects, based on the contemporaneous response of the aggregate stock market as explained in Section 2.2. The estimated response of the stock market is by construction much higher than for all other surprises, even though it is estimated quite imprecisely in the case of the KTW surprise. Importantly, the interaction effects are strongly significant, confirming that stocks of high-carbon firms respond more strongly to monetary policy surprises, independent of how this surprise is measured.

4 Other sources of heterogeneous effects

Considerable research has explored how interest rate shocks have different effects on companies' investment and operating behavior depending on firm-level characteristics such as leverage, age, size, liquidity, and profitability, among many others.[20] Assuming that investors anticipate these real-side heterogeneous responses, then equity price reactions to monetary policy will also vary with these characteristics. Indeed, in empirical analyses of U.S. data, firms' equity price responses to Fed monetary policy surprises depend on many of these same characteristics (Ozdagli, 2018; Ippolito et al., 2018; Ozdagli and Velikov, 2020; Gürkaynak et al., 2022; Döttling and Ratnovski, 2023). Given the substantial amount of empirical evidence on the heterogeneous transmission of monetary policy, two questions naturally arise in the context of our analysis: First, how does the impact of the ECB's monetary policy on individual stock returns depend on a wider set of characteristics of euro-area firms? Second, does the differential response of green and brown firms that we document represent a separate dimension of heterogeneity, or is it a reflection of other firm characteristics?

[20]For example, early research suggested that a monetary policy tightening had heterogeneous effects on small and large firms as the former faced greater informational asymmetries in accessing external finance (e.g., Oliner and Rudebusch, 1996a,b). Most recently, differing firm-level responses have been documented in the macro-finance literature (e.g., Cloyne et al., 2023; Ottonello and Winberry, 2020; Jeenas, 2023; Jungherr et al., 2024).

In addressing the first question, we note that the analysis of the monetary transmission to individual companies in Europe is of independent interest. Existing studies on the firm-level stock market effects of monetary policy have focused on the United States, and to the best of our knowledge there is no established evidence of the heterogeneous effects of ECB monetary policy on stock prices across European companies. To fill this gap, we consider a range of commonly used firm characteristics, and document how they affect the sensitivity of stock prices to ECB policy surprises. We consider most of the firm-level variables that various U.S. studies have identified for the monetary policy sensitivity of firms' equity returns (e.g., Ozdagli, 2018; Ippolito et al., 2018; Döttling and Ratnovski, 2023). For each of these firm characteristics, z_{it}, we estimate the following regression, where time t denotes ECB announcement events:

$$r_{it} = \delta_1\, mps_t\, z_{it} + \delta_2\, z_{it} + \gamma' X_{it} + \alpha_i + \alpha_{st} + \varepsilon_{it}. \tag{3}$$

This panel regression for stock returns resembles equation (2) except z_{it} takes the place of g_{it}. The significance and size of the δ_1 coefficient will indicate the importance of various firm characteristics for driving heterogeneous effects. The variables z_{it} are standardized, so that δ_1 can be interpreted as the change in the stock price sensitivity to ECB surprises for a one standard deviation increase in the firm characteristic. As in Section 3, we include additional firm-level controls, X_{it}, firm fixed effects, α_i, and sector-by-time fixed effects, α_{st}, with annual accounting and environmental variables measured with a two-year lag.

Table 6 shows estimates of regression (3) for different firm characteristics across each column, with the right-most column including all characteristics jointly.[21] Several firm characteristics significantly influence stock price sensitivity to ECB surprises. We now briefly consider each firm characteristic in turn.

The size of a firm could affect its sensitivity to monetary policy, because small firms are often younger and more financially constrained; indeed, size is often used as a proxy for the degree of borrowing information asymmetry faced by a firm. If smaller firms rely less on external financing, then they could be less sensitive to monetary policy. Ozdagli (2018) notes that earlier evidence for the U.S. is mixed on the effect of firm size in this context, but he finds that the stocks of large firms respond significantly more strongly to high-frequency Fed policy surprises than those of small firms—consistent with less borrowing constraints. For ECB surprises, we do not find a significant difference in the impact on small and large firms, using log market value as a measure of size following earlier literature. Nevertheless, interaction coefficient in column 1 of Table 6 has a negative sign, qualitatively consistent

[21] The last column omits tangibility, which is not available for many of the firms in our sample.

Table 6: Firm characteristics and stock price effects of ECB policy surprises

Interactions	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Size	−1.88									−1.82
	(1.33)									(1.15)
B/M		−0.70**								−0.84**
		(0.28)								(0.37)
Leverage			−0.65**							−0.49*
			(0.33)							(0.30)
Profitability				0.99**						0.72***
				(0.50)						(0.26)
Tangibility					0.37					
					(0.67)					
Liquidity						−0.10				−0.32
						(0.59)				(0.64)
Age							0.08			0.61*
							(0.43)			(0.34)
Beta								−2.64***		−2.36**
								(1.00)		(0.94)
Cash flow									0.03	−0.43
									(3.86)	(2.95)
Observations	55,730	55,730	55,730	55,730	39,323	55,710	54,753	55,616	55,730	54,619
Adjusted R^2	0.30	0.30	0.30	0.30	0.32	0.30	0.31	0.30	0.30	0.31

Regressions of daily stock returns on monetary policy surprises interacted with different firm characteristics. Additional controls include size, market-to-book equity, leverage, profitability, sales growth, investment, and log PP&E. The regressions also include firm and time-by-industry fixed effects. The sample period is from January 2012 to October 2023 and includes 107 ECB announcements. The policy surprise is the change in the one-year OIS rate over the ECB monetary event window. Standard errors clustered by firms and announcements are reported in parentheses. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

with Ozdagli's findings for the U.S.

A common measure of financial constraints is the leverage of a firm, usually defined as total debt divided by total assets, or book leverage. More financially constrained firms have less access to external financing and lower leverage, so their costs and profits are less sensitive to changes in interest rates. Consistent with this story, Ozdagli (2018) and Havrylchyk and Pourabbasvafa (2023) find that stocks of high-leverage U.S. firms respond more strongly to monetary policy surprises than those of firms with low leverage, and Anderson and Cesa-Bianchi (2024) show that the credit spreads of firms with high leverage respond more strongly to monetary policy. Our estimates in column (3) of Table 6 go in this direction as well: European firms with high leverage exhibit a more negative response to ECB policy surprises than the average firm.[22]

Young firms tend to have more constrained access to financing than older, more estab-

[22] Ozdagli (2018) notes that book leverage is a slow-moving, noisy measure of financial constraints, so given likely attenuation bias, the true effects of leverage may be even larger than our estimates.

lished firms. Firm age has often been used to proxy for the effects of financial frictions, but the empirical results are often not clear cut. Cloyne et al. (2023) find that the investment of young firms is more sensitive to exogenous changes in interest rates, and Havrylchyk and Pourabbasvafa (2023) find the stock prices of young firms respond more to monetary policy. By contrast, the estimates of Patozi (2024) suggest that the stock prices of old firms are more sensitive to monetary policy surprises. We estimate a positive coefficient on the interaction between policy surprises and age (measured as the time since a firm's IPO date). The coefficient is only marginally significant and only in the multivariate regression with all interaction effects. The positive sign of the coefficient implies that the stock prices of older firms may be somewhat less sensitive to monetary policy than for the average firm, in line with the findings of Havrylchyk and Pourabbasvafa (2023).

The duration of a firm's cash flows should be an important determinant of the impact of monetary policy on firm value, because the present value of longer-duration cash flows are more sensitive to changes in interest rates than shorter durations. Indeed, Ozdagli (2018) finds that U.S. firms with longer cash flow duration are more sensitive to policy surprises. A related dimension of heterogeneity is the difference between value and growth stocks according to valuation multiples like price-earnings or book-to-market ratios, since growth stocks tend to have longer-duration cash flows (Lettau and Wachter, 2007). The evidence of Offner (2023) suggests that U.S. growth firms are more sensitive to monetary policy than value firms. By contrast, Havrylchyk and Pourabbasvafa (2023) and Benchora et al. (2023) find that value stocks, with high book-to-market ratios or low Tobin's q, are more sensitive to monetary policy. The differences between these two sets of results is likely due to the different sample periods. Our estimates show that in the euro area, value stocks are in fact significantly more interest-rate sensitive, as shown in columns 2 and 10 of Table 6.

The sensitivity to movements in the overall stock market, as captured by its CAPM-beta, is likely the most important and prominent characteristic of a stock, given its central role in empirical asset pricing. Because the stock market responds strongly to changes in monetary policy, as shown by Bernanke and Kuttner (2005) and many later studies, one would expect the sensitivity of individual stocks to depend positively on their market beta. Bernanke and Kuttner (2005) confirmed this prediction using industry portfolios. While Ozdagli (2018) did not find a significant difference based on CAPM-implied stock sensitivites, Benchora et al. (2023) estimated a higher monetary policy sensitivity for high-beta stocks. Using a five-year rolling beta from Refinitiv for our euro-area sample, we also find that the price response of a stock to monetary policy depends positively on its market beta, as shown in columns 8 and 10 of Table 6.

Finally, our estimates show that profitability, which we measure as the return-on-assets (gross profit divided by total assets), significantly affects the stock price response to ECB monetary policy surprises. The sign of the estimated effect is consistent with the results of Ozdagli and Velikov (2020) and Benchora et al. (2023), who also find more profitable firms to be less sensitive to monetary policy.

We also considered several other variables that earlier papers have found to be relevant determinants of firm-level sensitivities to monetary policy: tangibility of the capital stock (Döttling and Ratnovski, 2023; Havrylchyk and Pourabbasvafa, 2023), liquidity (Ozdagli and Velikov, 2020; Jeenas, 2023), and cash flow (Ozdagli, 2018).[23] In our sample of euro-area stocks, none of the interaction effects of these variables with the ECB policy surprise end up as statistically significant. We have also investigated alternative specifications and measured the firm characteristics using categorical variables, and found our estimates to be robust.

Having documented the heterogeneous stock market effects of ECB policy surprises, we now turn to the second question: Is the differential monetary policy sensitivity of green and brown stocks due to systematic differences in the characteristics of low- and high-carbon firms? That is, do the differences in policy sensitivity that we have documented in Section 3 simply reflect an underlying firm-level heterogeneity that affects the transmission of monetary policy, or is it an separate, independent dimension of heterogeneity, and a new result in its own right?

Table 7 compares the firm-level characteristics of green and brown stocks in 2021 (though we obtain similar results using full sample averages). Brown firms had significantly higher leverage and tangibility and lower profitability and liquidity. Within industries, brown stocks tend to have higher book-to-market value, that is, they tend to be value stocks. Brown firms were also older than green firms. Some of these systematic differences could potentially explain the stronger sensitivity of brown stocks to monetary policy, because we found many of these characteristics to be associated with stronger impact of ECB policy surprises, in particular, leverage, profitability, and book-to-market.

To address this issue, we control for other dimensions of heterogeneity in our event-study regressions with emission intensities. Specifically, we estimate the regression

$$r_{it} = \beta_2\, mps_t\, g_{it} + \beta_3\, g_{it} + \delta_1\, mps_t\, z_{it} + \delta_2\, z_{it} + \gamma' X_{it} + \alpha_i + \alpha_{st} + \varepsilon_{it}, \tag{4}$$

where g_{it} is emission intensity (so low values of g_{it} indicate greener firms). The key question is again whether the coefficient on the interaction with greenness, β_2, is also significantly negative, as in our results in Section 3, once we control for the various firm-level character-

[23] We calculate tangibility as the ratio of tangible assets (PP&E) to the sum of tangible and intangible assets, following Havrylchyk and Pourabbasvafa (2023). For liquidity, we use the ratio of cash holding and short-term investments to total assets. We measure cash flow as the ratio of operating income to total assets.

Table 7: Mean firm characteristics for green and brown stocks

	Overall			Within-industry		
	Brown	Green	t-statistic	Brown	Green	t-statistic
Size	21.50	21.51	-0.10	21.49	21.52	-0.22
B/M	0.77	0.74	0.36	0.88	0.63	2.79
Leverage	0.31	0.23	5.82	0.30	0.24	4.15
Profitability	3.71	13.05	-3.86	5.46	10.6	-2.13
Tangibility	0.83	0.70	6.38	0.83	0.70	6.37
Liquidity	0.13	0.16	-3.40	0.14	0.16	-2.47
Age	22.75	18.65	3.43	21.85	19.56	1.90
Beta	0.96	1.02	-2.11	1.01	0.97	0.96
Cash flow	5.25	5.91	-1.23	4.95	6.20	-2.33

Mean values of firm characteristics for green and brown stocks in 2021. Green stocks are defined as those with emission intensities below the median, while brown stocks have emission intensities above the median. The last three columns report the comparison based on a separate grouping within each industry. We report t-statistics for differences in means between green and brown stocks. The sample is a cross section of 815 firms.

istics in z_{it} either individually or jointly. As before, g_{it} and z_{it} are standardized so that the coefficients β_2 and δ_1 capture the change in policy sensitivity for a one standard deviation increase in each variable.

The estimates in Table 8 show that the differential sensitivity of green and brown stocks appears to be largely unrelated to other sources of heterogeneity in the stock market response of European firms to ECB surprises. This is evident from the fact that across all specifications, the estimates of the interaction coefficient with emission intensity, β_2, shown in the first row, remains negative and strongly statistically significant. Even the magnitude of this coefficient is barely affected by the additional interaction terms, suggesting that these other controls for firm-level characteristics bear little relation with the heterogeneity that is the focus of our paper.

Our European result in this regard is broadly consistent with the U.S. studies of the monetary policy responses of green and brown stocks (Döttling and Lam, 2024; Havrylchyk and Pourabbasvafa, 2023; Benchora et al., 2023; Patozi, 2024). These studies also control for a variety of potential determinants of stock price sensitivity, and although there are differences in the controls used and the exact results obtained, across all four U.S. studies the estimates of the heterogeneous effects of monetary policy associated with greenness remains largely robust.[24]

[24]One exception are the results shown in Table 2 of Havrylchyk and Pourabbasvafa (2023), where the interaction between the monetary policy surprise and emission intensity becomes statistically insignificant

Table 8: Green-brown heterogeneity and controlling for firm characteristics

Interactions	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Emission intensity	−2.24***	−2.20***	−2.18***	−2.21***	−2.28***	−2.21***	−2.22***	−2.10***	−2.22***	−2.12***
	(0.36)	(0.33)	(0.33)	(0.32)	(0.42)	(0.33)	(0.32)	(0.32)	(0.32)	(0.50)
Size	−0.69									−0.89
	(1.32)									(1.23)
B/M		−0.84***								−0.91**
		(0.29)								(0.46)
Leverage			−0.62*							−0.48*
			(0.34)							(0.28)
Profitability				1.82						−0.88
				(3.11)						(2.32)
Tangibility					0.30					
					(0.85)					
Liquidity						0.70				0.50
						(0.79)				(0.79)
Age							0.42			0.66**
							(0.34)			(0.33)
Beta								−1.61**		−1.52**
								(0.64)		(0.74)
Cash flow									0.09	−2.93
									(5.17)	(4.33)
Observations	30,504	30,504	30,504	30,504	23,029	30,492	29,869	30,481	30,504	29,834
Adjusted R^2	0.37	0.37	0.37	0.37	0.40	0.37	0.38	0.37	0.37	0.38

Regressions of daily stock returns on monetary policy surprises interacted with different firm characteristics. Additional controls include size, market-to-book equity, leverage, profitability, sales growth, investment, and log PP&E. The regressions also include firm and time-by-industry fixed effects. The sample period is from January 2012 to October 2023 and includes 107 ECB announcements. The policy surprise is the change in the one-year OIS rate over the ECB monetary event window. Standard errors clustered by firms and announcements are reported in parentheses. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

Overall, we document a significant amount of heterogeneity in the responsiveness of euro-area stocks to ECB policy surprises. Our novel evidence is generally consistent with earlier findings for the U.S., although there are also some noticeable differences, as would be expected given our new sample of European firm-level data. Importantly, the differential sensitivity of green and brown stocks to ECB monetary policy is a robust and independent dimension of heterogeneity which is not explained by systematic differences in other firm characteristics.

5 Possible channels for green-brown heterogeneity

Our euro area analysis, along with related U.S. research, shows that tighter monetary policy reduces the equity prices of brown firms more than green ones. Here, we consider a variety

once all interacted controls are added to the regression.

of potential channels that could explain this difference in interest rate sensitivities.

A first possible explanation for green/brown differential interest-rate sensitivity is based on a "credit channel" that posits differences in the importance and availability of external financing between green and brown firms. As an example, Havrylchyk and Pourabbasvafa (2023) argue that brown firms have more tangible capital and are therefore more sensitive to changes in interest rates. This rationale is based on earlier evidence showing that firms with a greater share of tangible capital exhibit a stronger stock market reaction to changes in monetary policy (Döttling and Ratnovski, 2023). In theory, the more transparent collateral value of tangible capital can reduce lending informational asymmetries and allow a greater reliance on low-cost but interest-rate sensitive external finance. In their U.S. sample, Havrylchyk and Pourabbasvafa (2023) find that green firms appear to hold a greater share of capital in the form of knowledge and organizational intangible capital, while brown firms own more tangible capital such as property, plant, and equipment. After controlling for firms' capital tangibility, Havrylchyk and Pourabbasvafa (2023) find little difference in green and brown firms' reactions to monetary policy. In our European data sample, we also find that brown firms hold a significantly greater share of tangible capital (Table 7), but there is no evidence that capital tangibility even on its own accounts for any heterogeneity in firm-level monetary policy sensitivity (Table 6). In contrast, there are other firm characteristics—including leverage and profitability—that do plausibly capture a heterogeneous credit channel reliance on external finance and seem to influence the size of firm-level monetary policy surprise responses (Table 6). However, controlling for various firm characteristics that capture the reliance on external finance does not change the result that brown stocks respond more to ECB policy surprises (Table 8). In other words, we do not find evidence in support of the credit channel.

Two related channels are based on the role of a carbon premium, that is, higher expected returns for brown stocks. One of them involves the amount of transition risk. Brown firm are exposed to greater financial, reputational, and regulatory risks associated with business models that depend on carbon emissions. Investors in brown firms would therefore be expected to require compensation in the form of higher expected returns for holding additional climate transition risk, resulting in a "carbon risk premium" (e.g., Bolton and Kacperczyk, 2021; Pastor et al., 2022; Bauer et al., 2022). A carbon risk premium channel could imply a stronger sensitivity of brown stocks to monetary policy shocks. One mechanism works directly through changes in the amount of carbon risk. Döttling and Lam (2024) provide a theoretical framework in which brown firms are more sensitive to monetary policy exactly because they are more exposed to carbon transition risk: Tighter monetary policy increases the cost of replacing carbon-intensive assets, so brown firms delay transitioning and retain a greater exposure to carbon transition risk, which depresses their stock prices. Alternatively, rather than focus on the quantity of transition risk, another approach considers variation in the price of risk. There is ample theoretical and empirical research showing that tighter monetary policy raises effective risk aversion, the price of risk, and thus risk premia across the board (Bauer et al., 2023). The resulting increase in the carbon risk premium would tend to push down the prices of brown stocks—in order to produce higher expected returns—more than those of green stocks. Benchora et al. (2023) also argue that risk premia are known to depend on the stance of monetary policy as investors search for yield when risk-free rates are low. Such a climate risk-taking channel for monetary policy is given some support by Altavilla et al. (2024), who use granular loan-level data to show that the bank lending risk premium rises more for high emitters relative to firms committed to decarbonization following an unexpected increase in policy rates.

Another channel that is related to the carbon premium and could explain the lower interest-rate sensitivity of green stocks centers around investor preferences. As laid out by the asset-pricing model of Pastor et al. (2021), preferences for green securities by the representative investor would tend to lower brown firm valuations and raise their expected equity returns, resulting in a "carbon aversion premium." The key question is how these green preferences might affect the sensitivity of green and brown assets to shocks. Benchora et al. (2023) and Patozi (2024) provide theoretical models in which the investors who derive a non-pecuniary benefit from holding green assets are reluctant to substitute away from green stocks; thus, their demand for these stocks is relatively less sensitive to changes in interest rates. Under the assumption that this channel is relevant for asset pricing by the marginal investor, the green preferences then lead to a lower sensitivity of green assets to monetary policy shocks. Benchora et al. (2023) and Patozi (2024) provide some supporting evidence for this rationale by finding a correlation between the green/brown monetary policy response heterogeneity and some geographical or temporal dispersion in climate concerns.[25] We don't provide direct evidence on this potential channel, but our use of data from Europe—where surveys find that concerns about climate risk are much less contentious and more widely established—may provide a useful contrast to the United States.[26] In this regard, despite

[25] Patozi (2024) finds that the heterogeneous monetary policy response is more pronounced for green firms held by index funds that are located in U.S. counties where climate risk perceptions are stronger and during times of heightened climate concerns. Benchora et al. (2023) find that the green/brown heterogeneity varies over time with the overall level of climate awareness as proxied by newspaper coverage of climate change related events.

[26] An international survey of climate opinions was described in the press as finding that "The US is a hotbed of climate science denial when compared with other countries, with international polling finding a significant number of Americans do not believe human-driven climate change is occurring." (Milman and Harvey, 2019).

the ostensibly greater acceptance of incorporating climate risk into financial investment decisions in Europe, our results on green/brown monetary policy heterogeneity are somewhat surprisingly not stronger than in the United States. More analysis comparing the behavior of European and American investors may improve our understanding of this potential channel.

While intuitively appealing and potentially promising, explanations based on the carbon premium face the challenge of a lack of empirical consensus on this issue, given the contradictory results about the relative performance of green and brown stocks. Some empirical studies find that green stocks have had lower returns thus confirming a carbon premium, notably, Bolton and Kacperczyk (2021, 2023); Delmas et al. (2015); Busch et al. (2022); Görgen et al. (2020) and Bansal et al. (2021). In contrast, other studies have documented substantially positive historical returns for portfolios that go long in green stocks and short in brown stocks (Garvey et al., 2018; In et al., 2019; Huij et al., 2024; Pastor et al., 2022; Bauer et al., 2022; Zhang, 2024). This seemingly conflicting evidence could reflect the fact that realized green returns can differ from expected returns for a period of time if risk perceptions or preferences shift unexpectedly over time (Bauer et al., 2022). In fact, Pastor et al. (2022) and Ardia et al. (2023) provide evidence that green stocks may have had higher realized returns than brown stocks because of increased concerns about climate change, but similar or even lower expected returns. Lontzek et al. (2022) show that a sequence of large negative climate shocks can raise perceived climate risks, and during the transitional period growth in demand for sustainable investments could account for the empirical evidence on high green realized returns, meaning that there was a carbon premium in expected returns while at the same time green stocks had temporarily higher realized returns. Eskildsen et al. (2024) use direct estimates of expected returns and provide evidence that they were higher for brown stocks than for green stocks. Bauer et al. (2024a) show that firm announcements of decarbonization commitments raise their stock prices, consistent with a decline in the carbon premium for firms that become greener. Overall, a carbon risk premium channel may be a promising explanation for green/brown monetary policy heterogeneity, but future research is needed to provide further support.

A fourth possible explanation is a "demand channel" based on the differential interest-rate sensitivity of the demand for the products of green and brown firms. Some sectors sell products that have more cyclical demand, with greater sensitivity to changes in interest rates.[27] Such industry differences could matter for cross-industry heterogeneity of green and brown firms in their response to monetary policy. Havrylchyk and Pourabbasvafa (2023)

[27] Eijffinger et al. (2017) show that cyclical industries are more responsive to monetary policy. Petersen and Strongin (1996) and Willis and Cao (2015) document changes in interest-rate sensitivity across industries and over time.

argue that the unique characteristics of fossil fuel industries are part of the explanation for the green/brown policy heterogeneity in the United States. While these high-emitting industries indeed tend to be very interest-rate sensitive, they are much less relevant in the euro area and do not help explain our results.[28] More broadly, however, the stronger monetary policy sensitivity of browner industries may well be related to their greater cyclicality and interest-rate sensitivity. Furthermore, differential firm-level interest rate sensitivity could also be present *within* industries, with products of brown firms being more cyclical and more responsive to interest rates. This could result from a short-term orientation of brown businesses. Consistent with this view, evidence from Table 7 and Pastor et al. (2022) suggests that brown stocks tend to be value stocks, which typically have shorter cash-flow duration.[29] By contrast, green stock prices may reflect a longer time horizon that emphasizes positive future growth opportunities as demand for sustainable products likely has an upward trend and sustainable business models may be more stable. Indeed, earlier research shows that sustainable companies tend to be safer and more insulated from economic downturns (Eccles et al., 2014; Jagannathan et al., 2018). Overall, these arguments suggest that brown stocks might be more sensitive to monetary policy tightening because investors expect their business outlook to be more sensitive to changes in interest rates and cyclical fluctuations than for green firms.

We have argued that there is some empirical support for both a carbon premium channel and a demand channel for a differential sensitivity of green and brown stocks to monetary policy. But more research is clearly needed to get a clearer picture of the relative importance of the different channels, and to disentangle carbon premium effects coming from changes in risk premia and the role of green investor preferences.

6 Examination of the renewable energy sector

It is useful to return to the narrower debate described in the introduction about whether recent higher interest rates may have disproportionally slowed renewable energy investment. The view that higher interest rates slow down the green transition is typically focused on the renewable energy sector, rather than on the broad, whole-economy heterogeneity across green and brown firms that our paper and earlier U.S. studies explore. The fact that green

[28] We found that removing the 20 firms in our sample that are categorized in the Oil, Gas, Coal, Mining, and Metal industries (SIC 10, 12, 13, 14, and 33) actually strengthens the estimated green/brown heterogeneity. We omit the results for the sake of brevity.

[29] While we control for market-to-book ratios in Table 8, it is possible that brown stocks are more short-term oriented and thus more sensitive to near-term demand fluctuations in ways not captured by stock valuation multiples.

and brown firms selling a range of consumer and business goods and services are affected differently by monetary policy is of course relevant to the green transition. But a closely related issue is how the transition from fossil-fuel to renewable energy sources is affected by changes in interest rates and monetary policy. The role of higher interest rates in potentially slowing the adoption of renewable energy and thus the green transition has been widely discussed among policy makers, policy analysts, researchers, and market strategists (e.g., Schnabel, 2023; Egli et al., 2018; Schmidt et al., 2019; Kleintop, 2023). Indeed, the common view that higher interest rates will particularly hinder investment in renewables has prompted proposals—especially in Europe—for dual interest rates with a lower green interest rate for sustainable initiatives (Jourdan et al., 2024). For example, one proposal is that the ECB could set up a green targeted lending operation that would provide banks with a lower interest rate that incentivizes green loans.[30]

To better understand this issue, we investigate whether the interest rate effect on solar and wind energy investment and profitability outweighs the effect on oil and gas companies. Renewable energy facilities are the linchpin of any decarbonization pathway, and they require substantial initial construction financing but incur very low future operating costs (e.g., zero fuel costs). For such investments, higher interest rates should have substantial negative effects as future cash flows are discounted more heavily. Indeed, research with sectoral energy models shows that higher discount rates put low-carbon energy sources, with their very long cash flow duration, at a significant cost disadvantage relative to fossil-fuel sources (e.g., Schmidt et al., 2019; International Energy Agency, 2020; Bistline et al., 2023). That said, engineering cost comparisons do not necessarily translate into profitability much less equity pricing.[31]

To focus our investigation on the renewable and fossil fuel energy sectors, we examine the monetary policy response heterogeneity of several prominent stock market indexes representing global energy sectors. The green indexes include Wilderhill Clean Energy, S&P Global Clean Energy, ISE Global Wind Energy, and MAC Global Solar Energy. The brown indexes include the FTSE All World Oil & Gas & Coal, the S&P 500 Integrated Oil & Gas, and the STOXX Europe 600 Oil & Gas Price Index. For each group of indexes, we extract their common factor as the first principal component, which results in a brown factor and a green factor. We also calculate a brown-minus-green factor corresponding to the difference

[30] As French president Emmanuel Macron Macron (2023) advocated: "We must also put private financing and trade at the service of the Paris agreement. The cost of investment must be higher for players in the fossil-fuel sector. We need a green interest rate and a brown interest rate."

[31] Requirements for storage and dispatchability as well as regulatory and other impediments can insulate the relevant wholesale and retail energy prices from the costs of green or brown power generation (Hirth and Steckel, 2016).

of these two factors, which represents the return on an financial strategy of going long in oil and gas indexes and short in the renewable energy indexes. We use event study regressions to uncover the interest rate sensitivities of these energy sectors using three different measures of ECB policy shocks: the three-month and one-year OIS rate surprises, and the JK surprise from Jarociński and Karadi (2020), which accounts for possible information effects and is generally related more strongly to the stock market, as described in Section 2.2.

Table 9: Effects of monetary policy surprises on energy sector indexes

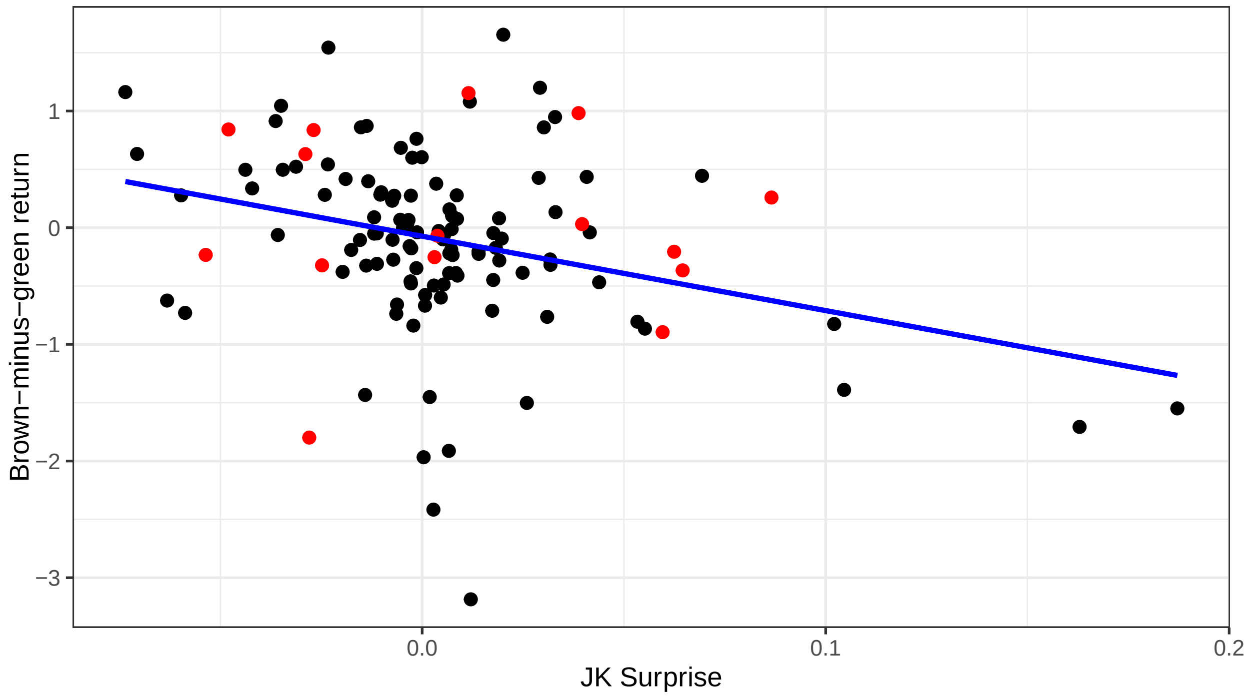
	OIS 3m			OIS 1y			JK		
	Brown	Green	BMG	Brown	Green	BMG	Brown	Green	BMG
mps	−5.47	−0.79	−4.68***	−3.62	−0.88	−2.74	−13.12*	−6.74	−6.38***
	(6.52)	(5.78)	(1.79)	(3.51)	(3.04)	(1.88)	(7.66)	(7.42)	(1.51)
R^2	0.02	−0.01	0.03	0.01	−0.01	0.01	0.23	0.06	0.09

Regressions of first principal components of selected green and brown indexes on alternative monetary policy surprises (described in the text). The sample period from July 2010 to October 2023 includes 124 ECB announcements. Standard errors are reported in parentheses. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

Table 9 shows the event-study regression results. The brown factor appears to be more negatively affected by tighter monetary policy than the green factor. Given the short sample, the estimates are imprecise, and the responses of the brown and green factors tend not to be statistically significant at conventional significance levels. But the responses are significantly different as the negative response of the BMG spread factor is statistically significant at the 1%-level for the three-moth OIS surprise and the JK surprise. These results suggest that for the energy production sector, the fossil fuel firms appear more sensitive to monetary policy than renewable energy firms, providing further confirmation to the broader brown-minus-green findings in Section 3.

Finally, we should note that the policy concerns of Schnabel (2023) and many others were prompted by worries specifically about the adverse effects of the tightening of monetary policy in 2022 and 2023. That episode also followed a long period during our sample of near-zero interest rates, so it is interesting to examine whether those recent observations are outliers compared to our full sample results. As we noted regarding Figure 1, which plots the economy-wide brown-minus-green return against monetary policy surprises, the recent sample of observations does not provide any evidence that the latest monetary policy tightening had a different stock market response. This conclusion also holds for the energy sector. Figure 2 shows a scatterplot of the brown-minus-green energy portfolio—narrowly focused on fossil fuel versus renewables equity returns—against the JK monetary policy surprise on

Figure 2: Reaction of brown-minus-green energy portfolio to ECB surprises



The figure plots the returns on a brown-minus-green energy portfolio—narrowly focused on fossil fuel versus renewables—against the JK monetary policy surprise on ECB announcement days. Brown-minus-green returns are constructed as for the regressions in Table 9, using the difference between the first principal component of selected brown and green energy indexes. The sample period from July 2010 to October 2023 includes 124 ECB announcements. ECB announcements in 2022 and 2023 are shown in red.

ECB announcement days (Jarociński and Karadi, 2020). Again, the ECB announcements in 2022 and 2023 shown in red appear consistent with the rest of the sample.

Our evidence shows that stocks in the renewable energy sector are actually less affected by rising rates from monetary policy compared to fossil fuel firms is at odds with the received wisdom on the adverse effects of interest rates on renewables capital investment cited above. Could these findings be reconciled? Specifically, could a firm curtail capital spending on renewables in response to higher interest rates and yet at the same time not see a decline in stock price? Typically, much macro-finance research assumes a fairly close relationship between equity valuations and real investment opportunities and spending. Indeed, such a connection is formalized in the Q theory of investment, which relates a firm's investment to the ratio of its market value to its replacement cost (Tobin's Q, which is closely related to the firm's market-to-book ratio). However, researchers have generally found little support for this theory in the data, with potential sources for this failure including the existence of financial constraints, decreasing returns to scale, and measurement problems, among other things (e.g., Oliner et al., 1995; Bond and Van Reenen, 2007). Beyond a possible disconnect between equity valuations and investment spending, another way to reconcile our results could be the higher tendency for brown firms to undertake green investments, including renewable energy technologies. As these investments have longer duration and would be disproportionally affected by monetary policy, brown firms would be more policy-sensitive in this case. Some evidence in Döttling and Lam (2024) indeed points in that direction. Relatedly, Fornaro et al. (2024) document that U.S. firms with more green patents reduce their investment more strongly in response to monetary contractions than other firms, and it is plausible that these firms are actually high-carbon firms, like energy companies that often play a big role in the development and adoption of new green technologies. The adverse effects of higher interest rates on renewables investment are an important topic for future research.

7 Conclusion

The debate in Europe about the effect of higher interest rates on the green transition motivated our investigation about whether equity prices of firms with a lower carbon intensity exhibit a greater response to monetary policy. Our analysis of the effect of high-frequency ECB policy surprises on publicly listed companies in the euro area uncovered three main results: First, euro-area green stocks appear significantly *less* affected by monetary policy surprises to interest rates than higher-carbon brown stocks, and this pattern is robust across various greenness metrics, policy surprises, and empirical specifications. Second, these heterogeneous effects are not explained by differences in firm-level characteristics such as leverage, size, capital tangibility, or market beta. Third, focusing on narrower stock market indexes for the green and brown energy sectors, we find that the interest rate reactions of the renewable energy industry are *weaker* than the response of the oil & gas energy sector—which is consistent with our whole-economy results. These conclusions are in broad agreement with recent research using U.S. data despite notable European differences from the United States in terms of climate and non-climate regulatory and fiscal policies, industry composition, and political, societal, and investor attitudes towards climate change and climate investing.

There are several possible theoretical channels that could explain the differential policy sensitivity of green and brown stocks. However, neither differences in observable firm characteristics (such as the amount of tangible capital) nor industry composition effects appear to account for our euro-area results. Instead, a carbon premium, while not firmly established empirically in the literature, seems to be a promising potential candidate explanation for the differential green/brown sensitivity. Both possible contributors to the carbon premium—a carbon risk premium driven by differences in transition risk and a carbon aversion premium driven by green investor preferences—may reduce the impact of monetary policy shocks, and possibly other shocks, on green asset prices. Another potential explanation is a demand channel, according to which the product demand for green firms is less cyclical and less interest-sensitive than for brown firms. While both the carbon premium and the demand channels likely contribute to the differential monetary policy sensitivity of green and brown stocks, more work is needed to supply definitive supporting evidence and to sharpen our theoretical understanding of these mechanisms.

The results in our paper and recent U.S. research are at odds with the consensus view from earlier analyses that higher interest rates unduly limit renewable energy production and may endanger the green transition more broadly. While a comprehensive reconciliation of earlier work with the evidence based on monetary policy surprises is beyond the scope of this paper, it may be that methodological differences are responsible for the conflicting conclusions. In our view, using exogenous rate changes as measured by high-frequency monetary policy surprises is one of the most reliable approaches for causal inference about the effects of changes in interest rates on economic and financial conditions. While further research is required, the growing body of evidence on the green/brown firm-level effects of monetary policy is starting to call into question some prevailing views about the relationship between interest rates and efforts to decarbonize our economies.

Our study has focused on the differential stock market effects of monetary policy surprises across firms–a methodology with the advantage of sharp econometric identification. Equity valuations reflect investors' forward-looking views of green and brown business prospects, but a crucial companion question is how does monetary policy actually affect future firm-level operational outcomes—including investment spending, profits, and GHG emissions. Understanding these real-side consequences would help clarify the heterogeneous effects of monetary policy on corporations and on the green transition. Using U.S. data, Fornaro et al. (2024) find that investment by green firms declines more strongly than by brown firms in response to monetary contractions, while Döttling and Lam (2024) report that brown firms reduce their emissions by more than green firms with tighter monetary policy. Clearly, more research is needed on understanding this important issue.

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