Green Preferences: Evidence from the Greenium in Green Bonds *

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Abstract

We investigate whether investors are willing to forgo returns for social benefits by studying green bonds. Using a novel method, we estimate the greenium by comparing green bonds to synthetic non-green bonds constructed using yield-curves bootstrapped from the same issuer's conventional bonds. In contrast to previous studies that likely underestimated the greenium by neglecting the green halo effect, we find an economically sizable greenium both at issuance and after trading. The greenium is larger when greenwashing concerns decrease or climate change awareness increases. Overall, our findings provide clear evidence of investors' nonpecuniary preferences for green assets.

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1 Introduction

Environmental, Social, and Governance (ESG) assets have emerged as an important area of research for both academics and professionals. According to a recent survey, global ESG assets are on track to exceed $53 trillion by 2025, representing more than one-third of the estimated global assets under management (Bloomberg, 2024). A central and highly debated question in this area is whether ESG or "green" assets have value to investors beyond the expected risk and return attributes (e.g., Starks, 2021). Specifically, if we were to present investors with two assets that have identical risks and payoffs but differing ESG profiles, are they willing to pay more for the greener asset?

The answer remains unclear. On the one hand, some experimental and survey studies suggest that social preferences play a more important role in socially responsible investing than financial motives (e.g., Riedl and Smeets, 2017; Bauer, Ruof, and Smeets, 2021; Heeb, Kölbel, Paetzold, and Zeisberger, 2023). There is also empirical evidence that investors allocate capital to green assets despite their lower financial returns (e.g., Hong and Kacperczyk, 2009; Barber, Morse, and Yasuda, 2021). On the other hand, other studies indicate that ESG investing is primarily motivated by financial considerations, with many investors citing higher returns as the main motivation for adopting ESG principles (Døskeland and Pedersen, 2016; BNP Paribas, 2019; BlackRock, 2020). In addition, asset managers also often market ESG assets as a source of superior alpha's (Lester and He, 2018).

To empirically disentangle the nonpecuniary motivations from the financial benefits associated with ESG investing presents a significant challenge. This requires identifying scenarios where assets have identical expected returns and risks while differing *only* in their ESG profiles. Several recent studies have turned to green bonds as a useful empirical laboratory to address this challenge (e.g., Larcker and Watts, 2020). Green bonds offer two advantages. First, green bonds are *nearly identical* to conventional (non-green) bonds from the same issuer, with the primary difference being their explicit allocation of proceeds to environmentally friendly and socially responsible projects. Second, the relatively small issuance size of municipal green bonds allows investors with green preferences to influence pricing by purchasing a substantial portion of the offerings. If the green bonds are issued or traded at a premium (i.e., higher prices or lower yields) relative to conventional bonds from the same issuer, this premium, known as the "greenium", would reflect investors' willingness to accept lower returns in exchange for holding assets that align more closely with their ESG values.

However, despite the increasing popularity of green bond issues worldwide, the existing literature on the presence of a greenium remains inconclusive. While some studies find a statistically significant, albeit economically small, greenium of several basis points (e.g., Zerbib, 2019; Baker, Bergstresser, Serafeim, and Wurgler, 2022), others report no greenium or even a negative greenium (e.g., Karpf and Mandel, 2018; Larcker and Watts, 2020). Although these mixed results can be attributed to the differences in sample selection and methodologies, the generally small greenium estimates are difficult to reconcile with the consistently cited pricing benefits associated with green bond issuance (e.g., Climate Bonds Initiative, 2022). We provide evidence suggesting that previous studies likely underestimate the true greenium due to the *green halo effect*, a phenomenon in which the issuance of a green bond can increase the prices of conventional bonds from the same issuer (Harrison, Partridge, and Tripathy, 2020). In particular, we show that the conventional bonds from the same issuer do not serve as a reliable control group, because they often involve repeated issuers whose overall cost of debt has already declined since their first green bond offerings. Therefore, a cleaner estimation strategy should focus on an issuer's first green bond issuance, while addressing the challenge of no readily available benchmark for first-time green issues.

To this end, this paper proposes, develops, and tests a new method based on the no-arbitrage pricing principle. We measure the greenium by comparing green bonds with equivalent non-green synthetic bonds that are constructed using bootstrapped yield curves. By replicating any fixed-coupon bond through a portfolio of zero-coupon bonds with maturities corresponding to the coupon dates, we can construct a synthetic non-green bond with the same financial risk and return of the green bond using the zero-coupon yield curve derived from the issuer's conventional bonds. This synthetic bond has the same credit risk and replicates the cash flows to bondholders but does not finance eco-friendly projects. Thus, we measure the greenium as the price or yield difference between the green bond and its synthetic counterpart. Simulation analyses and placebo tests show that our method provides reliable and unbiased estimates for bond prices and yields as it prices conventional bonds accurately.

We apply our method to a sample of 3,699 U.S. municipal green bonds issued between June 2013 and December 2020. Our greenium estimates are not only statistically significant but also economically sizable. The offering price greenium is 2.8% on average, corresponding to a yield greenium of 35 basis points (bps). After trading on the secondary market, the average price greenium decreases to 1.9% but remains significant, corresponding to a yield greenium of 25 bps. Further tests confirm that our greenium estimates cannot be explained by other bond characteristics or commonly known pricing and trading frictions in the municipal market. To further validate our methodology, we apply it to evaluate the first green bond issued by the German government, which demonstrates the applicability of our method beyond the U.S. municipal setting and the reliability of our approach in markets with minimal concerns about illiquidity and pricing frictions.

Importantly, our estimates suggest that the greenium is most pronounced for first-time green bond issues and decreases when issued repeatedly. The greenium estimates for first-time issues also drop by nearly half in the first two years after trading on the secondary market. These patterns are consistent with the green halo effect, which predicts that green bond issuance signals the issuer's environmental commitment to investors and thereby also reduces the yield of conventional bonds from the same issuer.

Moreover, we find that the greenium is mainly driven by the demand from green investors. As one of the main concerns among green bond investors is greenwashing (Grene, 2015), we find a higher greenium when investors are less concerned about greenwashing because of third-party certifications or better credit ratings. The greenium is also higher when local investors become more aware of climate change and place more trust in issuers' environmental commitment due to local environmental regulation and enforcement, and when individual investors dominate the investor base compared to institutional investors such as mutual funds.

Taken together, our study suggests that green bonds are offered and traded at an economically sizable premium, which increases with the demand from green investors. The significant greenium serves as direct evidence that investors have green preferences and are willing to forgo financial gains for environmental and social benefits.

Related literature

Our findings contribute to two strands of literature. First, we add to the growing empirical literature that attempts to separate investors' nonpecuniary motives from the financial benefits behind ESG investing. Specifically, we present evidence that investors are willing to pay a premium for green assets even when risk and returns are held constant. This aligns with recent studies showing that investors allocate capital to green assets or impact funds even though these investments yield lower financial returns than traditional alternatives (e.g., Hong and Kacperczyk, 2009; Barber, Morse, and Yasuda, 2021). As such, our paper supports the view that investors value positive societal externalities in utility in addition to wealth, which is a crucial assumption made in many theoretical models studying ESG investing (e.g., Hart and Zingales, 2017; Pastor, Stambaugh, and Taylor, 2021).

Second, our paper contributes to the expanding literature on green bonds by reconciling the disparate findings concerning the existence and magnitude of the greenium. Previous research has found very mixed results. For example, Baker et al. (2022) study a sample of both corporate and green municipal bonds issued between 2010 and 2016 in the U.S. and find an 8 bps lower yield for green bonds. Ehlers and Packer (2017) estimate the greenium at the issuance of EU and US green bonds between 2014 and 2017 and find a premium of 18 basis points using a matching methodology. Hachenberg and Schiereck

(2018) focus on the secondary market and use a matching procedure and panel regressions to study the global green market over 6 months between 2015 and 2016. They find a trivial yield premium of 1 bps. Zerbib (2019) uses a similar methodology to study 110 corporate green bonds issued globally from July 2013 to December 2017 and estimates a statistically significant but economically trivial greenium of 2 bps on the secondary market. Caramichael and Rapp (2024) analyze a global panel of corporate green and conventional bonds, estimating a greenium ranging from 3 to 8 bps. Two well-known studies even find no pricing difference at all for green bonds. Larcker and Watts (2020) explore a matched sample of nearly identical green and non-green municipal bonds in the U.S. and find the greenium to be essentially zero. Moreover, Flammer (2021) rejects the hypothesis that green bonds reduce the cost of debt by showing no price difference for corporate green bonds and matching "brown" bonds.

Our methodology distinguishes this study from the extensive literature that predominantly relies on regression- and matching-based approaches. We develop a new method based on the no-arbitrage pricing principle, which enables us to cleanly estimate the greenium for the first-time green bond issues despite the absence of readily available control groups. We also present evidence of the green halo effects and the endogeneity of bundled twin issues, which helps reconcile the mixed findings on greenium in earlier studies. Specifically, we show that prior research likely underestimates the true greenium by failing to account for the green halo effect, since the issuance of green bonds increases the values of an issuer's conventional bonds (e.g., Feldhütter and Pedersen, forthcoming). By focusing on an issuer's first green bond and employing our novel methodology, we offer a more precise estimation of the greenium, thereby providing robust empirical evidence of investor preferences for green assets.

2 Data

2.1 MSRB data

We obtain a comprehensive historical data set of municipal bond transaction prices from the Municipal Securities Rulemaking Board (MSRB) from January 2013 to December 2020. Each trade observation has data on the bond's identifier (CUSIP), coupon rate, issue date, maturity date, the date and time of the trade, the transaction price and yield, and a variable indicating whether the trade is sale to a customer, a purchase from a customer, or an interdealer trade. We clean the data using the procedure outlined in Green, Li, and Schürhoff (2010) to eliminate obvious data errors and obtain fundamental prices and liquidity measures. First, we exclude all trades in a bond if coupon and maturity information is missing for all trades in that bond. We further exclude trades if the coupon is listed as greater than 20% or the maturity is listed as over 100 years. We also drop all trades where the price is less than 50 (i.e., 50% of face value) or greater than 150 with a short time to maturity and exclude trades occurring after the bond's maturity, as these are likely data errors. We further drop bonds with fewer than 10 transactions, as these provide little information for our analysis.

Bond price As municipal bonds trade infrequently and intraday price variation can be large relative to the underlying fundamentals (Green, Hollifield, and Schürhoff, 2006), we smooth transaction prices and aggregate data to the weekly level so that our findings are not driven by intraday or daily price swings. Following Green et al. (2010) and Schwert (2017), we first construct daily "fundamental prices" by taking the midpoint of the highest price on customer sales and the lowest price on customer purchases on each day. When customer sales and purchases are unavailable on a given day, the daily fundamental price is the mean price of the interdealer trades. The weekly fundamental price is the average of the available daily fundamental prices each week.

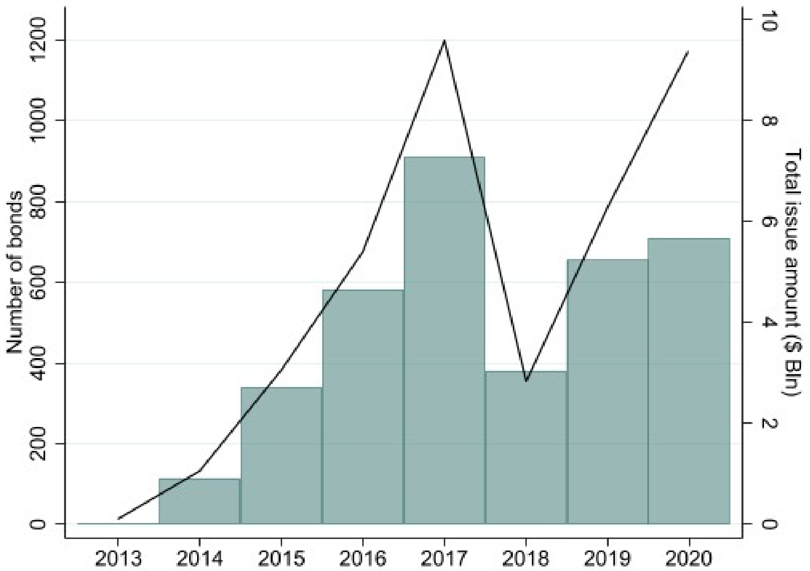
Liquidity measures Following Dick-Nielsen, Feldhütter, and Lando (2012) and Schwert (2017), we use the transaction-level data to construct three daily measures of bond liquidity, which can be aggregated to weekly or monthly level by taking the average or median values. The first measure is the number of trades on a given day, which captures the bond trading activity. The second measure is the daily round-trip trading costs. For days with at least one investor buy price and one investor sell price, the round-trip cost is calculated as the difference between the average investor buy price and average investor sell price, divided by the average investor buy price. The third measure is price impact Amihud (2002). The price impact of a trade is defined as the absolute return for this trade relative to the previous trade divided by the transaction volume of this trade. We then take the daily average of the price impact measure.

On-the-run bonds Default risk and liquidity risk have been shown to be the primary drivers of yield spreads in the municipal market (Cestau, Hollifield, Li, and Schürhoff, 2019). As discussed below, our methodology accounts for differences in default risk by studying bonds from the same issuer. To control for differences in liquidity risk within the issuer, we keep only on-the-run conventional bonds for any given issuer and week, i.e., the most recently issued bonds of a particular maturity. Bonds transition from on-the-run to off-the-run once a new bond of the same maturity is issued. On-the-run bonds are the most frequently traded security of their maturity and, therefore, typically trade at a premium (lower yield) than their off-the-run counterparts. Using only on-the-run bonds ensures that the price differences between on-the-run and off-the-run bonds do not drive our results. Note that we keep both on-the-run and off-the-run traded green bonds.

2.2 Green bond sample

The starting point for our sample is all U.S. self-labeled green bonds in the municipal market from Bloomberg's fixed income database, which industry professionals consider the most comprehensive publicly available source for green municipal securities. Our sample period is from June 2013 to December 2020 because the few issues before June 2013 are unlikely to have been marketed as green bonds (Larcker and Watts, 2020). We follow Schwert (2017) to drop issues smaller than $100,000 and to remove all federally taxable issues to ensure similar tax treatment across bonds in our sample. To simplify price calculations, we restrict the sample to fixed-rate coupon bonds. We further drop issues whose issuer has no bond transaction data in the MSRB database. Finally, we drop issues with fewer than 5 on-the-run conventional bonds being traded the week before the green bond issuance, leaving us with 3,699 issues from 115 unique issuers. The detailed data cleaning steps are outlined in Appendix Table A1. Matching the green bond issues to the MSRB data gives us trading data, including 79,032 bond-week observations in 3,687 distinct bonds.

Figure 1: Number and Issuance Volume of Green Bond Issues



This figure plots our green bond sample, issued between June 2013 and December 2020. The bars (left scale) show the number of green bond issues in each year, and the line shows the total issuance volume (in $ billion) by year.

Figure 1 shows the distribution of our sample by year. The number and size of green bond issues increased substantially from 3 issues in 2013 to 911 issues in 2017 but dropped sharply in 2018. However, this drop is not specific to green bond issues but to all municipal bonds in general because of the 2017 Tax Cuts and Jobs Act, which eliminates the ability for municipal issuers to advance refund outstanding new money bonds on a tax-exempt basis. Nevertheless, the green bond market quickly regained momentum and has surged since 2019. In 2020 alone, the total green bond issues amounted to almost $10 billion.

2.3 Summary statistics

Table 1 reports the descriptive statistics of the green bonds in our sample. The average bond price is 114.22 (% of face value) with an average yield of 238 bps. The offering amount of most green bond issues is small. About 75% of green bond issuers raise fewer than $10 million. The smallest issue in our sample is only $55 thousand, while the largest issue raises $408 million. On average, green bonds have a coupon rate of 4.19% and mature in around 12 years. Moreover, about 55% of our sample green bonds are callable, 9% are taxable at the state level, and 43% are first-time issues.

Table 1: Summary statistics of green bonds

	N	Mean	St. Dev.	P10	P25	P50	P75	P90
Price (% Par)	3,699	114.22	11.07	100.00	103.61	116.02	122.52	127.27
Yield (%)	3,699	2.38	1.00	1.03	1.60	2.38	3.20	3.69
Issue Amount ($ MM)	3,664	10.29	23.42	0.43	1.26	3.36	9.91	24.89
Coupon (%)	3,699	4.19	1.14	2.25	3.85	5.00	5.00	5.00
Maturity (years)	3,699	12.20	7.60	3.36	6.30	10.93	16.92	22.68
Callable	3,699	0.55	0.50	0	0	1	1	1
State Taxable	3,699	0.09	0.28	0	0	0	0	0
First Green Issuance	3,699	0.43	0.50	0	0	0	1	1
Certification								
CBI	3,699	0.25	0.44	0	0	0	1	1
ICMA	3,699	0.16	0.36	0	0	0	0	1
CBI & ICMA	3,699	0.10	0.30	0	0	0	0	0
Credit Rating								
AAA	3,699	0.34	0.47	0	0	0	1	1
AA	3,699	0.52	0.50	0	0	1	1	1
A	3,699	0.12	0.32	0	0	0	0	1
BBB	3,699	0.02	0.12	0	0	0	0	0
BB or Not Rated	3,699	0.01	0.09	0	0	0	0	0
Reference Bonds								
Number of Bonds	3,699	14.31	6.27	7	9	14	18	23
Round-Trip Costs (%)	3,498	0.75	0.60	0.13	0.30	0.54	1.11	1.54
Amihud $\times 10^6$	3,699	0.79	0.88	0.29	0.41	0.63	0.93	1.48

This table presents summary statistics of the green municipal bonds in our sample. The sample period runs from June 2013 to December 2022.

Regarding the third-party certification, 25% of our bonds are certified by the Climate Bond Initiative (CBI), 16% by the International Capital Market Association (ICMA), and 10% by both. For credit ratings, we translate Moody's and Fitch's ratings to the S&P

scale and take the maximum of the available ratings for each bond. Almost all bonds in our sample are investment-grade, with 34% rated as AAA and 52% as AA. Only 1% are rated as B.B. or not rated by any of the three rating agencies.

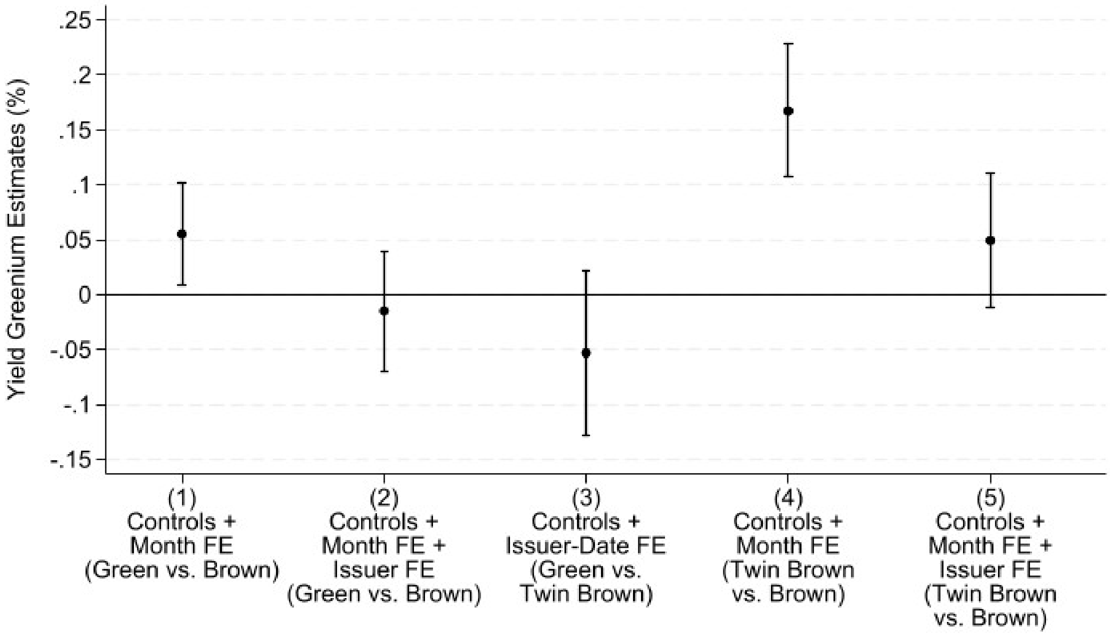
3 Green Halo and Limitations of Previous Methods

In this section, we discuss the potential drawbacks of the regression- and matching-based approaches commonly used in prior studies, and present evidence of the green halo effect (Harrison et al., 2020), which can lead to an underestimation of the greenium.

Recent research suggests that green bonds can serve as signaling tools. Flammer (2021) shows evidence that firms can credibly signal their commitment to sustainability through green bond issuance, while Maltais and Nykvist (2020) argue that reputation, rather than financial returns, is the key motivation for issuing green bonds. As stronger ESG engagement reduces issuers' downside risk (e.g., Hoepner, Oikonomou, Sautner, Starks, and Zhou, 2022) and bond yields (e.g., Hasan, Hoi, Wu, and Zhang, 2017; Saxena and Singh, 2024), issuing green bonds can lower an issuer's overall cost of debt and reduce the offering yield of new conventional issues (Feldhütter and Pedersen, forthcoming). Indeed, a recent study by Ahn, Attaoui, and Fouquau (2024) shows that a firm's first green bond issuance reduces its CDS spreads, implying a lower perceived default risk. Therefore, the green halo effect suggests that the yield differential between green and conventional bonds from the same issuer is likely to be small.

To illustrate how green halo influences the greenium estimates in previous studies, Figure 2 presents the OLS estimates of the offering yield greenium for the green bonds in our sample under different specifications. We begin by comparing offering yields on green and conventional bonds, controlling for various issue characteristics (e.g., issue size, credit rating, maturity) and month fixed effects. In this baseline specification, the OLS estimate is about 5.5 bps and statistically significant at the 1% level, which aligns with estimates in previous research such as Baker et al. (2022).

Figure 2: OLS Estimates of Greenium

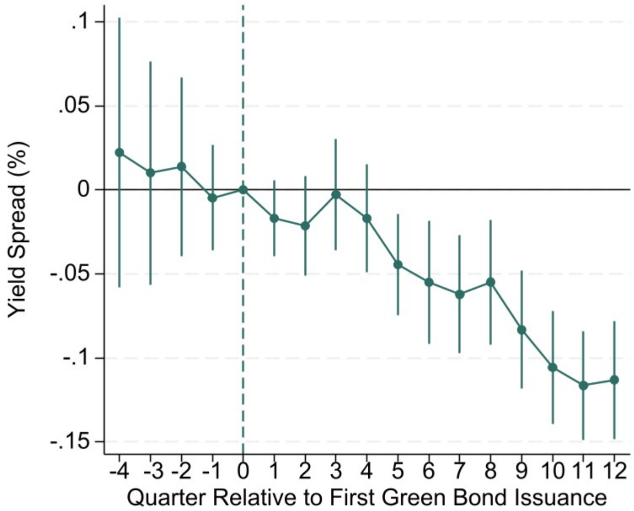


This figure plots the OLS estimates of the offering yield greenium across various specifications and samples. We show the coefficient estimates and their corresponding 99% confidence intervals. From left to right, the specifications are as follows: (1) a pooled sample of green and conventional issues, estimating the greenium by comparing offering yield differences between green and conventional bonds, while controlling for issue characteristics (e.g., issue size, rating, maturity) and month fixed effects; (2) the same as (1), but with the inclusion of issuer fixed effects; (3) the addition of issuer-date fixed effects. Estimates (4) and (5) focus on twin issues, where green and conventional bonds are issued on the same day by the same issuer. Estimate (4) examines offering yield differences between twin conventional and regular conventional issues, controlling for issue characteristics and month fixed effects. Estimate (5) extends (4) by also controlling for issuer fixed effects.

Next, we include issuer fixed effects to exploit within-issuer differences in offering yields. Under this specification, the greenium estimate falls to -1.5 bps and becomes statistically insignificant from zero, implying negligible pricing differences between green and conventional bonds issued by the same municipality around the same time. Based on these results, one might prematurely conclude that the greenium is small or nonexistent. However, such a conclusion likely understates the true greenium because newly issued conventional bonds by a green bond issuer do not serve as a *clean* control group when the issuer's overall cost of debt—and hence the offering yield of its conventional issues—has also been reduced by green bond issuance.

To explicitly test the green halo effect on the yield of conventional bonds, we plot in Figure 3 the quarterly yield spread changes of conventional bonds around the quarter when the issuer offers a green bond for the first time. Yield spreads are calculated relative to maturity-matched Treasury yields, and the changes are measured against the average spread in the quarter of green bond issuance. As shown, conventional bond yields decline significantly: over the three years following green bond issuance, the yield spread on those conventional bonds drops by about 12 bps, providing direct evidence of the green halo effect.

Figure 3: Green Halo Effect on Yield of Conventional Bonds



This plots the quarterly average yield spread changes of the conventional bonds over the 16 quarters around the quarter (0) when a municipality issues a green bond for the first time. Yield spreads are calculated against maturity-matched Treasury yields, and the changes are measured relative to the average spread in quarter 0. Error bars represent the corresponding 99% confidence intervals based on standard errors clustered at the bond level.

The green halo also affects the "twin" issue approach in Larcker and Watts (2020), which focuses on bundled green and conventional bonds with similar characteristics issued by the same issuer on the same day. By tightening the baseline regression specification with issuer-date fixed effects, we effectively replicate this approach and find that the greenium estimate is negative, small, and statistically insignificant, consistent with Larcker and Watts (2020). However, nearly 80% of these bundled issues are repeated issuances, where the green halo is likely already in effect.

Moreover, as discussed in Baker et al. (2022), the decision to bundle green and conventional bonds is likely endogenous, making those twin issues special cases. We illustrate this by comparing the yields of conventional bonds in twin issues with other conventional bonds, controlling for bond characteristics and month fixed effects. We find a 17 bps yield differential that is statistically highly significant, suggesting that twin conventional bonds are valued much more than regular conventional issues and, therefore, cannot serve as a reliable control group. After we additionally control for issuer fixed effects, this yield gap becomes insignificant, reinforcing the notion that conventional bonds from green bond issuers are priced more favorably, which is another indication of the green halo effect. This finding is in line with the argument in Baker et al. (2022): as bundled issues share the same offering document and marketing effort, it is unclear whether investors are able to distinguish green bonds from non-green bonds given the close connections.

Taken together, these findings suggest that the common methods of comparing green bonds with non-green bonds may systematically underestimate the true greenium due to the green halo effect and endogeneity issues. In particular, neither the same issuer's conventional bonds nor bundled "twin" conventional bonds serve as reliable controls, because they often involve repeated issuers whose overall cost of debt has already been lowered by green bond issuances, and because bundling decisions are themselves endogenous. Therefore, a more rigorous estimation strategy must isolate the impact of an issuer's *first* green bond, while circumventing the challenge that there is no readily available benchmark for first-time green issues. Our methodology, discussed in the following section, aims to address these confounding factors and offers a cleaner estimate of the greenium.

4 Methodology

In this section, we explain our methodology to estimate the premium of green bonds over equivalent synthetic conventional bonds from the same issuer.

4.1 Theoretical bond price and bootstrapped yield curve

Based on the no-arbitrage pricing principle, any fixed coupon bond can be replicated by holding a portfolio of zero coupon bonds with maturities corresponding to the coupon dates. Hence, the theoretical bond price equals the present value of all future coupon payments and principal, which are discounted using the zero curve. More precisely, suppose a bond pays deterministic coupon c_τ at time T_τ, $\tau = 1, \ldots, n$, and principal value K at maturity T_n, the price, B_t, at a time $t < T_1$, of this coupon bond is given by

$$B_t = K \cdot Z_{t,T_n} + \sum_{\tau=1}^{n} c_\tau \cdot Z_{t,T_\tau}, \tag{1}$$

where Z_{t,T_τ} denotes the price at time t of a zero coupon bond with maturity T_τ.

The common practice to derive the associated zero-coupon yields is to bootstrap the yield curve using information from traded coupon bonds. Suppose we have traded prices of M traded bonds with different maturities from the same issuer. Let $B_{m,t}$ denote the price of bond m at time t, $i = 1, \ldots, M$, and Y_{mn} denote the payment of bond m at time n, $n = t+1, \ldots, t+N$. Y_{mn}'s may be zero, e.g., if bond m matures before $t+N$. Then, the associated zero-rates (discount factors) $Z_{t,t+1}, \ldots, Z_{t,t+N}$ must satisfy the following system of equations

$$\begin{pmatrix} B_{1,t} \\ \vdots \\ B_{M,t} \end{pmatrix} = \begin{pmatrix} Y_{1,t+1} & \cdots & Y_{1,t+N} \\ \vdots & \ddots & \vdots \\ Y_{M,t+1} & \cdots & Y_{M,t+N} \end{pmatrix} \begin{pmatrix} Z_{t,t+1} \\ \vdots \\ Z_{t,t+N} \end{pmatrix}. \tag{2}$$

This system has M equations with N unknowns, which can be solved numerically, and the estimated yield curve could be further smoothed by using linear interpolation. Using this bootstrapped zero-coupon curve, we can now calculate the theoretical price of any fixed-coupon bond from the same issuer at time t.

Note that the usual problem with bootstrapping from coupon bond prices is that the system of equations does not have feasible solutions, for example, when $M \ll N$ or when the Y-matrix contains too many zeros. This problem typically applies to corporate bonds but much less to municipal bonds, as most municipal issuers have many outstanding bonds with the same structure and coupon frequency but a wide range of maturities at any point in time.

4.2 Estimating greenium

Our methodology follows the insights above and measures the greenium as the difference in the bond price (yield) between the green bond and an equivalent synthetic non-green bond constructed using the same cash flows and bootstrapped zero-coupon bonds as in Equation (1). In other words, we use a bootstrapped yield curve for each green bond to price it as if it is a conventional non-green bond.

More specifically, for each green bond i issued at time t by issuer j, we first extract all on-the-run conventional bonds from the same issuer j that traded in the week prior to t. We refer to these bonds as reference bonds. Using their most recent prices, we then bootstrap a zero-coupon yield curve, which inherently captures the issuer's credit risk because the reference bonds come from the same issuer. As long as there are a few reference bonds with sufficiently different maturities, the bootstrapping approach can construct the entire zero-coupon yield curve. Moreover, because on-the-run bonds typically have the highest liquidity within their respective maturities, liquidity differences are unlikely to drive our results. In Section 5.2, we explicitly show that variations in the liquidity of reference bonds do not significantly affect our greenium estimates.

We then use the bootstrapped zero-coupon yield curve to price bond i as if it is a conventional bond and obtain the estimated price, $\widehat{P}_{i,t}$, and its corresponding yield, $\widehat{Y}_{i,t}$. The premium of green bonds over conventional bonds is then defined in terms of prices as

$$\text{Price Greenium}_{i,t} = \frac{P_{i,t}^{Actual} - \widehat{P}_{i,t}}{\widehat{P}_{i,t}}, \tag{3}$$

and in terms of yield as

$$\text{Yield Greenium}_{i,t} = \widehat{Y}_{i,t} - Y_{i,t}^{Actual}. \tag{4}$$

4.3 Estimation errors

In practice, actual bond prices could deviate from their theoretical values because of other bond characteristics, such as restrictive covenants, tax status, or embedded call or put options. While none of the existing credit risk models is able to capture all such features, ignoring them could naturally introduce pricing errors in our greenium estimates. However, as different characteristics move prices in different directions, it is theoretically unclear whether the errors would, on average, cancel out or bias the estimates systematically.

To better understand the potential estimation errors, we conduct a "sanity check" using randomly sampled conventional bonds. Specifically, we draw 500 random samples of 3,000 bond-week observations from all the on-the-run conventional bonds in our cleaned MSRB data. We restrict to issuers who never issued a green bond during our sample period. For each bond-week observation in each sample, the estimation error is the price and yield differences between theoretical and actual values calculated as in Equation (3) and (4). We compute the key statistics (e.g., mean, median, and confidence interval) of the errors in each sample. The 99% confidence intervals (C.I.) are based on standard errors clustered at the issuer level, which corrects for potential sampling biases from large issuers with multiple traded bonds. Panel A of Table 2 presents the average value of these statistics across the 500 random samples.

We find that the average price error is 0.01%, and the average yield error is -2 bps. The quantiles and confidence intervals further indicate that the estimation errors are close to zero and statistically insignificant, suggesting that our methodology provides reliable and unbiased price and yield estimates for traded bonds. Next, we repeat the same exercise using 500 randomly drawn samples of 3,000 newly issued conventional bonds from issuers with trading data available in MSRB who have never issued green bonds. As shown in

Table 2: Potential Estimation Errors

	N	Mean	P25	P50	P75	99% C.I. Lower	99% C.I. Upper
Panel A: Traded Bonds							
Error in Price Estimates (%)	500 × 3,000	0.01	-2.00	-0.02	1.67	-0.27	0.29
Error in Yield Estimates (%)	500 × 3,000	-0.02	-0.29	-0.01	0.27	-0.05	0.02
Panel B: New Issues							
Error in Price Estimates (%)	500 × 3,000	0.09	-0.90	0.00	1.04	-0.14	0.32
Error in Yield Estimates (%)	500 × 3,000	0.04	-0.09	0.00	0.14	0.01	0.06
Panel C: Traded Bonds (Green Bond Issuers)							
Error in Price Estimates (%)	50 × 3,000	-0.03	-1.96	-0.02	1.69	-0.29	0.23
Error in Yield Estimates (%)	50 × 3,000	-0.02	-0.27	0.00	0.26	-0.05	0.02
Panel D: New Issues (Green Bond Issuers)							
Error in Price Estimates (%)	330	0.08	-1.32	0.06	1.94	-0.95	1.12
Error in Yield Estimates (%)	330	0.04	-0.12	0.01	0.28	-0.16	0.24

This table reports the errors in estimating prices and yields based on our methodology. In Panel A, we draw 500 random samples of 3,000 bond-week observations from all on-the-run conventional bonds in MSRB whose issuers never issued a green bond during our sample period. In Panel B, we draw 500 random samples of 3,000 newly issued conventional bonds from issuers who have available MSRB trading data and never issued green bonds. Panel C focuses on traded conventional bonds from green bond issuers prior to their first green bond issuance. Given the smaller pool, we draw only 50 random samples in this case. Panel D examines the 330 new conventional issues from green bond issuers that were issued before their first green bond. For each conventional bond observation (trade or issue), the estimation errors in price and yield are calculated as the difference between theoretical and actual values calculated as in Equation (3) and (4). We winsorize these errors at the 1st and 99th percentiles to mitigate the impact of outliers. In Panel A to C, we compute the key statistics (e.g., mean, median, and confidence interval) of the errors in each random sample, and report the average value of these statistics across the 500 (or 50, for Panel C) samples. The 99% confidence intervals are based on standard errors clustered at the issuer level.

Panel B of Table 2, the estimation errors in offering prices again remain close to zero and statistically insignificant, whereas those in offering yields are statistically significant. Nevertheless, the average error in offering yields is very small in magnitude at around 4 bps, with a 99% confidence interval ranging from 1 to 6 bps. As shown later, this yield error is economically minor compared to our estimates of the yield greenium.

We perform a similar analysis for conventional bonds from green bond issuers in Panels C and D. Panel C focuses on traded conventional bonds prior to the issuer's first green bond. Given the smaller pool, we draw only 50 random samples in this case. Panel D examines new conventional issues from green bond issuers before their first green bond. We obtain 330 new issues with data on offering prices, yields, and sufficient reference bonds. In both cases, we again observe only small and statistically insignificant pricing errors.

Overall, these findings suggest that, even though our methodology does not explicitly model every possible bond characteristics, it provides reliable estimates for bond prices and yields. This result is also not surprising, as our methodology carefully accounts for credit and liquidity risks, the two factors that have been shown to be the primary drivers in the municipal bond market (e.g., Schwert, 2017; Cestau et al., 2019).

5 Greenium

In this section, we estimate the greenium at issuance and after trading for the green municipal bonds in our sample. To mitigate the impact of outliers, we winsorize the greenium estimates at the 1st and 99th percentiles.

5.1 Greenium on the primary and secondary markets

Panel A of Table 3 reports the key statistics (e.g., mean, median, and confidence interval) of the estimated price premium and yield greenium at the time of issuance. The 99% confidence intervals are based on standard errors clustered at the issuer level, which accounts for potential sampling biases from large issuers with many traded bonds. The results show that the average price greenium is 2.8% and highly significant with a 99% confidence interval ranging from 1.8% to 3.9%. The quantiles further indicate that most price premiums are positive. Similarly, we find a significant yield premium with an average of 35 bps and a 99% confidence interval ranging from 24 to 46 bps. Moreover, municipalities tend to have an even higher offering greenium when they issue green bonds for the first time. Panel B of Table 3 shows that the average price greenium is 3.1%, and the average yield greenium is 38 bps for first-time issues.

Table 3: Univariate Analysis of Greenium

	N	Mean	P25	P50	P75	99% C.I. Lower	99% C.I. Upper
Panel A: At Issuance							
Price Greenium (%)	3,699	2.84	0.04	1.17	5.16	1.79	3.90
Yield Greenium (%)	3,699	0.35	0.01	0.20	0.61	0.24	0.46
Panel B: First Green Issue							
Price Greenium (%)	1,594	3.11	0.07	1.29	5.39	1.88	4.33
Yield Greenium (%)	1,594	0.38	0.01	0.21	0.62	0.24	0.52
Panel C: Secondary Market							
Price Greenium (%)	77,655	1.93	-0.51	0.81	4.36	1.01	2.84
Yield Greenium (%)	77,655	0.25	-0.09	0.13	0.53	0.12	0.37

This table reports the key statistics (e.g., mean, median, and confidence interval) of the estimated price premium and yield greenium (both in percentages). The 99% confidence intervals (C.I.) are based on standard errors clustered at the issuer level. Panel A reports the estimates at the time of issuance. Panel B reports the price premium and yield greenium estimates when the issuer offers green bonds for the first time. Panel C reports the estimates of price and yield greenium after trading on the secondary market.

Panel C of Table 3 presents our greenium estimates based on traded prices in the secondary market. The average traded price premium is 1.9% with a 99% confidence interval ranging from 1.0% to 2.8%. This corresponds to a yield premium with an average of 25 bps and a 99% confidence interval ranging from 12 to 37 bps. Although the estimates of traded greenium are, on average, smaller than those of the offering greenium, they indicate that greenium remains significant on the secondary market. This finding suggests that investors continue to place a premium on green bonds after issuance. Moreover, for all greenium estimates in Table 3, the 99% confidence intervals lie significantly beyond the 99% confidence intervals for pricing errors reported in Table 2.

Overall, the sizable magnitudes of both the offering and traded greenium imply that investors are willing to pay a premium for green bonds, even though these bonds share the same financial returns and risks as conventional bonds from the same issuer. In other words, green investments seem to have value for municipal bond investors beyond the typical considerations of expected return and risk.

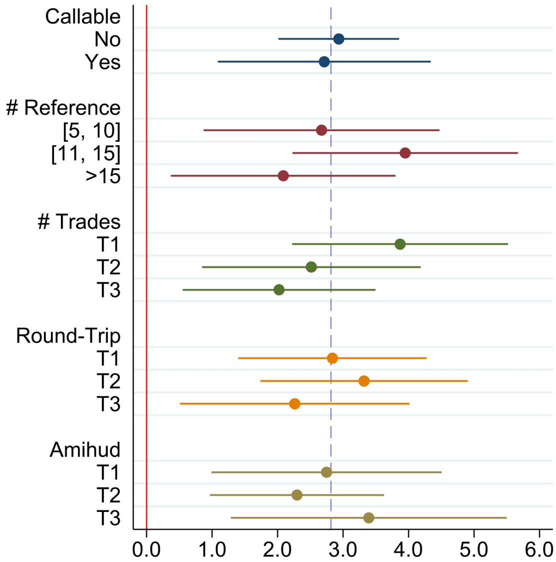
5.2 Greenium and pricing frictions

There are some potential pricing frictions that could influence our results. First, 55% of the green bonds in our sample are callable, which are known to have a lower price (thus higher yield) than otherwise identical non-callable bonds. Since our methodology treats those bonds as if they are non-callable, we might still find a premium even if no greenium exists. To test whether callability drives our results, we split the sample into callable and non-callable bonds and plot the average greenium and the corresponding 99% confidence intervals for each group separately in Figure 4. If callability explains the greenium estimates, we would expect to observe a significant premium only among callable bonds, with insignificant premium for non-callable bonds. However, we still find a significant premium for non-callable bonds, which is slightly higher than that for callable bonds.

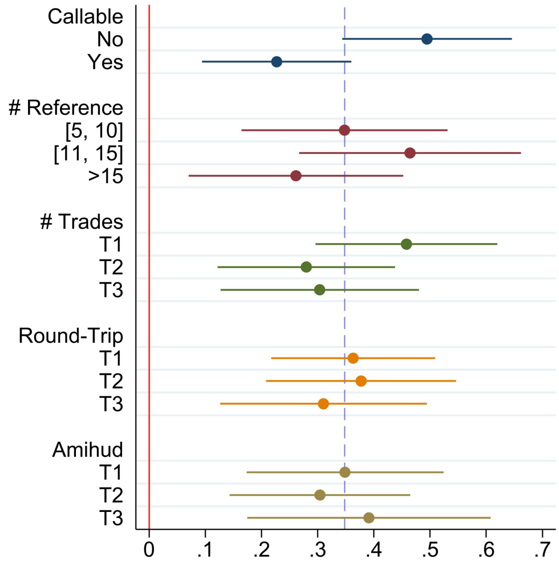
Second, the number of conventional bonds used in the bootstrapping procedure could affect the accuracy of our estimated zero-coupon yield curve. A small number of reference bonds also indicates infrequent trading, which may lead to less efficient prices. While we exclude green bonds for which we have fewer than five reference bonds, about 30% in our sample still have fewer than ten reference bonds. To test whether this affects our results, we split the sample into three groups based on the number of reference bonds, 5 to 10, 11 to 15, and more than 15. If poorly estimated zero-curves or inefficient prices drive our results. In that case, we would expect to see the highest greenium in the first group and the lowest and insignificant greenium in the third group. However, Figure 4 shows no such relationship between the number of reference bonds and our greenium estimates. The greenium estimates remain significant and comparable across all three groups.

A related concern is the illiquidity in the municipal bond market, which causes high trading costs and hinders price formation and efficiency. Following Schwert (2017), we construct three liquidity measures using data in the month before the green bond issue date, and sort green bonds into terciles based on each measure. The first measure is the number of trades, where more trades imply higher liquidity and trading activity. The

Figure 4: Greenium and Potential Pricing Frictions



(a) Price Greenium (%)



(b) Yield Greenium (%)

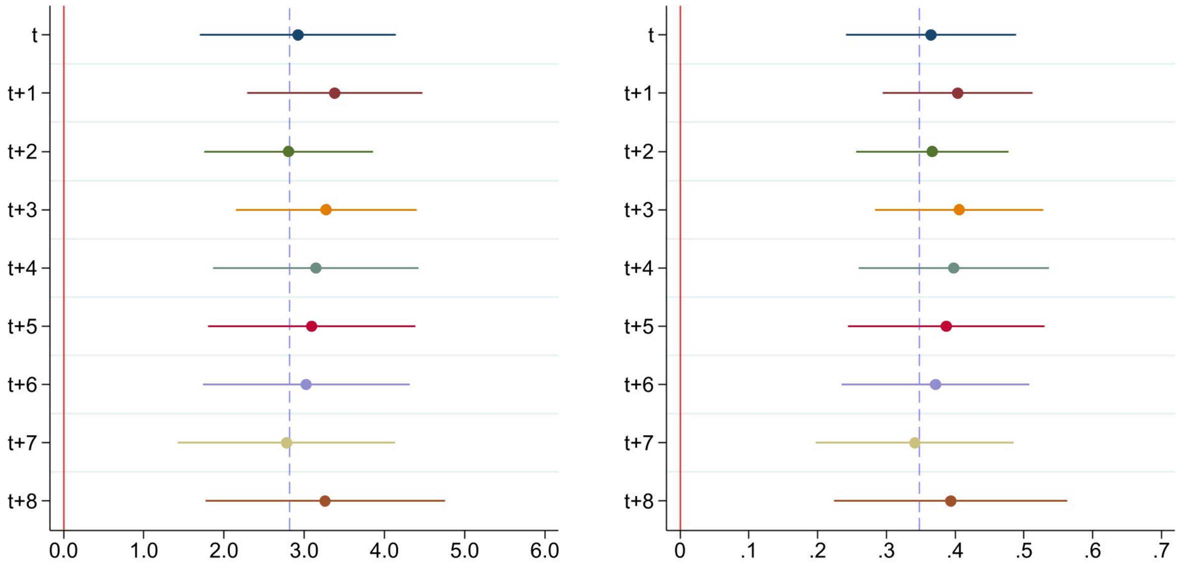
This figure shows how the offering greenium varies with different measures of potential pricing frictions. Panel (a) and (b) plot the results for price greenium and yield greenium, respectively. We consider the following pricing frictions: 1) whether the bond is callable; 2) the number of the reference conventional bonds; 3) the trading activity of reference bonds proxied by the average number of trades per day; 4) illiquidity proxied by the average round-trip cost of the reference bonds; 5) illiquidity proxied by the average Amihud value of the reference bonds. For the trading activity and illiquidity measures, we divide the sample into their terciles. We plot the average greenium and the corresponding 99% confidence intervals based on standard errors clustered at the issuer level. The dashed blue line represents the average greenium in our baseline analysis.

second is the median daily round-trip costs, where lower round-trip costs imply higher liquidity. The third is the average price impact measure of Amihud (2002), with a lower Amihud value indicating higher liquidity. For each measure, we take the average across reference bonds used for each green bond. As shown in Figure 4, there is no relationship between these liquidity measures and our greenium estimates. Importantly, the greenium remains significant and similar to the baseline even for green issues with the most liquid reference bonds.[1] To further alleviate the liquidity concern, we apply our methodology to the first German government green bond in Section 5.4. There, the reference conventional

[1] Appendix B presents the results of multivariate regressions that incorporate all these pricing frictions within the same model. We find no evidence that any of the pricing frictions drive our greenium estimates.

German government bonds are efficiently priced without liquidity issues, yet we again observe a significant greenium.

Figure 5: Greenium based on post-issuance prices of reference bonds



(a) Price Greenium (%) **(b)** Yield Greenium (%)

This figure shows the greenium estimated using reference conventional bonds traded in the weeks after the green bond issuance. Panel (a) and (b) plot the results for price greenium and yield greenium, respectively. We plot the average greenium and the corresponding 99% confidence intervals based on standard errors clustered at the issuer level. The dashed blue line represents the average greenium in our baseline analysis.

Another concern is that green bond issuance may coincide with new green projects, and these new projects, instead of the investors' green preferences, could also change the costs of capital for the issuers. If our greenium estimates simply reflect the value of these new projects that have not yet been incorporated into prices of the conventional reference bonds before green bond issues, we would observe a declining greenium over time as information about these projects is gradually incorporated into reference bond prices. To examine this, we re-estimate greenium using prices of reference bonds traded in the same week of green bond issuance, week t, as well as in each of the eight weeks after the issuance, week $t+1, \ldots, t+8$, respectively. As shown in Figure 5, the greenium does not decline over time. If anything, the average greenium is slightly higher than the baseline.

Taken together, the results show no evidence that our greenium estimates are explained by the callability of green bonds or by commonly known pricing frictions in the municipal bond market. We also obtain similar results when conducting the same set of tests for traded greenium.

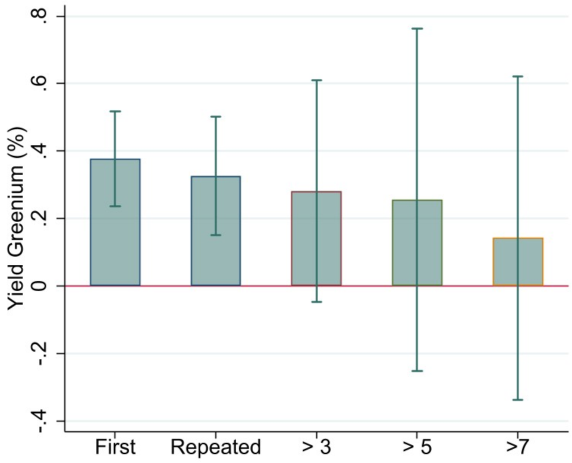
For the remainder of the paper, we follow the green bond literature to focus the discussion on the yield greenium for conciseness. The results for the price greenium are qualitatively identical and available upon request.

5.3 Greenium and green halo

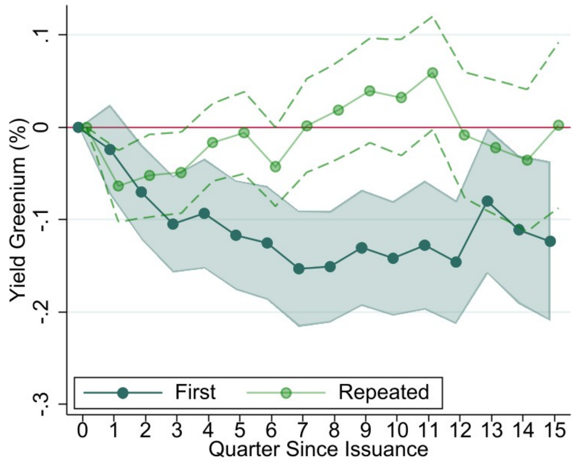
We now discuss in more detail why the greenium is higher for first-time issues and why it declines after trading on the secondary market. We attribute these patterns to the green halo effect, which predicts that the yield differential between green and conventional bonds narrows over time, especially after the first issuance of a green bond. In Panel (a) of Figure 6, we plot the average offering yield greenium by the number of times the issuer has already issued a green bond. The greenium is the highest for issuers' first green bond and decreases with each additional issuance. The offering greenium becomes insignificant after the third time of green bond issuance. This pattern is consistent with the notion that the first green bond issue signals a strong sustainability commitment to the market, whereas repeated issues have a weaker signaling effect.

Panel (b) of Figure 6 further shows the quarterly changes in traded yield greenium relative to the offering greenium over the quarters following issuance. For first-time issues, the greenium drops sharply by about 10 bps in the first year, decreases by another 6 bps in the second year, and then stabilizes. For repeated issues, the greenium declines by only 6 bps over the first two quarters, likely due to an already lower offering greenium at issuance. These patterns indicate that the yield differential between green and conventional bonds narrows significantly after trading. As shown in Figure 3, this decline is driven by the green halo effect, which decreases yields on comparable conventional bonds (rather than increasing yields on green bonds). This pattern also aligns with the theoretic model

Figure 6: Greenium and the Green Halo Effect



(a) First and Repeated Issues



(b) Traded Yield Greenium

Panel (a) plots the average offering yield greenium by the number of times the issuer has already issued a green bond. Panel (b) plots the quarterly changes of traded yield greenium relative to offering yield greenium over the 16 quarters since issuance, with the results for the first-time issues (dark green) and the repeated issues (light green) plotted separately. The shaded area and dashed lines in Panel (b) represent the corresponding 99% confidence intervals based on standard errors clustered at the bond level.

developed by Oehmke and Opp (forthcoming), which predicts that once the issuer secures financing for green projects and the green investors sell their stakes in the secondary market, the green bond becomes more fairly priced. Consequently, the greenium decreases in the secondary market as the initial driven by green preferences stabilizes.

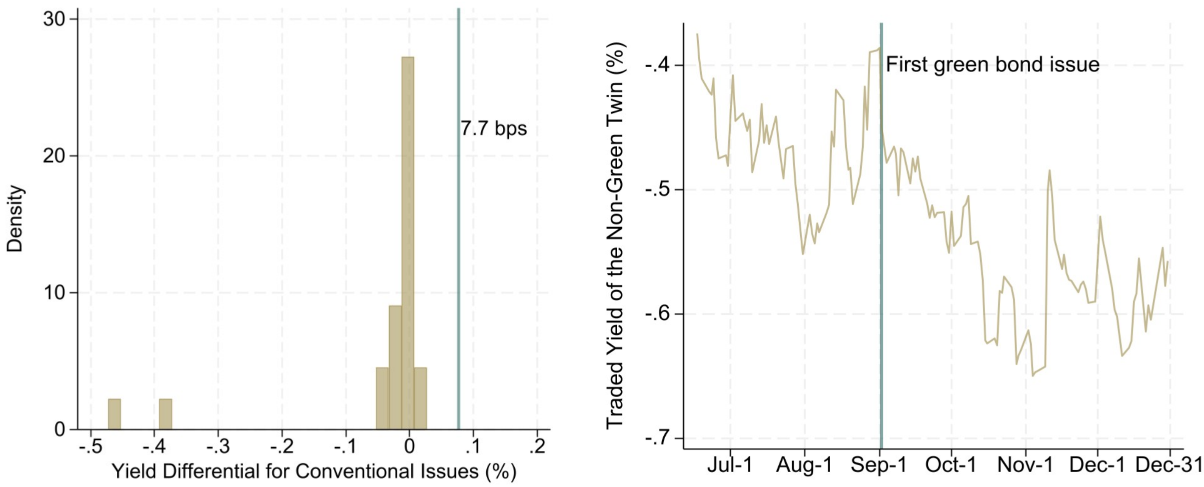
5.4 Robustness: German government green bond

In this section, we apply our methodology to price the first green bond issued by the German government. This exercise serves two purposes. First, it allows us to test whether our approach can be applied to markets beyond the U.S. municipal bond market. Second, German government bonds are known for their high liquidity and pricing efficiency, thereby minimizing the pricing frictions related to illiquid reference bonds.

We obtain the historical German Federal securities issuance data from the German

Finance Ministry[2] for the period from July 2018 to December 2021. In addition, we obtain daily price data for German Federal securities from July 1, 2020, to December 30, 2021, from the German Bundesbank[3]. For each trading day, we again keep only on-the-run conventional bonds for each maturity, and collect the Bundesbank reference price and yield on the Frankfurt Stock Exchange.

Figure 7: Evidence from German Government Green Bonds



(a) Green versus conventional issues

(b) Green halo effect on conventional bond

Panel (a) plots the histogram of the differences between actual and theoretical yields for newly issued conventional bonds by the German government from July 2018 to August 2020. The green vertical line represents the estimated offering yield greenium for the first green bond issued by the German government. Panel (b) plots the traded yields of the twin conventional bonds around the issuance of the first green bond on September 2, 2020.

We first apply our method to price the German federal green bond issued on September 2, 2020 (ISIN: DE0001030708), by extracting the zero-coupon curve from all on-the-run bonds traded on one day before (September 1, 2020). Our estimation implies an offering greenium of 7.7 bps, which is more sizable than the previously quoted range of 1-2 bps. For comparison, we also estimate theoretical offering yields for 22 new conventional bonds issued by the German government between July 2018 and August 2020 (prior to the first

[2] https://www.deutsche-finanzagentur.de/en/federal-securities/issuances/issuance-results

[3] https://www.bundesbank.de/dynamic/action/en/service/federal-securities/prices-and-yields/810710/prices-and-yields-of-listed-federal-securities

green bond issuance). Panel (a) of Figure 7 plots the histogram of the differences between actual and theoretical offering yields for these conventional issues. Most of these yield differentials cluster near zero, with only two notably negative outliers. In contrast, the green vertical line, representing the estimated offering yield greenium for the first green bond, is well above all observed differentials ($t = 4.6$), implying that investors value this green bond substantially more than conventional issues. Furthermore, these findings suggest that our methodology remains robust even in markets where illiquidity concerns are minimal, while reinforcing its applicability beyond the U.S. municipal setting.

It is noteworthy that the offering yield greenium for the German government bond is smaller than that observed for U.S. municipal bonds. The main reason is likely the significant difference in issue size. The issuance size of German government green bonds is substantially larger (€10 billion) than the average issuance size of green municipal bonds in our sample ($ 10.3 million). Because these municipal issues are much smaller, individual and household investors with green preferences can more easily act as the "marginal buyers", thereby bidding up the prices and increasing the greenium. In line with this view, we provide more evidence in Section 6.3 that greenium is primarily driven by individual rather than institutional investors. However, this is less likely to occur in large sovereign bond markets dominated by sophisticated institutional investors, where individual demand alone cannot generate a similarly large premium.

We also investigate whether green halo effects are present in this market. To do so, we study the "twin" conventional bond (ISIN: DE0001102507), which has the same coupon rate and maturity date as the first green bond, but was issued earlier (on July 17, 2020) with a much larger issuance amount. Panel (b) of Figure 7 shows that its traded yield declines sharply immediately after the first green bond issuance on September 2, 2020, dropping from -42 bps to -72 bps over the following two months. This provides clear evidence of a green halo effect driving up the value of the non-green bonds of the same issuer.

6 Variations in Greenium

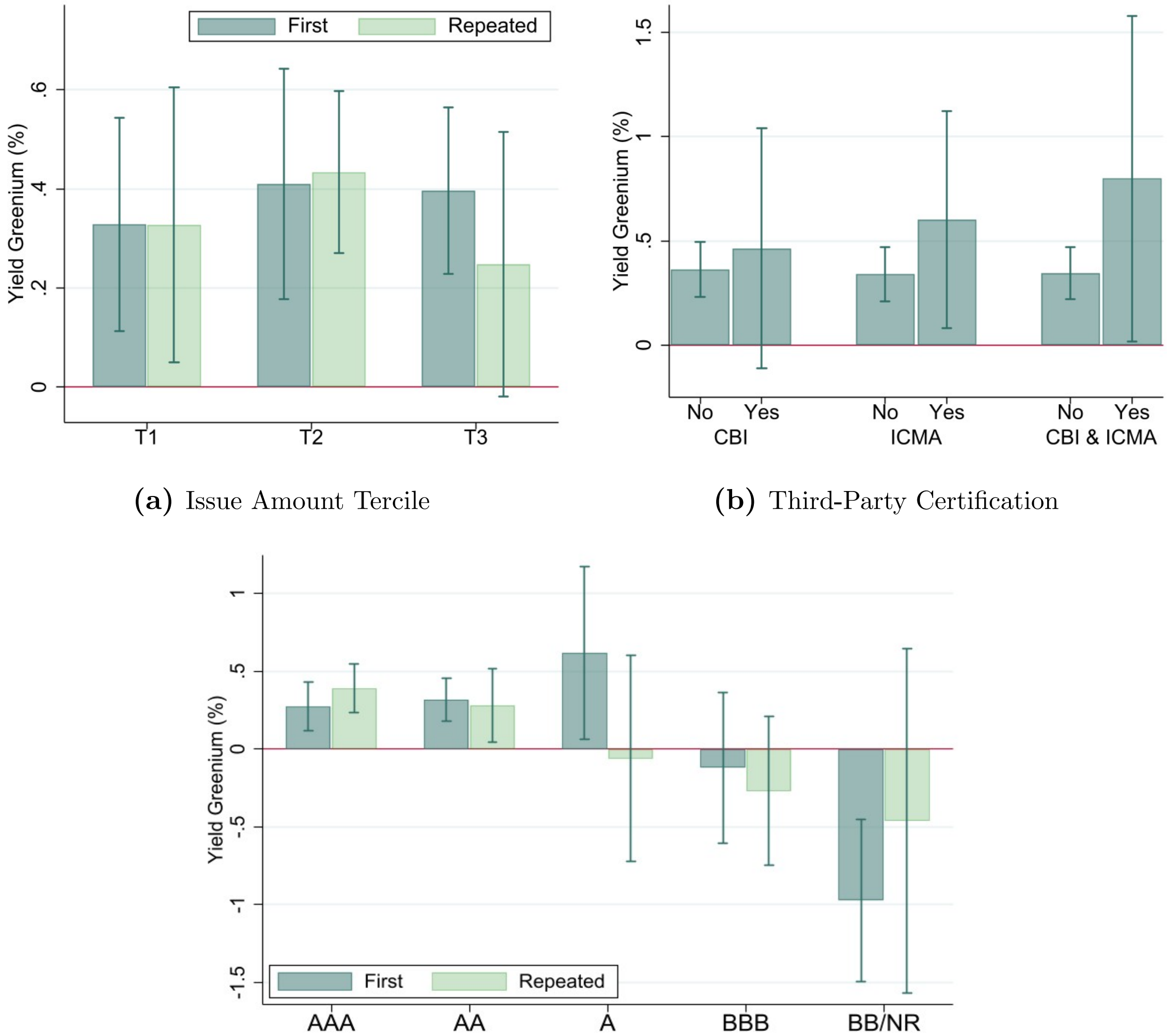
In Section 5, we provide compelling evidence that the greenium in the municipal market is economically sizable and statistically significant, suggesting that the marginal investor is willing to forgo financial gains to invest in eco-friendly assets. Nevertheless, there is significant variation in both the offering and traded greenium, with an interquartile range of about 60 bps. In this section, we examine and discuss the cross-sectional and time-series variations in greenium.

6.1 Greenium by bond characteristics

Issuance Size First, for a greennium to emerge, investors with green preferences must be the marginal investors such that the amount of green demand is sufficient to clear the entire supply of the green bond issue at a higher price. When the issuance size of a green bond is large, the demand from green investors might be insufficient to meet this supply, leading to a lower or even no greenium. To examine the effect of supply, we study the relationship between the issuance size of a green bond and its greenium estimate. We group green bonds into terciles by issuance size and plot the average offering greenium in Panel (a) of Figure 8. While we find no apparent relationship between issuance size and greenium, the greenium remains sizable even in the highest supply terciles (average issuance size of $26 million). The average offering greenium is 40 bps among first-time issues and 25 bps among repeated issues. This suggests that the "green" demand remains present even for relatively large bond offerings.

Third-Party Certification Second, we examine the impact of third-party certification on the offering greenium. A key concern among green bond investors is greenwashing (e.g., Grene, 2015), where bonds labeled as "green" might not actually fund projects with genuine environmental benefits. Since no universal criteria exist for green bonds, issuers may self-label if they can credibly claim environmentally friendly purposes. To mitigate such greenwashing concerns, several third-party institutions have emerged to certify the

Figure 8: Greenium by Issuance Size, Third-Party Certification, and Credit Rating



(a) Issue Amount Tercile

(b) Third-Party Certification

(c) Credit Rating

This figure shows how the offering greenium varies with issue sizes and credit ratings. Panel (a) plots the average yield greenium by issue amount of terciles. Panel (b) plots the average yield greenium of first-time issues with or without a third-party green bond certification (CBI or ICMA). Panel (c) plots the average yield greenium by credit ratings. Both panels plot the results for the first-time (dark green) issues and repeated (light green) issues separately. The error bars represent the corresponding 99% confidence intervals based on standard errors clustered at the issuer level.

use of proceeds for green bonds. For municipal green bonds, the Climate Bond Initiative (CBI) and the International Capital Market Association (ICMA) are the two primary certification providers (Chiang, 2017).

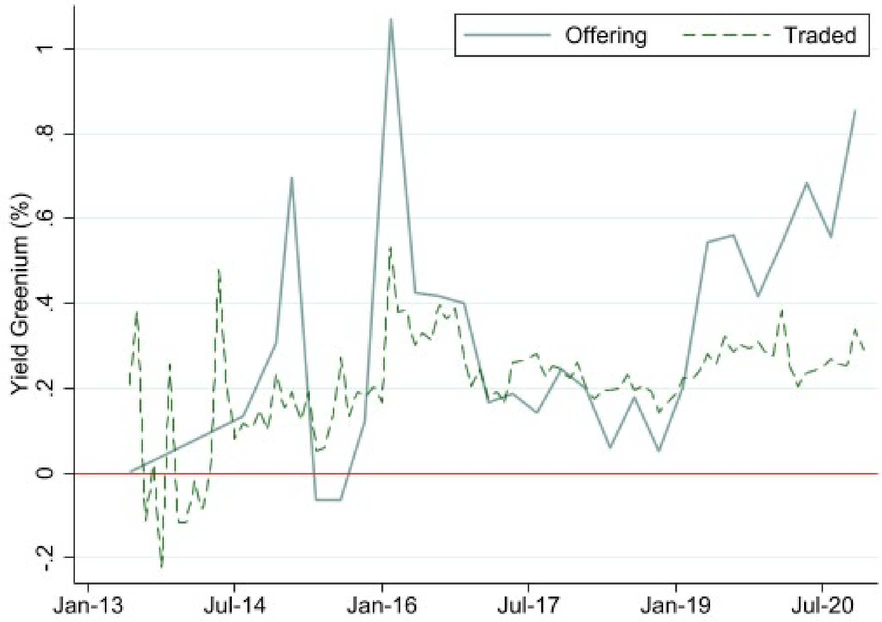
We manually identify the certified green bond issues in our sample and plot the average offering greenium of these issues versus uncertified issues in Panel (b) of Figure 8. We focus on the certification effect on first-time issues because issuers tend to pay for the certification of all their bonds. Extant certification is likely to downward-bias the greenium of repeated issues due to the green halo effect. We find that first green bond issues with either CBI or ICMA certification earn a higher offering greenium. When an issue is certified by both CBI and ICMA, its greenium is about 80 bps, more than twice as large as that of other issues (35 bps). This difference falls just short of statistical significance ($t = 1.51$) as we have only 109 issues with both certifications. Nevertheless, third-party certification seems to alleviate investors' concern about greenwashing and thereby increases the demand from green investors.

Credit Rating Third, we test whether a bond's credit rating at issuance influences its offering greenium. A high credit rating implies a lower risk of issuers diverting the proceeds to other purposes than green projects. If investor confidence about genuine environmental benefits drives the greenium, we expect more safely rated bonds to have a higher greenium. As shown in Panel (c) of Figure 8, the offering greenium is significantly positive for bonds rated AAA to A, but becomes negligible or even negative at BBB or lower ratings. The difference between first-time and repeated issues within each category is generally insignificant. This result is consistent with the notion that green investors prefer safely rated green bond issuers, where the probability of greenwashing is lower.

6.2 Greenium over time

Next, we explore how the average offering greenium varies over time. For each quarter from 2013Q2 to 2020Q4, we calculate the average offering greenium estimates across all newly issued green bonds and plot these quarterly averages in Figure 9. The greenium increased from nearly zero in 2013 to about 70 bps in 2014, then falls below zero in 2015 before rising again in 2016. These fluctuations in the early years are not surprising given the nascent stage of the green bond market at that time and the limited number of green issues prior to 2015. The peak in 2016Q1 is likely due to the increased awareness of climate change and sustainability following the Paris Agreement. The greenium dropped to around 20 bps in 2017-18 and has increased again since 2019. The monthly average of traded greenium follows a very similar pattern.

Figure 9: Greenium over Time



This figure shows how greenium varies over time. We plot the quarterly average offering greenium, and monthly average traded greenium from June 2013 to December 2020.

6.3 Regression analysis

We now use regression analysis to examine how the greenium is related to investors' green sentiment, local environmental regulation stringency, and mutual fund ownership.

Green sentiment Since municipal bonds are mostly bought by local individuals, either directly or through mutual funds, the level of climate change and sustainability awareness among local investors is likely to be the key determinant of demand for green bonds and thus the greenium. To test this hypothesis, column (1) of Table 4 reports a panel regression of the offering greenium on local investors' green sentiment and control variables. To measure local investors' green sentiment, we follow previous research to use monthly Google search trends for two specific green-related terms, "Climate Change" and

Table 4: Regression Analysis of Offering Yield Greenium

	Offering Yield Greenium					
	All Issues			First Green Issues		
	(1)	(2)	(3)	(4)	(5)	(6)
High Green Sentiment	0.335***			0.175*		
	(3.080)			(1.824)		
High Regulation Stringency		0.137*			0.353***	
		(1.834)			(2.635)	
Mutual Fund Ownership			-0.184**			-0.332***
			(-2.530)			(-3.334)
Log(Issue Amount)	0.008	0.008	0.018	0.007	0.011	0.018
	(0.412)	(0.417)	(0.910)	(0.230)	(0.352)	(0.483)
Callable	-0.379***	-0.395***	-0.412***	-0.506***	-0.480***	-0.485***
	(-4.329)	(-4.479)	(-4.397)	(-4.550)	(-4.240)	(-4.098)
State Taxable	-2.734***	-2.710***	-2.267***	-2.128***	-2.189***	-1.877***
	(-9.717)	(-9.745)	(-11.020)	(-8.400)	(-8.070)	(-9.243)
CBI	-0.126	-0.161	-0.204	-0.114	-0.147	-0.212*
	(-1.286)	(-1.644)	(-1.642)	(-0.898)	(-1.282)	(-1.723)
ICMA	0.055	0.076	0.087	0.436***	0.417***	0.415***
	(0.548)	(0.760)	(0.887)	(3.765)	(3.757)	(3.431)
First Green Issuance	0.096	0.084	0.047			
	(1.124)	(0.968)	(0.492)			
Observations	3,633	3,633	3,660	1,560	1,560	1,585
Adjusted R-squared	0.223	0.222	0.158	0.284	0.285	0.222
Fixed Effects	State, Maturity, Rating, and Year					

This table shows the regression results of how the offering yield greenium is correlated with investors' green sentiment, local environmental regulation stringency, state-level political ideology, and mutual fund ownership. Columns (1)-(3) report the results based on all green bond issues, and columns (4)-(6) report the results based on first-time green bond issues. In columns (1) and (4), high green sentiment is a state-month-level dummy variable indicating whether the state belongs to the top quartile of Google search trends for two specific green-related terms, "Climate Change" and "Global Warming". In columns (2) and (5), high regulation stringency is a state-year-level dummy variable indicating whether the state belongs to the top quartile of environmental regulation stringency, measured as the number of enforcement cases divided by the number of facilities. In columns (3) and (6), mutual fund ownership is a continuous variable representing the total mutual fund holdings of a given bond issue as of the quarter-end in which the bond was issued, sourced from the CRSP Mutual Fund Database. Standard errors are clustered at the issuer level, and the corresponding t-statistics are reported in parentheses. ***, **, and * denote significance at 1%, 5%, and 10%, respectively

"Global Warming", originated in the state where the green bond is issued (Pham and Huynh, 2020; Koziol et al., 2022). Control variables include issuance size and indicator variables for whether the bond is callable, taxable at the state level, certified by CBI or

ICMA, or a first-time issue. We also control for the state, maturity bucket, credit rating, and year-fixed effects, and cluster standard errors at the issuer level.

The regression result implies that offering greenium increases by 34 bps when local investors have high green sentiment (i.e., the top quartile of Google search trends). The coefficient on the sentiment variable remains positive and statistically significant when we only focus on first-time issues in column (4). Thus, the regression results are consistent with the idea that awareness of climate change increases demand for green assets and, thereby, the prices.

Regulation stringency As shown earlier, demand from green investors is likely higher when investors are less concerned about greenwashing. In addition to green bonds' third-party certification and credit rating, local environmental regulation can also reduce greenwashing risks and increase investors' trust in issuers. In the U.S., significant environmental legislation exists at the federal level under the Environmental Protection Agency (EPA). However, individual states enforce these laws to varying degrees, and some impose additional environmental requirements beyond those mandated by the EPA. More strict local enforcement helps mitigate concerns about greenwashing or other environmental misconduct. Thus, even when two issuers are committed to the environment in the same way, depending on the local regulatory stringency, the demand for their green bonds can differ, driving pricing differences.

To test whether local environmental regulation stringency affects greenium, we follow Seltzer, Starks, and Zhu (2022) to measure state-level environmental regulatory stringency per year. We obtain EPA enforcement data from the Integrated Compliance Information System for Federal Civil Enforcement Case Data. For each state and year, we use the number of enforcement actions, both informal enforcement actions (notifications of violation) and formal enforcement actions (fines and administrative orders), and normalize the number of enforcement actions by the total number of facilities subject to EPA regulations in that state and year. In column (2) of Table 4, we regress the offering greenium on this regulation stringency variable along with the same controls and fixed effects. The coefficient estimate implies that offering greenium is 14 bps higher for green bonds issued in states with more stringent environmental regulation (i.e., states in the top quartile of the regulation stringency variable). This effect is much stronger and statistically more significant when we focus on the first-time issues in column (5).

Mutual fund ownership We provide further evidence that greenium is driven mainly by individual rather than institutional investors. The idea is that U.S. municipal bonds are predominantly held by wealthy individuals and households. Unlike institutional investors who often operate under mandates that emphasize maximizing financial gains for their clients, individual investors can more directly incorporate personal preferences into bond prices. In particular, given the smaller issue size of municipal bonds, investors with strong "green" preferences can more easily become the "marginal buyers", bidding up prices and increasing the greenium.

Ideally we would like to observe the fraction of each offering purchased by individual investors, but such data are not available to us. Nevertheless, we are able to obtain the mutual fund ownership from the CRSP Mutual Fund Database. Specifically, for each bond, we measure the total mutual fund holdings at the end of the quarter in which the bond was issued. Mutual funds, on average, have bought about 15% of the bond issues in our sample. In column (3) of Table 4, we regress the offering greenium on this ownership variable along with the same controls and fixed effects. The coefficient estimate suggests that a one-standard-deviation increase in mutual fund ownership (0.303) is associated with a 6 bps smaller offering greenium. This effect is even more pronounced and statistically significant for the first-time issues in column (6). The estimate implies that if a green bond is entirely bought by mutual funds (i.e., 100% ownership), the offering greenium is close to zero.

In sum, our findings suggest that the greenium is primarily driven by individual investors with "green" preferences. Their demand is stronger when concerns about greenwashing are mitgated, when they become more aware of climate change, or when local environmental regulation and enforcement increase trust in issuers' sustainability commitments.

7 Conclusion

Despite the growing popularity of ESG investing, the motivations behind adopting this investment approach remain unclear. In particular, whether investors are willing to forgo financial returns for environmental and social benefits is debated among academics and ambiguous among industry practitioners. Recent studies have used green bonds a setting to empirically study investors' preferences for green assets. However, these studies find mixed results due to variations in sample selection and methodology, though they generally report an economically small greenium. We present evidence suggesting that these studies likely underestimate the true greenium due to the green halo effect.

To address these limitations, we propose a new method to estimate the greenium by comparing green bonds with equivalent non-green synthetic bonds constructed from bootstrapped yield curves.Applying this method to both U.S. municipal green bonds and German government green bonds, we find statistically significant and economically sizable greenium at issuance and after trading. These results provide robust evidence that investors prefer green assets, even when expected risk and return are held constant. Importantly, our analysis shows that the estimated greenium cannot be explained by other bond characteristics or commonly known pricing and trading frictions.

Finally, we identify several factors that influence the greenium. Specifically, the greenium is larger when concerns about greenwashing are mitigated, when investors become more aware of climate change, where stringent local environmental regulations and enforcements increase trust in issuers' sustainability commitments, and when individual investors, rather than institutional investors, are able to set the price by purchasing a significant portion of the offerings.

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Appendix

A Sample construction

Table A1

Data cleaning steps	Bonds	Issuers
Full Bloomberg green bond sample	10,951	636
Remove issues dated before June 2013	10,433	543
Drop issues smaller than $100,000	10,021	543
Remove federally taxable issues	8,651	453
Keep fixed-rate coupon bonds	8,555	437
Keep issuers with MSRB data	6,860	285
Keep issues with 5 or more conventional bonds traded in the week before the green bond issuance	3,699	115

This table describes the data cleaning steps in constructing our green municipal bond sample.

B Regression analysis: greenium and potential pricing frictions

Table A2

	Price Greenium (1)	Yield Greenium (2)
Callable	-0.250	-0.270***
	(-0.402)	(-4.155)
State Taxable	0.677	-0.007
	(0.694)	(-0.084)
Log(Number of Reference Bonds)	-0.600	-0.139
	(-0.541)	(-1.100)
Log(Number of Trades)	-0.496	-0.014
	(-1.267)	(-0.273)
Round Trip Cost	-101.054	-12.031
	(-1.556)	(-1.659)
Amihud $\times 10^6$	0.551	0.055
	(0.885)	(0.890)
Constant	6.334**	0.958***
	(2.123)	(3.334)
Observations	3,498	3,498
Adjusted R-squared	0.017	0.055

This table shows how the offering greenium varies with different measures of potential pricing frictions using multivariate regression analysis. Column (1) and (2) report the results for price greenium and yield greenium, respectively. We consider the following pricing frictions: 1) whether the bond is callable; 2) whether the bond is taxable at the state level; 3) the number of the reference conventional bonds; 4) the trading activity of reference bonds proxied by the average number of trades per day; 5) illiquidity proxied by the average round-trip cost of the reference bonds; 6) illiquidity proxied by the average Amihud value of the reference bonds. Standard errors are clustered at the issuer level, and the corresponding t-statistics are reported in parentheses. ***, **, and * denote significance at 1%, 5%, and 10%, respectively.