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# The Pricing and Ownership of US Green Bonds

Malcolm Baker,[1,2] Daniel Bergstresser,[3] George Serafeim,[1] and Jeffrey Wurgler[2,4]

[1]Harvard Business School, Boston, Massachusetts, USA

[2]National Bureau of Economic Research, Cambridge, Massachusetts, USA

[3]Brandeis International Business School, Waltham, Massachusetts, USA

[4]NYU Stern School of Business, New York, NY, USA; email: jwurgler@stern.nyu.edu





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## Abstract

We review the pricing and ownership of green bonds, whose proceeds are used for environmentally focused purposes. After presenting an overview of the literature on green securities and green bonds in particular, we summarize the US corporate and municipal green bond markets. Green municipal bonds provide the best opportunity for detailed empirical study of how pricing and ownership differ from those of ordinary bonds. Green bonds are issued at a small premium of several basis points over similar ordinary bonds except when they are issued simultaneously with ordinary bonds from the same issuer; in that situation, a premium emerges over time on the secondary market. Green bonds, especially small or nearly riskless ones, are also more closely held than ordinary bonds. These facts are consistent with a simple framework that incorporates assets with nonpecuniary utility.

# 1. INTRODUCTION

Climate change is accelerating, and effective adaptation and mitigation projects will require extraordinary sums. One estimate suggests that keeping the world below the 2°C scenario, a threshold viewed as limiting the likelihood of devastating consequences, will require $12 trillion over the next 25 years (Zindler & Locklin 2015).

In the absence of a global carbon pricing scheme, bond markets will be central to financing the necessary investments. In this review, we describe the US market for green bonds, which are an emerging category of bonds whose proceeds are used for environmentally friendly purposes. Examples include renewable energy, clean transportation, sustainable agriculture and forestry, and energy efficiency. After reviewing the market and green bond characteristics, we describe bond pricing and ownership patterns. The stark facts of climate change alone are enough to motivate the study of green bonds, but our framework and results also tie to broader themes in the socially responsible investing and taste-based asset pricing literatures.

Since the first green bond was issued in 2007 by the European Investment Bank (EIB), the market has expanded to include a variety of issuers, including supranationals, sovereigns, corporations, and US and international municipalities. This market is a growing and increasingly well-defined area within fixed-income markets. But despite the general acceptance of the notion of a green bond, there is not yet a universally recognized system for determining the green status of a bond. Green bonds may be labeled and promoted as such by the issuer, such as the 2007 EIB bond; they may be formally certified by a third party according to a particular set of guidelines; and they may be labeled green by a data provider, for example, Bloomberg. Below we review the origins of the market and standards for identifying green bonds.

While all green securities are of practical and academic interest, the US municipal bond market provides a particularly useful empirical laboratory for looking at this nascent market. Municipalities issue series of both green and ordinary bonds, allowing researchers to control for variation in both maturity and credit risk and isolate any impact of green status on pricing and ownership. A caveat is that the very transparency of the municipal bond market—that issuances are occasionally paired—makes this market unique. Investors who might otherwise be willing to pay a premium for green securities are confronted with an unusually clean benchmark. Perhaps for this reason, issuers have been reluctant to engage in price discrimination on issuance, instead focusing on attracting larger overall interest in their combined green and ordinary issues.

We focus on 3,983 green US municipal bonds issued between 2013 and 2018, and we provide descriptive statistics for 51 green US corporate bonds issued between 2013 and 2018. At the individual-CUSIP level, municipal bonds are typically far smaller than corporates; the total par issued for municipal green bonds and corporate green bonds is roughly the same as of the end of 2018, with $28 billion in green municipal bonds and $30 billion for green corporate bonds. On average, green municipals have slightly higher credit ratings and longer maturities than ordinary municipals and are more likely to be new money and backed by project revenue. Green corporate bonds resemble ordinary corporates along those dimensions.

Theories of green investing abound, from the general equilibrium model of Heinkel, Kraus & Zechner (2001) to the taste-based framework of Fama & French (2007) and more recent models by Oehmke & Opp (2020); Pastor, Stambaugh & Taylor (2020); and Pedersen, Fitzgibbons & Pomorski (2021). Like Fama and French, we use a simple framework featuring a subset of investors with a nonpecuniary component of utility, such as a sense of social responsibility from holding green bonds, in addition to standard portfolio mean and variance. In this framework, expected returns include the usual capital asset pricing model (CAPM) beta term plus a second term, reflecting demand for a security's environmental attributes, which illustrates that securities with higher scores—such as green bonds—are priced at a premium and earn lower returns. Note that it is easier to entice investors who derive direct utility from holding green securities. In the Oehmke & Opp (2020) model, where investors care about the ultimate impact of green investing but not the ownership of green securities per se, a free rider problem emerges.

Controlling for a battery of characteristics, we find that green municipal bonds are priced at a premium, with a caveat described in more detail below. After-tax yields at issue for green bonds versus ordinary bonds are 5 to 9 basis points below yields paid by otherwise equivalent bonds. Depending on specification, the estimates account for tax status and many other bond-specific characteristics, ratings–maturity–yield curve interactions, and even issuer fixed effects. On a bond with a 10-year duration, a yield difference of 5 basis points corresponds to a small but nontrivial 0.5-percentage-point difference in value.

The interesting caveat is that in a minority of cases where green bonds are issued simultaneously with ordinary bonds, they are initially priced the same. This point is highlighted by Larcker & Watts (2020). Nonetheless, we find that even in the Larcker and Watts sample, a differential appears to open up once the bonds are trading in the secondary market. This finding suggests a tension between underwriting and institutional pressures to price green and ordinary bonds identically on the primary market versus underlying strong investor demand for green bonds.

The taste-based framework of green investing also makes predictions for the ownership concentration of green bonds. Green bonds should be held disproportionately by concerned investors willing to accept their returns, which are slightly lower in equilibrium. This concentration increase will be greatest for small bonds, where tilting away from market weights is less consequential in terms of risk exposures, and when the bond is nearly riskless, since risk aversion limits the extent to which concerned investors are willing to pursue a nonpecuniary benefit. Using institutional bond ownership data, we find support for these predictions as well.

This article reviews and contributes to a growing body of research on green bonds. There are many issuers one might study—supranationals, sovereigns, municipals, agencies, corporates, and others—and each market differs in target investor base, currency risks, and trading and institutional environment. It is almost impossible to short-sell individual municipal bonds, which can limit the effectiveness of arbitrage in that market. Turning to the corporate market, Flammer (2021) undertakes a comprehensive analysis of international corporate green bonds, with an emphasis on the motives behind them. So far, pricing results have been mixed. In a sample of international corporate green bonds, Flammer does not find a premium at the issue. Using secondary market prices; a green versus ordinary bond matching procedure; and a sample that includes 135 large, investment-grade green bonds of many categories and currencies, Zerbib (2019) finds a moderate green bond premium in some subcategories. Karpf & Mandel (2017) use secondary market yields in a larger sample of municipals. In contrast to our own results, they find a green bond discount. Our sample is broader and our methodology is different, but to the extent they overlap, our results suggest that this conclusion may be incorrect. Pricing in the US municipals market is highly sensitive to tax features, as shown by Atwood (2003), and many of the bonds in the Karpf & Mandel (2017) sample were taxable on account of their association with special federal programs, so it would hardly be surprising that they traded at higher yields.[1] And, as mentioned

[1]The available practitioner research is also mixed. Shurey (2017, p. 2) finds a green bond premium in a sample of 12 supranational, euro-denominated green bonds, but reports that "similar yield curves for other portfolios, including U.S. dollar denominated and corporate-issued green bonds do not consistently demonstrate a premium for green securities." Ehlers & Packer (2017) review green bond certification schemes and find a green bond premium at issuance in a sample of 21 green bonds collected across issuer and currency categories.

above, we reconcile our results with those of Larcker & Watts (2020). Considering municipal bond yield differentials measured in basis points, it is perhaps not surprising that empirical results have at times been sensitive to sample and to how taxes are incorporated into the analysis.

Another body of related research has examined the stock returns of companies that have potentially negative social effects, such as those that produce alcohol, tobacco, or firearms or manage prisons or casinos. Hong & Kacperczyk (2009) suggest that so-called sin stocks trade at a discount and display higher average returns. Statman & Glushkov (2009) caution socially responsible investors from fully excluding "shunned stocks" from portfolios for this reason, but the issue is not settled; Blitz & Fabozzi (2017) attribute the outperformance of sin stocks to other characteristics. Bansal, Wu & Yaron (2019) find results that appear time varying, with socially responsible stocks tending to outperform during favorable economic times; from this result, they conclude that socially responsible investing is a luxury good.

In summary, this review provides a detailed academic introduction to the US market for green bonds; a consistent framework to study both pricing and ownership patterns; and a consistent set of empirical results in a comprehensive sample, including a reconciliation with results that have been interpreted as rejecting a green bond premium. Clearly, the green bond market is only the first step toward addressing enormous problems. There is a commensurate need for further research on green bonds and other areas of climate finance. We review the larger context of environmental investing at the end of the article.

The rest of the review proceeds as follows. Section 2 presents an overview of the green bond market and the characteristics of green bonds versus ordinary bonds. Section 3 uses a simple model to develop the prediction that green bonds should price at a premium, then tests and confirms that prediction. Section 4 extends the framework to predict that green bonds should be held in greater concentrations, then confirms that prediction and some finer ones. Section 5 concludes, and Section 6 puts green bonds in the larger context of environmental investing and discusses some research directions.

## 2. AN OVERVIEW OF GREEN FINANCIAL INSTRUMENTS

Financial instruments targeting specific sustainability outcomes were almost nonexistent before 2013. Since then, cumulative issuance has exceeded $2.1 trillion through 2020. **Figure 1** categorizes green financial instruments in three ways. The first, and least interesting, is to separate publicly listed bonds and privately issued loans. The second categorization separates out bonds that are targeting a specific environmental issue, such as reductions in carbon emissions or supply of clean water. These are green bonds, and they can be distinguished from a broader notion of sustainability that includes social impact, such as product affordability, worker safety, or customer health. These are sustainability and social bonds and loans.

The third categorization indicates whether the instrument is a use-of-proceeds instrument or a linked instrument. Use-of-proceeds instruments, such as green bonds, use specific criteria for qualifying projects that limit where the proceeds may be used. The coupon or interest rate, though, is independent of any ex post sustainability results. In contrast, linked instruments, such as sustainability bonds, do not restrict the use of proceeds. However, the coupon or interest rate depends on predetermined and contracted sustainability results. Linked instruments emerged in 2018, and they grew in 2019 and 2020, with most of them being privately issued loans rather than publicly listed bonds. In contrast, use-of-proceeds instruments are the more mature market; the green bond market is the largest, at more than $1.2 trillion or 50% of the cumulative sustainable debt issuance. Given this institutional background and the history of green financial instruments, we focus our discussion below on green bonds.

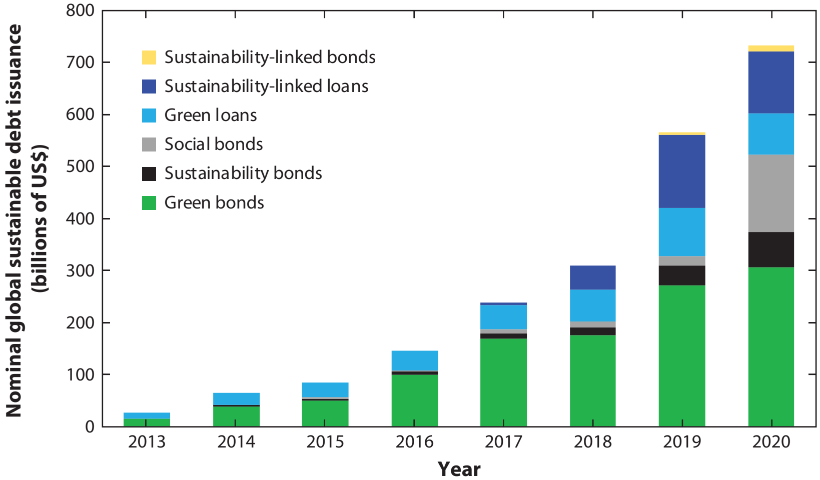


**Figure 1**

Global issuance of sustainability liabilities. Data on bonds and loans come from Bloomberg (Bullard 2021) and are categorized into green, sustainability, sustainability linked, and social. Data are in nominal, billions of US dollars.

## 2.1. Historical Origins of Green Bonds

The green bond market is young: The first bond labeled and marketed as green was issued in 2007 by the EIB. Within only a decade, green bonds were issued by the most prominent issuer types. A benchmark example of a modern sovereign green bond is France's $10 billion bond from 2017. The first corporate green bonds were issued in 2013 by the French utility EDF, the Swedish property development company Vasakronan, Bank of America, and a solar subsidiary of Berkshire Hathaway. The first US municipal bonds to use the green bond label in offering documents were issued by Massachusetts in 2013. The first subsovereign issuer outside of the USA was Gothenburg, Sweden, which issued SEK500 million par value in 2013 (UNFCCC 2013). Other recent international issuers include the Province of Ontario, Canada, and Johannesburg, South Africa. Fannie Mae has pioneered green mortgage-backed securities, which pool mortgages made to finance environment-related investments.

The emergence of the green bond market occurred alongside the development of other services for issuers, regulators, and investors. In 2014, a consortium of investment banks established voluntary guidelines for the green bond market. These "Green Bond Principles" are organized around four elements: the use of proceeds of the bond issue, the process for evaluating projects, the management of the proceeds, and reporting and disclosure regarding the proceeds and the project financed (ICMA 2021). Third-party agents offer certification services for potentially green bonds, and Moody's and Standard & Poor's (S&P) ratings agencies have also developed criteria and indexes for this market. The first green bond exchange-traded fund launched in 2017 and the second in 2018, further evidencing a maturing market.

## 2.2. Green Bond Literature

The green bond literature has addressed several questions. The first and most-researched question is the pricing of green bonds. Results thus far have been inconclusive; some authors have found that green bonds trade at premium prices, some at discounted prices, and some at equal prices, in analyses of bond yields. Ehlers & Packer (2017) study a sample of 21 green bonds, analyzing their pricing in the primary market between 2014 and 2017, and find a premium of 18 basis points, driven mostly by riskier bonds. They find no difference in yields in the secondary market. Hachenberg & Schiereck (2018) find that green bonds issued by corporations and financial institutions trade at a premium relative to comparable, matched nongreen bonds, but they find no difference in sovereign bonds. Zerbib (2019) analyzes 110 green bonds and finds a small premium of 2 basis points, driven by riskier bonds, with sovereign bonds having a lower premium than bonds issued by financial institutions. Gianfrate & Peri (2019) find an 18-basis-point premium among 121 European green bonds, with corporate issuers benefiting the most. Dorfleitner, Utz & Zhang (2020) find that external certification of greenness is an essential force behind green bond premia in the American municipal bond market. Fatica, Panzica & Rancan (2020) and Kapraun & Scheins (2019) also find evidence that external certification of this kind is important in international bond markets (see also Li et al. 2019 for work specifically focused on the Chinese green securities market). MacAskill et al. (2021) provide a meta-analysis concluding that there is a green premium in both primary and secondary markets, particularly for those green bonds that are government issued, investment grade, certified, and with stronger reporting procedures.

The second question is about the signaling value of green bond issuance and the ownership structure of green bonds. Flammer (2021) finds positive abnormal stock price reactions to the announcement of a green bond issuance, which is stronger for green bonds that are certified by independent third parties and first-time issuers. Moreover, green bond issuers improve their environmental performance post issuance and experience an increase in ownership by long-term and green-labeled investors. Tang & Zhang (2020) analyze global corporate green bonds and also find a stock market reaction to green bond issuance. Institutional ownership, especially by domestic institutions, and stock liquidity increase after a green bond issue. These authors do not find a statistically significant premium for green bonds.

## 2.3. Identifying Green Bonds

What is a green bond? The category is not as well defined as "S&P 500 stocks" but is not as fuzzy as "junk bonds" or "growth stocks." We use the CUSIP-level Bloomberg green bond tag as the first step for our sample of US corporate and municipal bonds as an objective, replicable identification method that meets institutional standards. We also add municipal green bonds identified by Mergent. To avoid the difficulties of comparing bonds across disparate institutional environments, we do not include supranational, international corporate, or government issues herein.

Bloomberg describes the task of identifying green bonds as follows:

> There are many shades of green. . . . In addition, terminology often varies, with issuers using different titles to promote the environmental benefits of their bonds. While the use of proceeds often varies by bond as well, all issuers must commit to deploying 100% of bond proceeds for environmental sustainability-oriented activities for their bond to be identified as a labeled green bond. (Shurey 2016, p. 3)

Bloomberg's process is based loosely on the Green Bond Principles described above.

Specifically, Bloomberg considers issuer self-labeling as green and/or additional statements in the issuance documentation about the issuer's intention to deploy funds toward environmentally friendly projects. Acceptable uses of funds include renewable energy, energy smart technologies, green infrastructure, clean transportation, sustainable water management, sustainable agriculture and forestry, pollution control, biodiversity conservation, climate change adaptation, and eco-efficient products.

We exclude municipal bonds issued under the federal Clean Renewable Energy Bond (CREB) and Qualified Energy Conservation Bond (QECB) programs. We identify these by hand from offering statements. These bonds differ in several ways from the generic, self-labeled green bond. First, the label "green bond" was rarely even used in their offering documents. Second, these bonds were typically federally taxable, unlike most municipal bonds, inviting a different investor base. Third, the federal government subsidized the municipal issuer's interest payments if the proceeds were used for clean energy or energy conservation purposes, which broke the link between the issuer's cost of capital and the investor's return at an even more fundamental level than taxes. Fourth, both programs were eliminated effective January 1, 2018 by the Tax Cuts and Jobs Act. In summary, while these bonds may be an interesting niche for climate finance researchers to study, they are a problematic source for insights into green bonds more generally.

In contrast to green municipal bonds, there are far fewer US green corporate bonds. This is perhaps unsurprising given the imperative to isolate and designate proceeds exclusively for projects with the uses listed above. Several corporates do satisfy Bloomberg's requirements, however, and, occasionally, Bloomberg will tag a corporate bond as green, even if it is described as for general corporate purposes, if the issuer is a pure play in that "all the company's business activities fit solely within the list of accepted green activities" (Shurey 2016, p. 8).

## 2.4. Sample, Market Size, and Growth

The unit of observation is an individual bond, identified by a CUSIP. Starting from the union of Bloomberg- and Mergent-based green bond CUSIPs (excluding the QECB/CREB municipal bonds), we require a full set of characteristics and initial yields data for a bond to enter the final sample. For corporate bonds, we use Bloomberg for those data items; for municipal bonds, we use Mergent. The Mergent data are from the official statements filed with the Municipal Securities Rulemaking Board (MSRB). MSRB regulations require that the statement be filed with each municipal bond issue. We exclude floating-rate bonds, which in any event are rarely green.

As **Table 1*a*** indicates, our municipal bond sample, which begins with the Massachusetts green bonds in 2013, runs through the end of 2018 and includes 3,983 green bonds with sufficient characteristics and yields data. Municipal bonds are typically sold in issues that consist of multiple bonds; an issue is a set of bonds that are sold at the same time and are generally subject to the same bond indenture but may include both green and ordinary bonds across a range of maturities. For example, all three green bonds of 2013 were issued by Massachusetts on the same day.

For comparison, we list ordinary municipal bond issuance dollar volume. Over the first 6 years of the US municipal green bond market, labeled green bond issuance in our sample totaled $28 billion, which contributed around 1.4% of the $2 trillion of fixed-rate municipal bond dollar volume. In 2017, the percentage of total municipal volume due to green bonds hit 2.8%, which fell back in 2018 even as the number of unique municipalities issuing green bonds continued to increase. In general, green bonds are a rapidly expanding but still modest segment of the municipal market.

The corporate bond sample also begins in 2013. There are far fewer US corporate than municipal green bonds. Corporate bonds are much larger at the CUSIP level, so total dollar issuance volume is the same or even slightly greater, but relative to total corporate bond issuance the sum is still small: $30 billion in corporate green bonds make up only 0.3% of total corporate bond issuance over these 6 years.[2] Green corporate bonds therefore remain a very small component

[2] Flammer's (2021) US sample, also drawn from Bloomberg, contains 194 corporate green bonds over the same time period. The difference reflects 140 "solar bonds" issued directly to investors by SolarCity, later bought

**Table 1 Issuance of US green and ordinary bonds**[a]

| Year | Green | | | Ordinary |
|---|---|---|---|---|
| | Unique bonds | Unique issuers | Millions of US$ | Billions of US$ |
| **a Municipal** | | | | |
| 2013 | 3 | 1 | 100 | 286 |
| 2014 | 298 | 15 | 2,166 | 290 |
| 2015 | 550 | 31 | 3,493 | 368 |
| 2016 | 882 | 40 | 7,241 | 399 |
| 2017 | 1,242 | 53 | 10,526 | 372 |
| 2018 | 1,008 | 55 | 4,443 | 289 |
| Total | 3,983 | 195 | 27,969 | 2,004 |
| **b Corporate** | | | | |
| 2013 | 3 | 2 | 2,500 | 1,489 |
| 2014 | 5 | 4 | 2,070 | 1,477 |
| 2015 | 13 | 7 | 7,070 | 1,679 |
| 2016 | 8 | 5 | 5,320 | 1,626 |
| 2017 | 10 | 8 | 5,130 | 1,787 |
| 2018 | 12 | 10 | 7,925 | 1,538 |
| Total | 51 | 36 | 30,015 | 9,596 |

[a]Data on municipal bonds come from Mergent, and data on corporate bonds come from Bloomberg. Floating-rate bonds are excluded. Dollar values are nominal par issuance amounts.

of the US corporate bond market. This is perhaps not surprising considering the difficulty of ring-fencing corporate proceeds and reporting in the presence of unclear benefits.

## 2.5. Uses of Green Bonds

Green bonds are defined by their environmentally friendly uses. To save space, we omit the full breakdown of uses, which is available on request, and summarize it here. The most popular uses for municipal green bonds proceeds—aside from the "general purpose" label that is applied in cases where there are many categories of use or they are insufficiently described in offering documents—include public power, mass transit, multifamily housing, education (e.g., energy-efficient school buildings and dormitories), and water and sewer projects. In no category are labeled green bonds a majority of municipal issuance between 2013 and 2018. Intrinsically environmentally sensitive uses, such as pollution control and mass transit, are still overwhelmingly financed by bonds without the green label, although more than a quarter of mass transit bonds did use the label. Green corporate bonds are most commonly used in the context of renewable energy. Energy-efficient retrofits or green facilities are another common use.

## 2.6. Bond Characteristics

**Table 2** presents bond-level summary statistics, beginning with the municipal sample (**Table 2*a***). For each of the agencies S&P, Moody's, and Fitch, we record the bond rating at issuance on a common scale. We translate the other agencies' ratings to the S&P scale and then to a numerical

by Tesla. To avoid skewing the summary statistics, we exclude these, as they were not rated and are small by corporate bond standards.

**Table 2 Characteristics of green and ordinary bonds[a]**

| Variable | Green | | | | Ordinary | | | | Diff | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | Median | Min | Max | Mean | Median | Min | Max | Mean | $p$ value |
| **a Municipal** | | | | | | | | | | |
| Rating (AAA = 1) | 2.90 | 3.00 | 1 | 14 | 3.74 | 3.00 | 1 | 21 | −0.83 | (<0.001) |
| Maturity (years) | 11.55 | 10.63 | 0 | 35 | 9.89 | 8.97 | 0 | 35 | 1.66 | (<0.001) |
| Insured (yes = 1) | 0.070 | 0.00 | 0 | 1 | 0.172 | 0.00 | 0 | 1 | −0.10 | (<0.001) |
| Taxable (yes = 1) | 0.076 | 0.00 | 0 | 1 | 0.058 | 0.00 | 0 | 1 | 0.02 | (0.418) |
| Taxable AMT (yes = 1) | 0.015 | 0.00 | 0 | 1 | 0.012 | 0.00 | 0 | 1 | 0.00 | (0.800) |
| Taxable state (yes = 1) | 0.023 | 0.00 | 0 | 1 | 0.088 | 0.00 | 0 | 1 | −0.07 | (<0.001) |
| Bond size (millions of US$) | 7.0 | 2.2 | 0.1 | 408 | 3.1 | 0.7 | 0.1 | 12,850 | 3.96 | (<0.001) |
| Bank qualified (yes = 1) | 0.035 | 0.00 | 0 | 1 | 0.333 | 0.00 | 0 | 1 | −0.30 | (<0.001) |
| New money (yes = 1) | 0.677 | 1.00 | 0 | 1 | 0.477 | 0.00 | 0 | 1 | 0.20 | (<0.001) |
| General obligation (yes = 1) | 0.140 | 0.00 | 0 | 1 | 0.469 | 0.00 | 0 | 1 | −0.33 | (<0.001) |
| Callable (yes = 1) | 0.531 | 1.00 | 0 | 1 | 0.468 | 0.00 | 0 | 1 | 0.06 | (<0.001) |
| Puttable (yes = 1) | 0.001 | 0.00 | 0 | 1 | 0.002 | 0.00 | 0 | 1 | 0.00 | (0.002) |
| CBI-certified green (yes = 1) | 0.182 | 0.00 | 0 | 1 | 0.000 | 0.00 | 0 | 0 | 0.18 | (0.011) |
| Pretax yield | 2.44 | 2.48 | 0 | 6 | 2.32 | 2.34 | 0 | 12 | 0.13 | (0.012) |
| After-tax yield | 2.34 | 2.35 | 0 | 6 | 2.24 | 2.25 | 0 | 10 | 0.10 | (0.056) |
| **b Corporate** | | | | | | | | | | |
| Rating (AAA = 1) | 8.45 | 8.00 | 1 | 15 | 9.34 | 9.00 | 1 | 21 | −0.89 | (0.261) |
| Maturity (years) | 10.08 | 9.08 | 2 | 31 | 9.74 | 7.99 | 0 | 35 | 0.34 | (0.812) |
| Bond size (millions of US$) | 399.7 | 350.0 | 0 | 2,250 | 277.2 | 4.4 | 0 | 9,000 | 122.5 | (0.070) |
| Pretax yield | 4.02 | 4.00 | 1 | 6 | 4.55 | 4.19 | 0 | 15 | −0.53 | (0.109) |

[a]Data on municipal bond characteristics come from Mergent. Corporate bond characteristics are from Bloomberg. $p$ values for test of differences in means are calculated using a one-variable regression model, with standard errors adjusted for issuer-level clustering. The municipal sample runs from 2013 to 2018 issuance and includes 3,983 green bonds and 653,939 ordinary bonds with complete data on all characteristics. The corporate sample runs from 2013 to 2018 issuance and includes 51 green bonds and 20,362 ordinary bonds with complete data on all characteristics except yield; yield data are for 43 green bonds and 8,873 ordinary bonds.
Abbreviations: AMT, alternative minimum tax; CBI, Climate Bonds Initiative.



scale, with 1 assigned to the top rating of AAA, 2 to the next-highest rating of AA+, and so forth. BBB−, the lowest S&P rating considered investment grade, is a 10 on this scale. When any agency reports an enhanced rating, we use it, on the assumption that the bond yield on issuance will reflect the ratings enhancement as well as the municipality's own credit quality. We take the maximum available rating of as many as all three ratings agencies. In some cases, Mergent does not report a bond rating from any of the agencies. In those cases, we use Mergent's header rating for the bond. The median rating for both green and ordinary municipal bonds in our sample is AA.

Green municipal bonds also have longer maturities. The difference between the mean maturities is 1.66 years. Green bonds are less likely to be identified by Mergent as being sold with third-party insurance or other credit guarantees. Green bonds are slightly more likely to be federally taxable; recall that we exclude the taxable CREBs/QECBs. They are equally likely to be subject to the alternative minimum tax and are somewhat less likely to be subject to state tax.

Green bonds are larger and, on average, part of larger bond issues than ordinary bonds, a fact that may owe something to the fixed costs of green status. They are less likely to be bank eligible, a category of bonds where commercial banks are allowed to deduct 80% of the interest cost incurred in order to own the bond. These bonds are legally required to be small and have other restrictions that may be difficult to square with green status.

Green bonds are much more likely to be new money bonds as opposed to being used to refund existing bonds. They are much less likely to be general obligation bonds; their security consists of a claim on the issuer's tax revenue and not merely to the revenue generated by a specific project. To repeat, whether a bond is labeled green is based on its use of proceeds, not its backing. Green bonds are slightly more likely to be callable.

Some labeled green bonds are certified by third parties as conforming to a green bond standard. Issuers may pay for certification to highlight the bond to investors as a green bond; an interesting question is whether certification is associated with pricing or ownership patterns above and beyond those associated with the general green bond label (Saha 2016). Such effects could arise because the issuer engages the third-party verifier in the preissuance phase (there would be little benefit to the issuer to pay to certify the bond as green after it is floated); certification then enables the issuer and underwriters to market the bond as certified in their roadshow. To provide ex post reconciliation, after the bond issuance and the allocation of proceeds, the verifier must confirm that the bond aligns with the postissuance requirements of, for example, the Climate Bond Standard.[3]

In our sample, 18.2% of green municipal bonds were certified by a third party and subsequently registered with the Climate Bonds Initiative (CBI) as conforming to the Green Bond Principles (CBI 2015). We refer to such bonds as CBI certified. Certification is a recent but growing practice. All the certified bonds registered with the CBI were issued in 2016 or later, and they involve only nine issuers, some quite prolific.

We concentrate on the after-tax yield at issue to allow prices to be measured on the yardstick most relevant to the tax-sensitive municipal bond market. We also consider Mergent's pretax yields from the offering statement in a robustness check. We combine data from multiple sources to compute after-tax yields.[4] Green and ordinary bonds have different characteristics and any pricing effects due to the green label are likely to be small, so we report yield summary statistics simply to give a perspective on municipal yields in general and defer our conclusions until we have careful controls for maturity, rating, issue month, and so on.

**Table 2*b*** presents corporate bond–level statistics. The credit ratings of green corporate bonds do not differ significantly from those of ordinary bonds. Green corporates exhibit slightly larger size but are similar to ordinary corporate bonds. We report yields for completeness, but their characteristics are too diverse to draw conclusions from unconditional summary statistics. The simple takeaway of our brief exploration of US corporate green bonds is that there are still far fewer of them than US municipal green bonds; see Flammer (2021) for a comprehensive study of an international sample of corporate green bonds.

[3]For details on the process, see **https://www.climatebonds.net/certification**. The cost of the third-party certifier/verifier—in our sample, usually Sustainalytics, but sometimes a Big Four firm, environmental consultancy, or environmental NGO—is negotiable; anecdotal evidence suggests that it falls between \$10,000 and \$50,000, depending on issuance size. Registration of the bond with the Climate Bonds Standard Board requires a further modest fee.

[4]Federal tax rates come from the Tax Policy Center. The marginal tax rate used is the tax rate prevailing at the highest income levels in that year. Post-2013 tax rates include the 3.8% Affordable Care Act surcharge. State tax rates come from the Taxsim model of the National Bureau of Economic Research; the state rate used is also the rate applicable to top income levels. We then calculate a pretax and an after-tax yield as the internal rate of return on each bond's cash flows before and after taxation, respectively. In cases where our calculated pretax yield differs from that reported by Mergent, we reset the after-tax yield to the Mergent yield from the official statements minus the difference between our calculated pretax and after-tax yields.

# 3. PRICING GREEN BONDS

## 3.1. Asset Prices with a Nonpecuniary Clientele

Numerous papers have made theoretical predictions for the impact of environmental concerns on asset pricing and investment. This literature includes papers by Heinkel, Kraus & Zechner (2001); Fama & French (2007); Oehmke & Opp (2020); Pastor, Stambaugh & Taylor (2020); and Pedersen, Fitzgibbons & Pomorski (2021), among others. Heinkel, Kraus & Zechner (2001) and Oehmke & Opp (2020) develop general equilibrium models in which firms and investors are jointly optimizing.

With our focus on the pricing and ownership of green bonds, we present a simplified version of the models of Pedersen et al. and Pastor et al. Our model focuses solely on the investor's problem, and it assumes that some investors have explicit preferences for a project's environmental score. In contrast, in the model by Oehmke and Opp, investors care only about the ultimate environmental consequences of firm investment, irrespective of their own individual portfolio allocations. Pastor et al. also introduce a hedging motive for systematic climate risks. We reach the same prediction for equilibrium returns (equivalently, the costs of capital) as Pastor et al. and Pedersen et al., in a simpler, less complete setting, but we refer the reader to their papers for richer theoretical treatments and a wider range of predictions.

For the simplicity of exposition, we hew most closely to Fama & French (2007), who examine the effect of investor biases and tastes on asset prices, also taking firm behavior as exogenous. A leading example of "tastes" in their model is socially responsible investing. Neither Fama and French nor Heinkel et al. specifically investigate ownership concentration as we do below. Also, both use calibrations to examine the potential impact of tastes on asset prices, as well as corporate behavior in the case of Heinkel et al., and compare these calibrations with moments in the data. We limit our focus to the municipal green bond market.

## 3.2. A Simple Framework for the Pricing of Green Bonds

There are two groups of investors, each facing a one-period portfolio choice problem. Both groups have a common risk aversion parameter $\gamma$ and common expectations for security returns $\mathbf{r}$ and risk $\Sigma$. They choose a vector of portfolio weights $\mathbf{w}$ in each security. Group 1 investors are mean-variance maximizers, while Group 2 investors also care about environmental ratings (or another nonpecuniary attribute). That is, some securities have positive environmental scores $e > 0$, and Group 2 investors obtain extra utility from holding them. Without loss of generality, we assume the overall average $e$ is zero. Specifically, the two groups solve as follows:

$$\text{Group 1}: \ \max \mathbf{w}_1'\mathbf{r} - \frac{\gamma}{2}\mathbf{w}_1'\boldsymbol{\Sigma}\mathbf{w}_1,$$

$$\text{Group 2}: \ \max \mathbf{w}_2'\mathbf{r} + \mathbf{w}_2'\mathbf{e} - \frac{\gamma}{2}\mathbf{w}_2'\boldsymbol{\Sigma}\mathbf{w}_2.$$

Note that Group 2's objective function resembles how ESG mandates are implemented in practice. In particular, if Group 2 investors require that their portfolios maintain a minimal average environmental score, then this is equivalent to imposing a linear constraint of the form $\mathbf{w}_2'\mathbf{e} \geq k$ and leads to the same maximization problem as above. Also, this formulation accommodates not only so-called positive screening, where extra utility is gained by holding (for example) green bonds, but also negative screening, where extra utility is lost by holding (for example) fossil fuel or sin stocks, by appropriately flipping signs and redefining $e$.[5]

[5] In the case of $e$ measured by a green bond indicator, the $e > 0$ designation is at the extreme because the score is binary and green bonds are comparatively rare. This means that a $z$-scored green flag will contain many

The two groups have capital of $a_1$ and $a_2$, respectively, and the market clears. Because we are also interested in ownership concentration in a following section, we stipulate that Group 1's capital comes from $a_1$ individuals each with \$1 and, likewise, that Group 2's capital comes from $a_2$ individuals each with \$1. We express this as

$$\frac{a_1}{a_1 + a_2}\mathbf{w}_1 + \frac{a_2}{a_1 + a_2}\mathbf{w}_2 = \mathbf{w}_{\mathrm{m}},$$

where $\mathbf{w}_{\mathrm{m}}$ is the market portfolio, a vector of weights in each security equal to its market values as a fraction of the total market value of all securities.

We start with the uninteresting case where $a_2$ is equal to zero, so that there are only Group 1 investors, who have no environmental preference. They choose weights, given common return and risk expectations, and these representative investor weights must equal market weights for the market to clear:

$$\mathbf{w}_1 = \frac{1}{\gamma}\boldsymbol{\Sigma}^{-1}\mathbf{r} = \mathbf{w}_{\mathrm{m}}.$$

We can use this equation to compute the expected return of the market as a whole, which allows us to substitute the market Sharpe ratio for the inverse of risk aversion $\gamma$, leading to the familiar CAPM formula:

$$\mathbf{r} = \frac{r_{\mathrm{m}}}{\sigma_{\mathrm{m}}^2}\boldsymbol{\Sigma}\mathbf{w}_{\mathrm{m}} = \boldsymbol{\beta} r_{\mathrm{m}}.$$

Now, we add Group 2 investors, who have an environmental preference, to the mix. Their portfolio weights are simply

$$\mathbf{w}_2 = \frac{1}{\gamma}\boldsymbol{\Sigma}^{-1}\left(\mathbf{r} + \mathbf{e}\right).$$

Because the average environmental score is mean zero, we can make the same substitution for $\gamma$ using market clearing. The CAPM then holds up to a small twist:

$$\mathbf{r} = \frac{r_{\mathrm{m}}}{\sigma_{\mathrm{m}}^2}\boldsymbol{\Sigma}\mathbf{w}_{\mathrm{m}} = \boldsymbol{\beta} r_{\mathrm{m}} - \frac{a_2}{a_1 + a_2}\mathbf{e}.$$

**Prediction 1:** Securities with positive environmental scores (such as green bonds) have lower expected returns.

When some investors have an additional nonpecuniary preference for a security, they bid up its price. We test this prediction next.

## 3.3. Yield Regressions

To examine the prediction that green bonds sell for a premium, we regress after-tax yields on green bond indicators and controls (**Table 3**). We have considered a variety of fixed effects to control for maturity, rating, and market conditions at the time of issuance. The first column uses maturity–rating–issue month interaction fixed effects, thus taking account of twists in the credit curve and even issuer fixed effects. In all specifications the table also includes size decile categories for both the size of the bond CUSIP itself and the total value of all bonds brought by that issuer on that day, the presence of insurance, tax features (as a further precaution, as we are already directly measuring after-tax yield at issue), bank qualification status, new money, general obligation collateralization,

small negative scores and relatively few very positive ones in order to preserve zero mean and unit standard deviation.

**Table 3 Offering yields of municipal bonds: additional regressions[a]**

| Variable | Offering yield | | | | | |
|---|---|---|---|---|---|---|
| | Base | Pretax yield | Certification | Ownership data sample | Ownership data missing | Bundled issue types |
| Green | –4.8<br>[–3.09] | –4.6<br>[–2.91] | –5.4<br>[–3.01] | –8.0<br>[–2.01] | –4.3<br>[–2.92] | –6.3<br>[–2.99] |
| Green X CBI certified | | | 3.0<br>[1.09] | | | |
| Green X ordinary also issued | | | | | | 1.8 |
| Today | | | | | | [0.67] |
| Ordinary X green also issued | | | | | | –5.5 |
| Today | | | | | | [–3.25] |
| *R*-squared | 0.96 | 0.96 | 0.96 | 0.97 | 0.96 | 0.96 |
| Adjusted *R*-squared | 0.96 | 0.96 | 0.96 | 0.96 | 0.96 | 0.96 |
| *N* | 653,723 | 653,840 | 653,723 | 52,494 | 597,503 | 653,723 |

[a]Ordinary least-squares regressions of bond yields at issue in basis points on green bond indicators and other bond characteristics and fixed effects described in **Table 2**. The first column under "Offering yield" is a baseline specification of after-tax yield at issue, where after-tax yield is calculated using Mergent, Tax Policy Center, and National Bureau of Economic Research data. "Green" is a dummy variable for bonds that Bloomberg or Mergent tags as green. The second column uses pretax yield as a dependent variable. The third column allows for a differential effect for green bonds that are certified and registered with the CBI. The fourth and fifth columns split the sample according to whether we have ownership concentration data. The sixth column allows for a differential effect of green and ordinary bonds in cases where both types of bonds were issued by the same issuer on the same day. All specifications include issuer fixed effects, maturity–rating–month interactions, and bond characteristics fixed effects (bond size decile, issue size decile, insured, taxable, taxable AMT, taxable state, bank qualified, new money, general obligation, callable, puttable, and use of proceeds). *T*-statistics clustered by issuer are shown in brackets.

Abbreviations: AMT, alternative minimum tax; CBI, Climate Bonds Initiative.



optionality features, and use of proceeds. These controls account for most of the variation in after-tax yields at issue.

The first column of **Table 3** is consistent with green bonds selling for a moderate premium, holding characteristics and the yield and credit curves equal. It is the most flexible and conservative with respect to the fixed effects that we consider; in general, green bonds are issued at after-tax yields, around 5 to 9 basis points lower than those of ordinary bonds, controlling for bond and credit market characteristics (other combinations of fixed effects lead to larger green coefficients). To put these numbers in perspective, consider that the average after-tax yield for AAA ordinary bonds in our sample is 2.06%. The average after-tax yield for an ordinary bond rated BBB−, which is the lowest investment-grade rating and nine notches lower than AAA, is 3.03%. This works out to an approximately 11-basis-point increase per ratings notch. A coefficient of 5 or 6 basis points thus suggests that green bonds are priced as if they were around half a notch more highly rated.

Of course, the green label is not assigned to a bond at random; no natural experiment is available. Given that the regressions control for use of proceeds, maturity–rating–issue month fixed effects, collateral type, and even issuer fixed effects, the most straightforward explanation is simply that there is a clientele willing to pay a modest premium to hold green bonds over essentially similar municipal bonds. The premium would be too small to attract arbitrage activity, in light of realistic transaction costs, and perhaps is too small to be readily apparent to many market participants. As we show next, there is further texture that qualifies and sharpens these results.

The first column of **Table 3**, with issuer and maturity–rating–month fixed effects, provides a baseline 5-basis-point coefficient. Our first robustness exercise shows that the green bond dummy coefficient is almost identical for pretax issue yields. Karpf & Mandel (2017) report that green bonds had higher (not lower) pretax yields at issue. However, many of the green bonds in their sample are not standard, labeled green bonds but rather taxable CREB and QECB subsidy bonds to which Bloomberg attached the same green bond flag. Tax effects alone would easily overwhelm a modest green bond premium. In any case, in a sample unconfounded by these bonds, the tax adjustment does not matter. Both pretax and after tax, there appears to be a small premium on labeled green bonds.

In the next exercise, we consider CBI certification. The first CBI-certified bonds in the sample appear in 2016. In an early version of this review, based on data through 2016, we found that CBI certification was associated with an incremental green bond premium. The additional 2 years of data show that that effect has not persisted. In data through 2018, CBI certification is not associated with a pricing benefit that is incremental to labeled green bond status and whatever certification effect may have become embedded in the issuer's fixed effect as it repeatedly issued CBI-certified bonds. An interesting possibility is that investors may have come to accept self-labeling green bonds by US municipalities as sufficiently credible; in the absence of widespread abuse, early concerns about greenwashing, once addressed by certification, may have faded.

We study ownership patterns of green and ordinary bonds later in this review. The required ownership concentration data are available for only a small portion of the sample, so we confirm that the green bond effect in initial yields is present in both the ownership sample and the nonownership sample.

## 3.4. The Case of Bundled Green and Ordinary Offerings

Larcker & Watts (2020) point out that tranches of green bonds are sometimes bundled with tranches of ordinary bonds. In our sample, approximately one-third of green bonds, 1,360 out of 3,983, are issued on the same day as ordinary bonds. In such cases, a given green bond may be able to be matched to an ordinary bond, with identical credit characteristics and maturity. In a sample of 640 green–ordinary bond matched pairs from bundled issues, Larcker and Watts find that there is no premium at issue on the green bond. Typically, the green and ordinary bonds are issued at the same yield, which is consistent with their interviews of market participants. This is a compelling stylized fact to be reconciled with our results.

Such matching approaches are well suited to addressing concerns about unmeasured differences in risk between green and ordinary bonds. However, this approach raises other potential concerns. Most obviously, the decision to bundle green and ordinary bonds is endogenous. An issuer in the matched sample has decided on a green bond but also has decided that in this case it should be bundled with an ordinary bond, with a conjoined offering document and marketing effort. In our sample, when green and ordinary bonds are issued simultaneously, Mergent typically reports the same use of proceeds code for both, underscoring the close connection.

To reconcile the absence of an issue-day premium on green bonds in bundled offerings with the full-sample regression results, we start with the last column of **Table 3**. The regression specification potentially allows us to go a step further, as the presence of ordinary and green bond issues that are not bundled together allows us to assess yields on bundled issues in a more complete way. The estimates confirm that green bonds bundled with ordinary bonds are indeed priced identically; furthermore, both appear to be priced at a premium to typical ordinary municipal bonds. Relative to all bonds, and controlling for many bond characteristics and credit market and issuer fixed effects, a bundled green bond is priced at a premium of 4.5 to 6.3 basis points, depending on whether one includes the insignificant point estimate for how green bonds are priced when bundled with ordinary bonds, while a bundled ordinary bond is priced at a similar premium with a point estimate of 5.5 basis points. This pricing is consistent with the bundled ordinary bond receiving extra attention from Group 2 or socially responsible investors who might otherwise not be interested.

**Table 4 Secondary market pricing**[a]

| Variable | Traded yield difference | |
|---|---|---|
| | After first month | Month by month |
| Month > 1 after issue | –2.5 [–2.38] | |
| Month 2 | | –0.9 [–0.45] |
| Month 3 | | –8.3 [–3.59] |
| Month 4 | | –3.3 [–1.92] |
| Month 5 | | –6.1 [–2.72] |
| Month 6 | | –4.4 [–1.39] |
| *R*-squared | 0.26 | 0.35 |
| Adjusted *R*-squared | 0.11 | 0.17 |
| *N* | 1,103 | 550 |
| **Fixed effects** | | |
| Match fixed effects | Yes | Yes |

[a]Ordinary least-squares regressions of the difference in traded bond yields between matched green and ordinary bonds in basis points on time since the issue date: yield on the traded green bond minus the yield on the traded ordinary bond. The sample consists of daily observations with at least one transaction in green and one transaction in ordinary, recorded on the same trading day for a pair of bonds matched by maturity, issuer, and issue date, from a set of 640 such matched pairs (provided by David Larcker and as analyzed in Larcker & Watts 2020). *T*-statistics are reported in brackets.

Secondary market data can shed even more light on the market reception of bundled green bonds. To the extent that bundling affects primary market pricing, driving green and ordinary bond prices together on the issue date, it should be irrelevant once each bond is seasoned and can trade individually. In other words, if there is indeed a modest but robust green bond premium, then it should eventually appear even among the bundled green bonds on the secondary market.

We test this hypothesis using the sample of bundled green and ordinary issues used by Larcker & Watts (2020), provided to us by the authors. We collect transaction data from the MSRB website through December 2018. We compute the difference in reported transaction yields on days in which both the green bond and the matched ordinary bond traded at least once.[6]

**Table 4** confirms that bundled green bonds indeed move to lower yields relative to their matched ordinary counterparts. Relative to the average yield difference prevailing in the first month of the bundled offering—often zero, since the first-month transactions include the initial placement—the bundled green bond trades at a 2.5-basis-point-lower yield, on average.[7] For

[6]If a bond trades multiple times in a day but all trades are within 50 basis points, we average the reported yields together.

[7]By way of explanation, the 1,103-trading-day sample in the first column includes trading data on 192 of 640 possible matched pairs. For a match to be included in the analysis, we require at least 1 day within the first month where both sides of the match trade and, as a comparison, at least 1 day after the first month (and before the end of 2018) where both sides of the match trade. In the second column, the comparison trade(s) must occur within 6 months of the issue date.

trades that occur within 6 months after the issue, the drop in the yield differential settles down to around 5 basis points.

In summary, the Larcker & Watts (2020) results do not challenge the existence of a green bond premium, but these results do help us better understand the green bond premium. In the typical case, when green municipal bonds are not issued alongside ordinary bonds, there is a small but robust premium of several basis points at the issue date, controlling for various characteristics and fixed effects. This is the basic large-sample regression result. When green municipal bonds are issued bundled with ordinary bonds, there is no green bond premium at the issue date, but a modest premium emerges over time on the secondary market.

# 4. OWNERSHIP CONCENTRATION OF GREEN BONDS

## 4.1. Ownership with a Nonpecuniary Clientele

Returning to the framework that we used to study pricing, we can examine ownership patterns by substituting expected returns into each group's first-order condition. The impact of investors' tastes for environmental scores leads portfolios that deviate from market weights:

$$\text{Group 1: } \mathbf{w}_1 = \mathbf{w}_\text{m} - \frac{1}{\gamma}\frac{a_2}{a_1 + a_2}\boldsymbol{\Sigma}^{-1}\mathbf{e},$$

$$\text{Group 2: } \mathbf{w}_2 = \mathbf{w}_\text{m} + \frac{1}{\gamma}\frac{a_1}{a_1 + a_2}\boldsymbol{\Sigma}^{-1}\mathbf{e}.$$

Group 2 investors, with their environmental objective, overweight securities with positive environmental scores. This overweight portfolio allocation and market clearing require Group 1 investors to be underweight for those securities. The magnitude of the overweight portfolio positions is a function of the environmental score and the relative size of Group 2. When Group 2 is small and the environmental scores are extreme, the overweight positions can be material. The Group 1 investors are underweight securities with a positive environmental score because equilibrium expected returns of these returns are lower, due to the enhanced demand of the Group 2 investors.

We can also compute the concentration of holdings. To simplify notation, we define the vector $\tilde{\mathbf{e}} = \boldsymbol{\Sigma}^{-1}\mathbf{e}$. In the case of uncorrelated returns, the elements of $\tilde{\mathbf{e}}$ are simply equal to a security's environmental score divided by its return variance, or $\tilde{e}_i = e_i/\sigma_i^2$. This is the risk-adjusted environmental score. Because investors are risk averse, risk reduces the extent to which the score influences portfolio choice.

We measure ownership concentration using the familiar Herfindahl–Hirschman index (HHI), the sum of the squared percentage holdings. For security $i$,

$$\text{HHI}_i = \frac{1}{c_i^2}\sum_{s=1}^{a_1}\left(w_{\text{m}i} - \frac{1}{\gamma}\frac{a_2}{a_1 + a_2}\tilde{e}_i\right)^2 + \frac{1}{c_i^2}\sum_{s=1}^{a_2}\left(w_{\text{m}i} + \frac{1}{\gamma}\frac{a_1}{a_1 + a_2}\tilde{e}_i\right)^2,$$

where $c_i$ is a constant equal to the total market value of security $i$. Holding constant total capital at $a_1 + a_2$, we find that this sum is minimized when the risk-adjusted environmental score is zero or when there are no investors with an environmental preference so that $a_2$ is equal to zero. In both cases, the holdings are constant across all investors, so concentration is minimized. As the number of investors becomes large, the total approaches zero. By contrast, holding constant the proportions of investor types, we find that the sum is maximized at extreme levels of the risk-adjusted environmental score. The derivative of HHI with respect to $\tilde{e}_i$ is

$$\frac{2}{\gamma^2 c_i^2}\frac{a_1 a_2}{a_1 + a_2}\tilde{e}_i.$$

As a function of the environmental score, HHI is a parabola with a minimum at zero—concentration is minimized for a security with a neutral environmental score. Securities with extreme scores, whether favorable or unfavorable, have higher ownership concentration.

Although green bonds, and especially green municipal bonds, are difficult or impossible to short-sell in practice, for simplicity, we have not precluded short positions here, so the HHI is not bounded in the usual way. But one can see that, with two investor types, it is possible to get to maximum concentration even without short positions. For example, suppose that there is a single individual in Group 2 with environmental preferences, so that $a_2$ is equal to one, and that the risk-adjusted environmental score is large enough to make the optimal weight in Group 1 exactly equal to zero. This is an example of maximal concentration: A single investor holds the entire capitalization of the security.

To build further intuition, let us consider the case where $a_1 = a_2 = a$. Because we have assumed that each investor has \$1 in order to discuss ownership concentration, in equilibrium the total number of investors $N$ equals the total capitalization of all securities $C$ (i.e., $N = a_1 + a_2 = 2a = C$). After some algebra, we can write equilibrium concentration more intuitively:

$$\mathrm{HHI}_i = \frac{1}{N} + \left(\frac{1}{2\gamma\left(\frac{c_i}{C}\right)}\right)^2 \tilde{e}_i^2.$$

The HHI parabola rests at its theoretical minimum value of $1/N$, the uniform ownership that would obtain if investors were homogeneous or if the risk-adjusted environmental score were zero. Concentration then rises as the risk-adjusted score moves away from zero in either direction. Here, we also see that the effect of environmental scores is stronger when the security has a smaller weight in the market portfolio and when risk aversion is low, so that Group 1 investors are willing to tilt their portfolios more aggressively in response to differences in price and Group 2 in response to differences in environmental benefits.

> **Prediction 2:** Securities with positive environmental scores (such as green bonds) have more concentrated ownership, particularly for those with low total market values and low risk.

Again, this is based on a symmetric effect. If there were a set of particularly nongreen securities that could be measured sensibly on the same spectrum, they would also be held in greater concentration. This observation may be useful in the sin stocks' context. In our empirical setting of municipal bonds, however, the situation is simpler. There is a small set of green bonds, with high environmental scores, and a large set of ordinary bonds, with scores near zero.

## 4.2. Ownership Data

Bond ownership data are from the Thomson Reuters eMAXX database, used by Manconi, Massa & Yasuda (2012). The database includes fixed-income positions of thousands of US and international insurance companies, pension funds, and mutual funds. Insurance company holdings are based on National Association of Insurance Commissioners disclosures, mutual fund holdings are based on Securities and Exchange Commission disclosures, and pension fund holdings are disclosed voluntarily.

Our ownership sample is based on 12 quarters of reported holdings of municipal bonds, from the first quarter of 2014 through the last quarter of 2016. Full ownership summary statistics are available on request; key statistics are noted here. Most smaller bonds do not appear in eMAXX because they are owned entirely by retail investors or small institutions; nonetheless, we have documented above that the main regression result involving offering yields holds within the sample of bonds for which we have ownership data. There are 495 green and 69,180 ordinary bonds that appear in eMAXX and have other data required to be included in the analyses above. For these bonds, a majority of par amount outstanding is owned within eMAXX: The green bonds have a mean of 61.5% of par amount outstanding held within eMAXX, and ordinary bonds have a similar mean of 58.8% ownership within the database.

We use HHI as a more formal estimate of ownership concentration that maps onto the analytical framework. We estimate concentration under the assumption that the distribution of holdings is the same across both unobserved investors outside the eMAXX database and those we observe within it. In light of this approach, we require at least 25% of a bond's par outstanding to be reported within eMAXX to balance coverage against measurement error in the calculation of HHI. We use ownership data from the first quarter for which this level of bond ownership is available. Because eMAXX-reporting institutions often buy municipal bonds at the issue date and hold for long periods, often to maturity, most of our ownership data reflect the cross section of holdings that prevails within one quarter of the issue date. HHI can be calculated for 395 green bonds and 56,137 ordinary bonds. Green bonds display a higher average HHI than ordinary bonds, at 0.56 versus 0.52, but this is merely an unconditional average.

We use certain strings in the fund name in eMAXX to identify owners with a known orientation toward socially responsible investing.[8] This restrictive definition of green fund ownership undercounts the number of bondholders who consider social objectives, but it nonetheless shows that green bonds are indeed much more likely to be held by concerned investors. For the average green bond in this subsample, 15.5% of par outstanding can be associated with a socially responsible fund through the fund's name. In contrast, for the average ordinary bond in this subsample, only 0.6% can be associated with a socially responsible fund. This is clear evidence that the green bond label is recognized by concerned investors.

## 4.3. Ownership Regressions

**Table 5** presents our regression tests involving green bond ownership concentration. For consistency, we include the same controls and fixed effects as in the yield regressions, although maturity–rating–issue month fixed effects seem less necessary here.

The main concentration prediction receives strong support. Green bonds are held in greater concentration, controlling for various bond characteristics and fixed effects. HHI is on the order of 0.06 to 0.10 higher for green bonds, which can be viewed in the context of the sample's unconditional average HHI around 0.50, as reported in **Table 4**. The inclusion of issuer fixed effects increases the coefficient somewhat, consistent with investors discriminating within issuers for their green versus ordinary bonds. We again include the most flexible combination of fixed effects in the reported baseline specification.

Many distributions of ownership across investors will generate a typical interior level of HHI. As a potential example to illustrate an HHI difference of 0.10, suppose that two investors each owned half the par outstanding (remember that par amounts for individual municipal bonds can be small) and all remaining investors held zero. This is an HHI of 0.50. Now, if one investor instead held 72% of par outstanding and a second held the remainder—in the logic of the model, perhaps the first investor paid a premium to accumulate this position—then the HHI would be 0.60. This may clarify the magnitude of the coefficients in **Table 5**.

The other columns of **Table 5** show further ownership regressions. All specifications include issuer fixed effects and maturity–rating–issue month fixed effects, a baseline drawn from the last

[8]The substrings are CALVERT, CATHOLIC, CHURCH, CLEAN, DOMINI, ENVIRON, ESG, FAITH, GREEN, IMPACT, KLD, PARNASSUS, SOCIAL, SRI, and WALDEN.

**Table 5 Ownership concentration of municipal bonds: additional regressions**[a]

| Variable | HHI | | | | | |
|---|---|---|---|---|---|---|
| | Base | Green fund ownership | Safe and small | Safe and small (v2) | Certification | Bundled issue types |
| Green | 0.10 [2.81] | 0.09 [2.93] | 0.02 [0.47] | 0.02 [0.38] | 0.09 [2.12] | 0.15 [2.73] |
| Green fund ownership | | 0.66 [13.46] | | | | |
| Green X rating = AAA | | | 0.16 [2.50] | | | |
| Green X rating = AAA or AA+ | | | | 0.12 [2.02] | | |
| Green X bond size decile < 10 | | | 0.06 [1.19] | | | |
| Green X bond size decile < 9 | | | | 0.19 [3.23] | | |
| Green X CBI certified | | | | | 0.11 [1.73] | |
| Green X ordinary also issued | | | | | | –0.07 |
| Today | | | | | | [–1.03] |
| Ordinary X green also issued | | | | | | 0.05 |
| Today | | | | | | [1.86] |
| *R*-squared | 0.53 | 0.53 | 0.53 | 0.53 | 0.53 | 0.53 |
| Adjusted *R*-squared | 0.40 | 0.40 | 0.40 | 0.40 | 0.40 | 0.40 |
| *N* | 52,494 | 52,494 | 52,494 | 52,494 | 52,494 | 52,494 |

[a]Ordinary least-squares regressions of HHI on green bond indicators and other bond characteristics and fixed effects described. The first column under HHI is a baseline. "Green" is a dummy variable for bonds that Bloomberg or Mergent tags as green. The second column adds green fund ownership, the percentage of bonds owned by a fund that has some green or social investing orientation according to string matches on its name. The third and fourth columns allow for differential effects for green bonds that are safe or small par issued. The fifth column allows for a differential effect of green bonds that are certified and registered with CBI. The sixth column allows for a differential effect of green and ordinary bonds in cases where both types of bonds were issued by the same issuer on the same day. All specifications include issuer fixed effects, maturity–rating–month interactions, and bond characteristics fixed effects (bond size decile, issue size decile, insured, taxable, taxable AMT, taxable state, bank qualified, new money, general obligation, callable, puttable, use of proceeds). *T*-statistics clustered by issuer are shown in brackets.
Abbreviations: AMT, alternative minimum tax; CBI, Climate Bonds Initiative; HHI, Herfindahl–Hirschman index.

column of **Table 4**. We start by showing that ownership concentration is also higher for bonds that are present in the portfolios of eMAXX institutions that are explicitly linked to green or socially responsible investing. Again, this finding is consistent with such bonds being targeted by an identifiable subset of investors. This variable remains highly significant alongside the green bond indicator, demonstrating that the green label is not the only criterion that makes a concentrated position in a particular CUSIP desirable to socially responsible investors.

The model predicts that concentration of green bonds should be particularly high when the bond is relatively small and low risk, therefore presenting only mild trade-offs for investor-level portfolio weights or disutility due to risk aversion. To test this idea, we denote a green bond CUSIP as small if it is not in the top decile (alternatively, top quintile) of the bond size distribution. Almost all green bonds are investment grade, so risk, like size, is a relative concept in this market. We denote a bond as safe if its rating is AAA (alternatively, AAA or AA+), which is the modal municipal green bond rating. The goal is simply to split the sample into roughly equal parts, not to capture fine notions of size or risk.

The results generally support these predictions. AAA-rated, effectively riskless green bonds have an HHI around 0.16 higher than other bonds, controlling for various combinations of fixed effects, while green bonds that are not in the top size decile have an HHI that is 0.06 higher, but this difference is not statistically significant. When the risk and size criteria are relaxed slightly, both low-risk and small green bonds display statistically and economically elevated concentration. The coefficient on the green bond flag largely disappears after including these interactions; the concentration effect indeed appears to be driven by smaller and safer green bonds.

The next specification suggests that CBI-certified green bonds are held in greater concentration, contrasting with our earlier finding that certification is not associated with a clear pricing benefit, at least for post-2016 issues. The last specification provides more evidence that investors appear not to discriminate as clearly between an issuer's green and ordinary bonds when they are issued simultaneously. Ordinary bonds issued bundled with green bonds also see a statistically significantly elevated concentration. Note that this pattern is quite consistent with the pricing of such bundled issues in **Table 3**. There, we observe that when an ordinary bond is issued bundled with a green bond, the ordinary bond also receives somewhat better pricing, as if some Group 2 investors also became interested in it.

Overall, the ownership results are consistent with the yield findings and with the simple analytical framework described above. A subset of investors appear to sacrifice some yield to hold labeled green bonds. Green bonds are disproportionately held by these investors. Ownership is particularly concentrated in smaller and riskless green bonds. The yield and concentration effects are clearest when issuers separate their green and ordinary bond issues.

## 5. CONCLUSION

Climate change is now and will continue to be an urgent challenge, and the market for green bonds is an important and growing channel for municipalities, financial institutions, and corporations seeking to finance interventions to reduce carbon emissions. In this review, we study the US green bond market, with a focus on green municipal bonds that complements Flammer's (2021) focus on corporate green bonds. We start with a history and overview of the US green bond market and basic green bond characteristics. A simple asset pricing framework that incorporates an investor preference for nonpecuniary attributes—in our application, a preference for green versus ordinary bonds—predicts that green bonds will sell for a premium and be held in greater concentration. The data support these predictions. Overall, it appears that, faced with a supply–demand imbalance, a subset of investors sacrifice a small amount of yield in the municipal bond market to hold green bonds.

## 6. FUTURE RESEARCH

Limiting global warming to 1.5°C above preindustrial levels requires net zero carbon emissions by 2050, according to the IPCC (2018). In turn, this goal requires sustained investments at a rate of 3% to 4% of global GDP to support the transformation of much of the economy, according to Henderson & Serafeim (2020). The role of capital markets, alongside fiscal and regulatory policy and private sector leadership, will be critical in funding these investments. Here, we highlight three opportunities for future research and climate action.

First, there is a substantial role for financial innovation in climate finance. Climate finance is arguably the most important test of, for example, Lerner & Tufano's (2011) argument that financial innovation improves social welfare. While their paper focuses on the largest current market, green bonds, newer instruments such as sustainability-linked bonds that provide direct incentives to the issuer to improve its environmental performance may have greater efficacy. For example, Enel issued sustainability bonds with coupon rates that will increase in the future by 25 basis points if the company does not hit a contractually specified target percentage of its energy usage to be generated by renewables. This type of instrument has been used for non-climate-related objectives in the past, but to date there is little evidence about whether these social impact bonds related to climate will amount to a meaningful change in climate-related corporate behavior. Carbon offset markets are another focus area. The global carbon offset market declined significantly during the financial crisis, but regional offset markets in Europe have recovered since then. As an increasing number of organizations spend billions to reach net zero, understanding the market design, pricing, and trading of these offsets represents another important research opportunity.

The second opportunity for research and action is in the definition, measurement, and disclosure of "green." Scaling green investments will require a clear identification of the environmental benefits from different activities, operations, and capital expenditures. The European Union has created a green taxonomy that is likely to influence the categorization of green activities. Similarly, measures of the ex post environmental performance of organizations and their associated transition to net zero emissions are in development. Measuring the incremental environmental benefits or costs of any public or private firm or activity is challenging. Bringing consistency, transparency, and efficacy is especially important given the variety of environmental metrics and ratings and the different impacts that they aim to measure (Christensen, Serafeim & Sikochi 2019).

Third, the disruption of business as usual that is required in many sectors to reach net zero—including energy, transportation, agriculture, and infrastructure—will require a focus on both funding and governance. In late 2020 and early 2021, investors accelerated their funding of electrifying transportation, such as batteries, fuel cells, electric vehicles, and charging stations. A similar shift in investor sentiment has supported the rise of plant-based protein companies. How to properly value and underwrite growth is a central challenge, given the scale of investment needed. Just as it fueled the transformation of businesses online in the late 1990s, investor sentiment may play a role in green finance. The flip side is a shift in investor preferences for incumbents who are farther away from a net zero target, perhaps driven by concerns about future risks emerging from regulation, technological obsolescence, and legal liability. For example, the valuation of fossil fuel reserves has emerged as a significant topic in shareholder engagements.

With respect to governance and active ownership, Dimson, Karakaş & Li (2015) argue that active ownership is already having significant consequences. Traditionally, a focus of active ownership on environmental issues was the purview of small, socially responsible investment funds. Now, an increasing number of large institutional investors, including institutional and index funds (as in Fink 2021) and activist hedge funds, are engaging with management teams, asking for environmental disclosure, targets, board leadership, and specific plans to achieve net zero emissions by 2050. How this engagement might affect the trajectory toward lower emissions and competitive dynamics within industries remains to be seen.

## DISCLOSURE STATEMENT

M.B. is a paid consultant for Acadian Asset Management, a firm that manages some environmentally oriented funds and accounts. G.S. has been an advisor and investor in funds that integrate environmental issues in the investment process and invest in climate solutions. He co-leads a laboratory at Harvard Business School on sustainability, climate impact, and artificial intelligence. The other authors are not aware of any affiliations, memberships, funding, or financial holdings that might be perceived as affecting the objectivity of this review.

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## Errata

An online log of corrections to *Annual Review of Financial Economics* articles may be found at http://www.annualreviews.org/errata/financial