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FINANCING THE RESPONSE TO CLIMATE CHANGE: THE PRICING AND OWNERSHIP OF U.S. GREEN BONDS

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Financing the Response to Climate Change: The Pricing and Ownership of U.S. Green Bonds
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ABSTRACT

We study green bonds, which are bonds whose proceeds are used for environmentally sensitive purposes. After an overview of the U.S. corporate and municipal green bonds markets, we study pricing and ownership patterns using a simple framework that incorporates assets with nonpecuniary utility. As predicted, we find that green municipal bonds are issued at a premium to otherwise similar ordinary bonds. We also confirm that green bonds, particularly small or essentially riskless ones, are more closely held than ordinary bonds. These pricing and ownership effects are strongest for bonds that are externally certified as green.

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1. Introduction

Climate change is accelerating. Since recordkeeping began in 1880, the six warmest years on record for the planet have all occurred since 2010.[1] The rising temperature and increasing acidity of ocean water, climbing sea levels and the retreat of ice sheets and glaciers, and the increasing frequency of droughts and floods all reflect a changing climate and increasing atmospheric carbon levels.[2] One estimate suggests that keeping the world below the 2 degree Celsius scenario, a threshold viewed as limiting the likelihood of devastating consequences, will require $12 trillion over the next 25 years (Bloomberg New Energy Finance, 2015), but simply adapting to existing conditions or foreseeable changes will also require enormous sums.

In the absence of a global carbon pricing scheme, bond markets will be central to financing these interventions. In this paper, we study the U.S. market for "green bonds," which we and others define as bonds whose proceeds are used for an environmentally friendly purpose. Examples include renewable energy, clean transportation, sustainable agriculture and forestry, energy efficiency, and biodiversity conservation. After reviewing the market and green bond characteristics, we set out and test predictions for pricing and ownership patterns. The stark facts of climate change alone are enough to motivate 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 U.S. and international municipalities. It is a small but increasingly well-defined area of the fixed income markets. Yet in spite of the general acceptance of the notion of a

[1] https://www.noaa.gov/news/noaa-2017-was-3rd-warmest-year-on-record-for-globe.

[2] https://climate.nasa.gov/evidence/.

“green” bond, there is not yet a single 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 issue; formally certified by a third party according to a set of guidelines; or, labeled green by a data provider, for example Bloomberg. We review the origins of the market and standards for identifying green bonds in the next section.

Our sample includes 2,083 green U.S. municipal bonds issued between 2010 and 2016 and 19 green U.S. corporate bonds issued between 2014 and 2016. Municipal bonds, at the cusip level, are typically far smaller than corporates; the total par outstanding for municipal green bonds and corporate green bonds is actually about the same as of the end of 2016, around $12 billion. In 2016, about 2% of new municipal bonds were green, while only about 0.3% of corporate bonds were green. On average, green municipals have higher credit ratings and longer maturities than ordinary municipals. They are more likely to be taxable, especially early in the sample, and are somewhat larger. Green corporate bonds resemble ordinary corporates.

Our analysis of pricing and ownership patterns is organized by a 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 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. The basic prediction is similar to those from the general equilibrium model of Henkel, Kraus, and Zechner (2001) and the taste-based framework of Fama and French (2007).

We confirm that green municipal bonds are indeed priced at a premium. After-tax yields at issue for green bonds versus ordinary bonds are roughly 6 basis points below yields paid by otherwise equivalent bonds. Depending on specification, the estimates control for ratings, maturity, the yield curve, tax status, other time-varying characteristics, 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 6 basis points corresponds to a plausible and economically meaningful 0.60 percentage-point difference in value. Interestingly, this premium doubles or triples for bonds that are not only self-labeled as green (and confirmed by Bloomberg) but also externally certified as green by a third party, according to industry guidelines, and publicly registered with the Climate Bonds Initiative (CBI).

Our framework also makes predictions for ownership concentration of green bonds. Green bonds should be held disproportionately by concerned investors, who must be willing to accept their equilibrium lower returns. This concentration will be particularly strong for small bonds, where tilting away from market weights is less consequential, and when the bond is almost 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 supportive evidence for these predictions. The Herfindahl-Hirschman index is indeed higher for green bonds, especially relatively small bonds and those rated AAA. Also, echoing the pricing effect, concentration is particularly elevated for CBI certified green bonds.

There is a small amount of other recent work on green bonds. There are many issuer types one might study—supranationals, sovereigns, municipals, agencies, corporates, and others—and each differs in its target investor base, currency risks, and trading and institutional environment. So far, pricing results have been mixed. Using secondary market prices, a green vs. ordinary bond matching procedure, and a sample that includes 135 large, investment grade green bonds of many categories and currencies, Zerbib (2017) finds a moderate green bond premium in some subcategories. Karpf and Mandel (2017) use secondary market yields in a larger sample of municipals. Quite 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 this conclusion may be incorrect. Pricing in the U.S. municipals market is highly sensitive to tax features, as shown by Atwood (2003). Many green municipal bonds in the first half of the sample are taxable, so they were issued and naturally traded at higher yields. In after-tax terms, however, they actually sold for a premium, i.e. lower yield.[3]

Although green bonds are a new setting, the analysis fits into an existing literature on socially responsible investing. Renneboog, Ter Horst, and Zhang (2008) survey the literature and conclude that that a subset of investors is willing to accept lower financial performance to invest in funds that meet social objectives. Martin and Moser (2015) confirm this in an experiment, while Riedl and Smeets (2015) provide further corroboration using administrative and survey data from a sample of Dutch investors in mutual funds that have Socially Responsible Investment (SRI) mandates. Białkowski and Starks (2016) examine U.S. equity mutual funds with SRI mandates and conclude that inflows to those funds have been higher than inflows to comparable funds without similar mandates and that SRI flows are less sensitive to performance. Barber, Morse, and Yasuda (2017) analyze the flows of limited partner investments across venture capital funds and reach a similar conclusion.

Experiments also suggest that some consumers integrate environmental benefits or positive social impact into their behavior. For example, Hainmueller, Hiscox, and Sequeira (2015) found that demand for the two most popular coffees in a U.S. grocery store chain rose by

[3] The available practitioner research is also somewhat mixed. Shurey (2017) 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" (p. 2). Ehlers and 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.

almost 10% when they carried a Fair Trade label versus a generic placebo label. Demand for the higher-priced coffee remained steady when its price was raised, but demand for the lower-priced coffee was highly elastic. Behavior might be very different in capital markets, of course. For instance, institutional investors are fiduciaries to the beneficiary while consumers act on their own behalf. In addition, consumption decisions might invoke identity and emotional responses that might not exist as strongly in investment decisions. Green bonds provide a novel setting to examine how capital markets treat environmental benefits.

Another body of related work has examined the stock returns of companies that have potentially negative social effects, such as those that produce alcohol, tobacco, or firearms, or that manage prisons or casinos. Hong and Kacperzyk (2009) suggests that “sin stocks” trade at a discount and display higher average returns. Statman and Glushkov (2009) use a broader definition of sin stocks and a different time period and come to the opposite conclusion. Bansal, Wu, and Yaron (2017) suggest that a time-varying investor taste for socially responsible stocks may help reconcile these contradictory conclusions.

In brief, our contributions relative to this prior work are to provide: an academic introduction to the U.S. market for green bonds; a consistent framework to study both pricing and ownership patterns; a consistent set of empirical results in a comprehensive sample; and, evidence that certification is important in this emerging market. Nonetheless, the green bond market is just a first step toward addressing enormous problems. There is a commensurate need for additional research on green bonds and other areas of climate finance.

The rest of the paper 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 concentration, then confirms that prediction and some finer ones. Section 5 concludes.

2. An Overview of U.S. Green Bonds

2.1. Historical Origins

The green bond market has international origins and embraces many bond issuer types. The first bond labeled as a "green bond" was issued in 2007 by the European Investment Bank. Other supranational issuers include the International Finance Corporation arm of the World Bank, which in 2013 issued the first $1 billion green bond. A benchmark example of a modern sovereign green bond is France's $10 billion bond, issued in 2017.

Corporate and sub-sovereign issuance of green bonds has also grown rapidly. The first corporate green bonds were issued by the French utility EDF, the Swedish property development company Vasakronan, and Bank of America. The first U.S. municipal bond to use the green bond label in its offering documents (that is, to self-label), as opposed to having acquired the label by market convention, was issued by Massachusetts in 2013. However, municipal bonds issued as early as 2010 under the federal Clean Renewable Energy Bonds (CREB) and Qualified Energy Conservation Bond (QECB) programs are considered labeled green bonds by market convention. These represent most of the early green bonds in our sample.[4]

The first sub-sovereign issuer outside of the U.S. was Gothenburg, Sweden, which issued SEK 500 million par value in 2013.[5] Other recent international issuers include the Province of

[4] Both programs were eliminated effective January 1, 2018 by the Tax Cuts and Jobs Act, which repeals tax credit bonds.
[5] http://unfccc.int/secretariat/momentum_for_change/items/9935.php.

Ontario 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 bonds 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.[6] Third-party agents offer certification services for potentially green bonds, and the Moody’s and Standard & Poor’s ratings agencies have also developed criteria and indexes for this market. The introduction of green bond ETFs is a further indicator of the maturation of the market.

2.2. Identifying Green Bonds

What is a “green bond”? The category is not as strictly defined as “S&P 500 stocks” but not as fuzzy as “junk bonds” or “growth stocks.” We use the Bloomberg green bond tag for our sample of U.S. corporate and municipal bonds as an objective, replicable identification method that meets institutional standards. To avoid the difficulties of comparing bonds across disparate institutional environments, we do not include supranationals or international corporate or government issues.

Bloomberg describes the task 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 in order

[6] https://www.icmagroup.org/green-social-and-sustainability-bonds/green-bond-principles-gbp. .

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 takes into account 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. CREB and QECB bonds are considered green bonds by Bloomberg and market convention and represent most of the early green bonds in the sample.

There are currently only a few U.S. corporate green bonds, which is unsurprising given the requirement 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" (p. 8).

A subset of labeled green bonds are certified by third parties as conforming to some green bond standard. An interesting question is whether certification, which is intended to highlight the bond to investors as a green bond but comes at a cost, is associated with pricing or ownership patterns above and beyond those associated with the general Bloomberg green bond flag.[7] Such effects could arise because the issuer engages the third-party verifier in the pre-issuance phase (there would be little benefit to the issuer to pay to certify the bond as green after it is floated); certification at this phase thereby enables the issuer and underwriters to market the

[7] https://www.brookings.edu/blog/the-avenue/2016/10/25/green-bonds-take-root-in-the-u-s-municipal-bond-market/

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 post-issuance requirements of, for example, the Climate Bond Standard.[8]

2.3. Sample, Market Size, and Growth

Using the Bloomberg identifications of green bonds, we gather initial yields and other characteristics data for corporates from Bloomberg and for municipals from Mergent (which is more comprehensive for municipal bonds). The Mergent data are from the Official Statements filed with the Municipal Securities Rulemaking Board in the context of bond issuances. MSRB regulations require that filing with each municipal bond issue. We exclude floating rate bonds, which in any event are rarely green.

The unit of observation is the individual bond, as identified by a separate CUSIP number. 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.

As the top panel of Table 1 indicates, our total municipal bond sample, which runs from 2010 through 2016, contains 2,083 green bonds, versus 643,299 ordinary bonds. There are 204 unique issuer-year observations. The green bond sample begins in 2010 with the introduction of the CREB and QECB programs. As a percentage of ordinary bond issuance dollar volume, green bonds increased by a factor of ten over the sample period, from 0.18% of ordinary issuance in 2010 to 1.9% of ordinary issuance in 2016. Hence, green bonds are a still-modest but rapidly expanding segment of the municipal market. It is worth noting that the green municipal bond market has been growing even though the CREB and QECB programs, which presented special incentives for issuers, have now phased out.

[8] For more details on the process, see: https://www.climatebonds.net/standards/certification/get-certified.

The corporate bond sample begins in 2014 and contains only 19 green bonds, with 13 unique issuer-year observations. In 2016, they represented 0.31% of total corporate dollar volume. Green corporate bonds therefore remain a very small component of the U.S. corporate bond market. As mentioned above, this is not surprising in light of the difficulty of ring-fencing corporate proceeds and reporting in the presence of unclear benefits.

2.4. Uses of Green Bonds

Green bonds are defined by their environmentally-friendly uses. Table 2 shows the breakdown of uses by Mergent for green municipals. It also shows our own characterization of uses for green corporates based on offering documents and other sources. The most popular uses for municipal green bonds proceeds include public power, mass transit, education (e.g., energy-efficient school buildings and dormitories), and water and sewer projects. In no category are green bonds a large fraction of municipal issuance between 2010 and 2016, however. The table suggests that numerous municipal bonds which are not labeled green by Bloomberg, because they were not self-labeled as such by the issuer, could be labeled green. Put differently, the study of green bonds is as much a study of the effect of the green label as a study of bonds with fundamentally new uses of proceeds.

For example, intrinsically environmentally-sensitive uses such as pollution control and mass transit are overwhelmingly financed by ordinary bonds. This in turn suggests that the U.S. green bond "market" could enlarge dramatically just by broader use of the label, but in terms of financing climate change solutions this is significant only to the extent that there are unique patterns in ownership or pricing associated with the label (which we document later) or has real effects in terms of financing projects that could or would not have been financed by ordinary bonds. Indeed, the Climate Bond Initiative (CBI) was set up with a focus on this broader "climate aligned" bond market, which dwarfs the labeled green bond market. The majority of the climate aligned bonds were financing low carbon transportation solutions such as railways. The pricing of all climate aligned bonds, as opposed to explicitly labeled green bonds, is a natural topic for future research.

2.5. Bond Characteristics

Table 3 presents bond-level summary statistics. Panel A begins with the municipal sample. We use the first rating available in Mergent, regardless of whether it is from Standard and Poor's, Moodys, or Fitch. When required, we translate the other agencies' ratings to the S&P scale and then to an ordinal numerical 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. Green municipal bonds carry higher credit ratings than the ordinary bonds, with a median of AA+. The median rating of the ordinary bonds is AA. The modal green bond carries an essentially riskless AAA rating.

Green municipal bonds also have longer maturities. The difference between the mean maturities is 1.25 years. Green bonds are less likely to be identified by Mergent as being sold with third-party insurance or other credit guarantees. Driven by the CREB and QECB green bonds from the first few years in the sample, green bonds are much more likely to be federally taxable, which is crucial to incorporate into their pricing at issue. Green bonds are slightly less likely to be subject to state tax and their coupons are never subject to the Alternative Minimum Tax, unlike some private-activity bonds issued to fund stadiums, hospitals, or similar projects.

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 significantly less likely to be bank-eligible, a category of bonds where commercial banks are allowed to deduct 80 percent 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—14.7 percent versus 46.8 percent for ordinary bonds—to be general obligation bonds, meaning that 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.

Finally, 11.7% of green municipal bonds in our sample are certified by a third party, most often Sustainalytics, as confirming to some standard. Just over half of these, or 6.6% of the total green bond sample, are further registered with the Climate Bonds Initiative as conforming to the Green Bond Principles. We refer to such bonds as "CBI certified." Anecdotal evidence suggests that this further affirmation is an important distinction, recognized by institutional investors, so we look at CBI certified bonds closely. Certification is a recent but growing practice. The first green bonds in our sample that were certified by any third party were issued at the end of 2014, and all of the certified bonds registered with the CBI were issued in 2016.

Corporate bond-level statistics are presented in Panel B. Credit ratings of green corporate bonds do not differ significantly from those of ordinary bonds. Green corporates exhibit slightly lower maturity and larger size but are, in the main, similar to ordinary corporate bonds.

3. Pricing Green Bonds

3.1. Asset Prices with a Nonpecuniary Clientele

We start with a relatively standard asset pricing framework to understand how a clientele for green bonds (or, generically, a non-financial objective) affects prices and portfolio choice.

The model reproduces the asset pricing effect in Henkel, Kraus, and Zechner (2001) and Fama and French (2007), among others. Henkel et al. develop a general equilibrium model where firms and investors are jointly optimizing; we reach the same prediction for equilibrium returns (equivalently, the costs of capital) in a simpler setting. Our treatment is closer to Fama and French, 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 paper investigates ownership concentration, as we do later herein. Also, both of these papers use calibrations to examine the potential impact of tastes on asset prices, as well as corporate behavior in the case of Henkel et al., and compare these calibrations to moments in the data. We take predictions to the municipal green bond market, directly examining pricing and ownership patterns.

There are two groups of investors, each facing a one-period portfolio choice problem. Both groups have a common risk aversion parameter γ and common expectations for security returns $\mathbf{r}$ and risk $\boldsymbol{\Sigma}$. 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:

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

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

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, 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*.[9]

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 Group 2's capital comes from a_2 individuals each with \$1. We express this as:

$$\frac{a_1}{a_1 + a_2}\mathbf{w}_1 + \frac{a_2}{a_1 + a_2}\mathbf{w}_2 = \mathbf{w}_m$$

where $\mathbf{w}_m$ 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, which 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:

$$\mathbf{w}_1 = \frac{1}{\gamma}\mathbf{\Sigma}^{-1}\mathbf{r} = \mathbf{w}_m$$

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 γ, leading to the familiar Capital Asset Pricing Model (CAPM) formula:

$$\mathbf{r} = \frac{r_m}{\sigma_m^2}\mathbf{\Sigma}\mathbf{w}_m = \boldsymbol{\beta} r_m$$

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

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

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

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

$$\mathbf{r} = \frac{r_m}{\sigma_m^2}\mathbf{\Sigma}\mathbf{w}_m = \boldsymbol{\beta} r_m - \frac{a_2}{a_1 + a_2}\mathbf{e}$$

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.

3.2. Yield Data

The green bond market is young and there have been few, if any, defaults. To detect differences in expected returns, we focus on yields at issue. Due to the very small number of U.S. corporate green bonds we concentrate on municipal bonds for the rest of our analysis.

Like ordinary municipal bonds, green municipal bonds are generally tax exempt. As mentioned earlier, green bonds issued under the CREB and QECB programs were taxable, however. We therefore concentrate on the after-tax yield at issue to allow yields on green and ordinary bonds to be judged on the yardstick most relevant to the tax-sensitive investors who influence the municipal bond market.

We combine data from multiple sources to compute after-tax yields. Data on the tax status of the bonds come from Mergent and are based on the issues' official statements. These data identify both the federal and the state tax status of each bond. Bonds are identified as being taxable, tax-exempt, or subject to Alternative Minimum Tax at the federal level. Bonds are also identified as being taxable or not at the state level.

Federal tax rates come from the Tax Policy Center.[10] 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% ACA surcharge in addition to the 39.6% top marginal income tax rate applicable through 2016. State tax rates come from the Taxsim model of the National Bureau of Economic Research.[11] For each state the rate used is also the rate applicable to top income levels.

We then calculate a pre-tax and after-tax yield as the internal rate of return on each bond's cash flows before and after taxation, respectively. We assume that the bond's relevant tax rate is the rate at the time of issuance and that the bond is held by a top-income resident of the state from which the bond is issued. In cases where our calculated pre-tax yield differs from the yield reported by Mergent, we reset the after-tax yield to the Mergent yield from the official statements minus the difference between our calculated pre-tax and after-tax yields.

Table 4 shows average yields by year for green and ordinary bonds. The need to carefully account for tax features is apparent for the 2010-2013 green bonds sample, which is dominated by taxable CREB and QECB bonds.[12] Overall average after-tax yields are somewhat lower for green bonds than ordinary bonds, at 2.28% versus 2.50%. We have seen that green bonds and ordinary municipal bonds can be different with respect to certain characteristics that are likely to

[10] http://www.taxpolicycenter.org/statistics/historical-individual-income-tax-parameters.
[11] http://users.nber.org/~taxsim/state-rates/.
[12] Karpf and Mandel (2017) found that green bonds had higher yields at issue but did not adjust for the fact that early green bonds were disproportionately taxable.

correlate with their yields, of course, and coincidental movements in the credit curve can upset the impression from simple averages.

3.3. Yield Regressions

To more properly test the prediction that green bonds sell for a premium, we regress after-tax yields on green bond indicators and controls in Table 5. In all specifications, we control for maturity, rating, and month fixed effects. We also include size decile categories both for the size of the bond cusip itself and for the total value of all bonds brought by that issuer on that day, the presence of insurance, tax features (effectively as a precaution, since we are already directly measuring after-tax issue yield), bank qualification status, new money, general obligation collateralization, and use of proceeds. In some specifications we use maturityXratingXmonth interaction fixed effects, thus taking account of twists in the credit curve, and even issuer fixed effects. These controls account for most of the variation in yields.[13]

All specifications support the prediction that green bonds sell for a moderate premium. Holding characteristics and the state of the yield and credit curves equal, green bonds are issued at after-tax yields around five to seven basis points lower than those of ordinary bonds. To put this in extremely crude perspective, consider that the average after-tax yield for AAA ordinary bonds is 2.31% (unreported). 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 3.27% (unreported). This works out to about a 12 basis point increase for every ratings notch. A green bond coefficient on the order of six basis points thus implies that green bonds are priced as if they were "half a notch" more highly rated.

[13] The inclusion of maturityXratingXmonth interactions generates approximately 18,000 fixed effects. The inclusion of issuer fixed effects generates approximately 21,000 fixed effects.

Of course, greenness is not assigned to a bond at random, so the extent of causality cannot be pinpointed. Our perspective is that given that the regressions control for use of proceeds, maturityXratingXmonth interaction fixed effects, collateral type, and even issuer fixed effects, it is a stretch to attribute the full coefficient to some systematic difference in the risk of green versus ordinary bonds that has been perceived and priced by muni investors since market inception but remains unmeasurable and unrecognized by ratings agencies.

Interestingly, bonds that are CBI certified green are priced at an even greater premium. These are a subset of the Bloomberg green bonds, so the total premium for CBI certified over ordinary bonds is the sum of the two coefficients in Table 5. In the first specification, CBI certified green bonds have yields 26 basis points lower than ordinary bonds with similar characteristics and timing. In the context of low-risk municipal bonds issued in a historically low interest-rate environment, this is a sizeable difference, since 26 basis points is equivalent to the reduction in yield that comes from climbing two ratings notches. Even with issuer fixed effects and many other controls and interactions, the average difference between the after-tax issue yield on CBI certified green bonds and ordinary bonds amounts to 15 basis points per year.

We conduct some additional exercises and robustness tests in Table 6. In all specifications, we include the fullest set of fixed effects, including maturityXratingXmonth interactions, issuer effects, uses of proceeds effects, and other collected flags, as in the last column of Table 5.

The first two columns aim to address any potential differences between the early green bonds, largely associated with the CREB and QECB federal programs, and more recent bonds. The first column switches to pretax yields as a dependent variable. The premium on green bonds remains, but is smaller in pretax terms, while the coefficient on CBI certification increases in size and significance relative to its after-tax yield coefficient. The second column breaks the green bond effects into early green bonds and more recent ones, and finds similar if not slightly larger effects in the more recent subsample. These exercises indicate that any differences in the technical aspects of the early green bonds are not associated with offering price differences.

The third column investigates whether any third-party certification of the greenness of a bond, as opposed to the dual layer of third-party certification and registration with the CBI that is fairly widely recognized by institutional investors, is also associated with offering yields. In unreported results, we find that the coefficient on "Any Certification" is strongly significant when "CBI Certification" is excluded. When both certification variables are included, however, the picture muddies. Overall, the combination of third-party certification and registration with the CBI appears is associated with the largest and most robust certification-related pricing difference.

The last regression investigates any crossover pricing effects in the circumstance that green bonds are issued not in isolation but simultaneously with ordinary bonds on the same issue date. If investors have allocated a sum toward an issuer-date with given risk and maturity characteristics, for instance, they may view the green bonds as preferable on the margin (e.g., they satisfy a mandate that ordinary bonds of identical risk do not), leading the ordinary bonds to a worse price than if they were issued separately. The coefficient on "Both Types Issued Today" measures the extra yield on an ordinary bond in this situation, while the sum of this coefficient plus that of the interaction of the Both Types variable with the green indicator measures the extra yield that appears on a green bond. (Note that the regression already controls for the individual bond size and the total size of all bonds, green and ordinary, issued on that day.) All else equal, when the two types are issued together, the green bond's after-tax yield is higher by about a basis point—that is, the usual green premium shrinks by a small amount—while the ordinary bond's after-tax yield is higher by a more meaningful four basis points. A tentative conclusion from this is that issuers may want to issue green bonds separately to avoid siphoning off demand from their ordinary bonds.

3.5. Is Certification Worth It?

Like the green bond label itself, green bond certification by third parties is not randomly assigned—municipalities must pay for it—so it is unclear how much of the incremental reduction in yield associated with CBI certification is causal. If bonds that are CBI certified were already recognized by investors and priced as "especially green," for example, the coefficient will overstate the effect of certification. On the other hand, a fundamental reason green bond issuers pay for third-party certification is that they fear that the bond would not otherwise attract the full attention of concerned investors. From that perspective, the coefficient on CBI certification might understate the price that investors will pay for an indisputably green bond.

A back of the envelope calculation sheds some light on the benefits and costs of certification. There are five CBI-certified municipal issues in our sample. These comprise 137 individual bonds. The median total issue size, corresponding to the 22-bond issue by San Francisco Public Utilities in December 2016, is $259 million. As an upper bound, if the full amount of the coefficients in Table 5 were taken as causal, a reduction of ten basis points per year would imply a savings of $259,000 per year. Even a tiny amount of causality, however, consisting of a single basis point, would still save the municipality $25,900 per year, which has a nontrivial present value. In the context of a larger issuer which brings numerous bonds to market every year, CBI certification may offer a potentially meaningful cost reduction.

Against this pricing benefit falls two categories of costs. Internal processes to allocate and confirm the management of proceeds might involve some costs, but we have no evidence on their magnitude. We have more evidence on external costs related to parties contracted for the certification. The main certification fee is to be paid once and immediately after the issuance of the bond. The cost of the third party certifier/verifier—in our sample, usually Sustainalytics, but it can also be a Big 4 firm, environmental consultancy, or environmental NGO—is negotiable; anecdotal evidence suggests that it falls between $10,000 and $50,000 depending on issuance size.[14] If the issuer chooses, it can engage a certifier for ongoing evaluations. Registration of the bond with the Climate Bonds Standard Board requires a further fee equal to one-tenth of a basis point of the bond principal. All together, the present value of the external costs of certifying an issue appear to be well under $100,000 and most likely a fraction of that. Comparing these costs to the potential pricing benefits suggests that CBI certification could be a good deal for larger and/or longer-maturity bonds.

4. Ownership Concentration of Green Bonds

4.1. Ownership with a Nonpecuniary Clientele

Coming back to the framework used to study pricing, we can examine ownership patterns by substituting expected returns into each group's first-order condition. These are neatly summarized as deviations from market weights:

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

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

[14] For example: https://www.cdfa.net/cdfa/cdfaweb.nsf/pages/31935/$file/How%20Green%20Bond%20Issuers%20Weigh%20Certification%20_%20The%20Bond%20Buyer.pdf .

As is intuitive, Group 2 investors, with their environmental objective, overweight securities with positive environmental scores and vice-versa. The magnitude of the overweights are a function of the environmental score and the relative size of Group 2. When Group 2 is small and the environmental score is extreme, the overweights are material. Market clearing requires Group 1 investors to do the opposite. They underweight securities with a positive environmental score because their equilibrium expected returns are lower, for reasons that are not related to risk.

We can also compute the concentration of holdings. To simplify notation, define the vector $\tilde{\mathbf{e}} = \mathbf{\Sigma}^{-1}\mathbf{e}$. 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 $\widetilde{e_i} = \frac{e_i}{\sigma_i^2}$. 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*,

$$HHI_i = \frac{1}{c_i^2}\sum_{s=1}^{a_1}\left(w_{mi} - \frac{1}{\gamma}\frac{a_2}{a_1 + a_2}\tilde{e}_i\right)^2 + \frac{1}{c_i^2}\sum_{s=1}^{a_2}\left(w_{mi} + \frac{1}{\gamma}\frac{a_1}{a_1 + a_2}\tilde{e}_i\right)^2$$

where c_i is a constant equal to the total market value of security *i*. Holding constant total capital at $a_1 + a_2$, 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, and hence concentration is minimized. As the number of investors becomes large, this total approaches zero. By contrast, holding constant the proportions of investor types, the sum is maximized at extreme levels of the risk-adjusted environmental score. The derivative of HHI with respect to $\tilde{e}_i$ is:

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

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 are difficult to short in practice, we have not precluded short positions here for simplicity, 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 1, 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, consider the case where $a_1 = a_2 = a$. Since we have assumed that each investor has one dollar 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, this allows us to write equilibrium concentration in a more intuitive form:

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

The HHI parabola rests at its theoretical minimum value of $1/N$, the uniform ownership that would obtain if investors were homogenous or if the risk-adjusted environmental score is zero. Concentration then rises as the risk-adjusted score moves away from zero in either direction. Here, we can 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 market values and low risk.*

Again, this is based on a symmetric effect. If there were a set of particularly non-green securities that could be measured sensibly on the same spectrum, they will 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, and Yasuda (2012) and others, which includes fixed income positions of thousands of U.S. and international insurance companies, pension funds, and mutual funds. Insurance company holdings are based on NAIC disclosures; mutual fund holdings are based on SEC disclosures; and pension fund holdings are disclosed voluntarily.

Our ownership sample is based on twelve quarters of reported holdings of municipal bonds from the first quarter of 2014 through the last quarter of 2016. Ownership summary statistics are in Table 7. Most smaller bonds do not appear in eMAXX because they are owned entirely by retail investors or small institutions. For bonds that do appear, a majority of par amount outstanding is owned within eMAXX. In particular, green bonds have a mean of 61.9%

of par amount outstanding held within eMAXX and ordinary bonds have a mean of 58.6% ownership within the database.

Next, we use the fund name to estimate the percentage of par outstanding held by concerned investors. Specifically, we proxy for whether a fund has "green" concerns based on whether it has a substring in its eMAXX fund name that indicates an association with socially responsible investing.[15] This substantially undercounts the number of investors that actually consider social objectives, since many such funds do not include one of these substrings in their names. Nonetheless, even this methodology indicates that green bonds are disproportionately held by socially-oriented investors. For the average green bond in this subsample, 13.5% 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 shows that green bonds are recognized by the types of concerned investors one would expect.

We use HHI as a more formal estimate of ownership concentration that maps into the analytical framework. We estimate concentration under the assumption that the distribution of holdings is the same across investors outside the eMAXX database as we observe within it. To balance coverage against measurement error in the calculation of HHI, at least 25% of a bond's par outstanding must be reported within eMAXX. When calculating HHI we use ownership data from the first quarter for which this level of bond ownership is available. Since 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

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

one quarter of the issue date. In all, we are able to calculate HHI for 436 green bonds and 70,690 ordinary bonds.

The table shows no univariate difference in HHI between green and ordinary bonds, but this is inconclusive because we need to control for various differences in bond characteristics between green and ordinary bonds. For example, green bonds are larger, so they are likely to have a broader investor base and lower HHI, all else equal, which may obscure the predicted positive green effect on concentration.

4.3. Ownership Regressions

Our regression tests involving green bond ownership concentration are in Table 8. We simply include the same controls and fixed effects to be consistent with the yield regressions, although maturityXratingXissue-month effects, for example, are less needed than in the case of yield regressions.

In all specifications, green bonds are held in greater concentration, all else equal. The relationship is statistically significant and economically plausible. Controlling for numerous bond, month, and issuer characteristics, HHI is on the order of 0.05 higher for green bonds, which can be viewed in the context of the sample's unconditional bond HHI of 0.79.

As in the case of yields, CBI certified green bonds provide especially strong support for model predictions. The total predicted difference in concentration between a CBI certified green bond and an ordinary bond, all else equal, is the sum of the two coefficients reported in Table 8. For example, the first specification suggests that relative to ordinary bonds with similar characteristics, HHI is 0.04 higher for green bonds but 0.24 higher for CBI certified green bonds. The extent to which this effect is causal is unclear, but, as with the pricing results it seems likely that there is a degree of causality, given that certification is costly and its explicit purpose is to improve the marketing of the bond to concerned investors.

As mentioned above, the theoretical framework predicts that concentration of green bonds should be particularly high when the bond is relatively small and low risk, therefore presenting relatively small consequences for investor-level portfolio weights or disutility due to risk aversion. We turn to these finer predictions in Table 9.

We define a green bond as "small" if it is below the top quintile of the full sample bond size distribution. Since green bonds are larger than ordinary bonds, as confirmed in Table 3, this roughly divides the green sample into equal halves, small and large (i.e., not small). Almost all green bonds are investment grade, so risk, like size, is a relative concept in this market. We define a bond as "low risk" if its rating is AAA, which is the modal municipal green bond rating and which also divides the sample of green bonds with ownership data roughly into halves.

The results in Table 9 support these two finer predictions. AAA-rated, effectively riskless green bonds have an HHI between 0.03 and 0.08 higher than other bonds, controlling for various combinations of fixed effects. Green bonds that are not in the top size quintile have an HHI between 0.07 and 0.10 higher than other bonds, controlling for various combinations of fixed effects. As in the previous table, there remains a strong and distinct effect of CBI certification and ownership concentration.

Overall, the ownership results tie together the yield findings and a simple analytical framework. A subset of investors appears willing to sacrifice some return to hold green bonds, particularly "certified" green bonds. Green bonds are held disproportionately by these investors. Ownership is further concentrated in smaller and riskless green bonds.

5. Conclusion

The need for climate change solutions is imminent, and green bonds are currently the front-line response offered by the financial markets. In this paper, we study the U.S. corporate and municipal green bond markets. Our work complements other research in climate finance which focus on how investors might measure and manage climate risks.

We start with a history and overview of the U.S. green bond markets and basic bond characteristics. We then narrow the focus to the municipal bond sample, since there are currently far more green municipal bonds than green corporate bonds available for study and much of the response to climate change necessarily involves public infrastructure of some form.

A simple asset pricing framework that incorporates an investor preference for nonpecuniary attributes—in our application, a preference for green versus ordinary bonds—makes two predictions. The first is that green bonds will sell for a premium. After controlling for numerous fixed and time-varying factors, we find that green bonds indeed are issued at a premium, with yields lower by several basis points. This is a natural flip side to the Hong and Kacperczyk (2009) result from equities markets that sin stocks are associated with higher returns. The second prediction is that green bond ownership is more concentrated, with a subset of investors holding them at higher weights, particularly when the par value is small or the bond is especially low risk. The data also support those predictions.

Overall, the most natural explanation is that a subset of investors is willing to sacrifice some return to hold green bonds, which is consistent with other findings in the SRI literature. An additional finding with practical implications is that both the pricing and ownership effects, while apparent across green bonds, are stronger among bonds that are certified by external verifiers. This has practical implications for green bond issuers and supports efforts to create standards upon which certifications could be granted.

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Table 1. Volume of issuance of U.S. green and ordinary bonds by year. Data on municipal bonds come from Mergent and data on corporate bonds come from Bloomberg. Within each category of bonds, data from Bloomberg are used to identify green bonds. Floating-rate bonds are excluded. Dollar values are nominal par issuance amounts, and are not adjusted for inflation.

	Green			*Ordinary*
Year	**Unique Bonds**	**Unique Issuers**	**$ (M)**	**$ (M)**
Panel A. Municipal				
2010	116	32	466	255,000
2011	97	34	137	180,000
2012	106	24	180	261,000
2013	78	15	261	224,000
2014	309	22	2,130	244,000
2015	593	38	2,940	309,000
2016	784	39	6,530	353,000
Total	2,083	204	12,644	1,826,000
Panel B. Corporate				
2014	2	2	700	1,270,000
2015	11	6	6,720	1,390,000
2016	6	5	4,080	1,330,000
Total	19	13	11,500	3,990,000

Table 2. Volume of issuance of green and ordinary bonds by use of proceeds. Based on data from Mergent, with green bonds identified using data from Bloomberg. Dollar figures are par value issued, and are not adjusted for inflation. Municipal bond data cover 2010-2016 issuance, and corporate bond data cover 2014-2016 issuance.

	Green			*Ordinary*
Use	**Unique Bonds**	**Unique Issuers**	**$ (M)**	**$ (M)**
Panel A. Municipal				
Agriculture	0	0	0	93
Airlines	0	0	0	2,300
Airports	0	0	0	54,600
Bridges	0	0	0	6,830
Courts	0	0	0	2,170
Civic/Convention Centers	0	0	0	8,100
Correctional Facilities	10	2	6	7,080
Multiple Public Utilities	0	0	0	14,900
Economic Development	31	2	267	12,200
Public Power	246	40	1,080	64,600
Fire Station/Equipment	0	0	0	1,530
Flood Ctl/Storm Drain	0	0	0	2,430
Gas	0	0	0	5,600
General Purpose	515	41	2,380	591,000
Government/Public Buildings	2	2	9	8,650
Higher Education	194	20	1,010	161,000
Hospitals	3	3	101	86,900
Industrial Development	0	0	0	3,360
Irrigation	0	0	0	831
Library or Museums	0	0	0	3,560
Malls/Shopping Centers	0	0	0	22
Mass/Rapid Transit	83	4	1,480	27,100
Multi-Family Housing	0	0	0	14,900
New Public Housing	0	0	0	16
Nursing Homes	0	0	0	3,740
Office Bldg	0	0	0	864
Other Healthcare	5	1	53	29,400
Other Public Service	0	0	0	233
Other Recreation	0	0	0	1,840
Other Education	0	0	0	7,050
Other Housing	20	1	40	5,480
Other Transportation	43	2	492	45,900
Other Utilities	0	0	0	2,070

Table 2. (Continued)

	Green			*Ordinary*
	Unique Bonds	**Unique Issuers**	**$ (M)**	**$ (M)**
Parks/Zoos/Beaches	0	0	0	4,360
Pension Funding/Retirement	0	0	0	4,750
Parking Facilities	0	0	0	2,250
Police Station/Equip	1	1	7	648
Pollution Control	21	1	19	10,200
Land Preservation	0	0	0	505
Primary/Secondary Education	114	33	262	335,000
Redevelopment/Land Clearance	5	1	2	11,400
Retirement Centers	0	0	0	3,500
Sanitation	24	1	167	1,340
Seaports/Marine Terminals	0	0	0	10,800
Single Family Housing	0	0	0	23,400
Single/Multi-Family Housing	0	0	0	2,690
Stadiums/Sports Complex	0	0	0	5,460
Student Loans	0	0	0	4,170
Theaters	0	0	0	228
Toll Road and Highway	0	0	0	51,500
Tunnels	0	0	0	40
Veterans	0	0	0	1,510
Solid Waste	42	3	51	6,060
Water and Sewer	724	32	5,210	170,000
Total	2,083	190	12,637	1,826,160
Panel B. Corporate				
(Not Green)				3,990,000
Green Buildings	3	3	1,200	
Renewable Energy	12	6	6,700	
Mixed Green Use	4	4	3,600	
Total	19	13	11,500	3,990,000

Table 3. Characteristics of green and ordinary bonds. 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 2010 to 2016 issuance and includes 2,083 green bonds and 643,299 ordinary bonds. The corporate sample runs from 2014 to 2016 issuance and includes 19 green bonds and 8,315 ordinary bonds.

	Green				*Ordinary*				*Diff*	
Variable	**Mean**	**Median**	**Min**	**Max**	**Mean**	**Median**	**Min**	**Max**	**Mean**	**P-Value**
Panel A. Municipal										
Rating (AAA=1)	2.78	2.00	1	14	3.40	3.00	1	21	-0.63	(0.005)
Maturity (Years)	11.94	11.22	1	30	10.70	9.82	1	30	1.25	(<0.001)
Insured (Yes=1)	0.060	0.00	0	1	0.170	0.00	0	1	-0.11	(<0.001)
Taxable (Yes=1)	0.280	0.00	0	1	0.069	0.00	0	1	0.21	(<0.001)
Taxable AMT (Yes=1)	0.000	0.00	0	0	0.011	0.00	0	1	-0.01	(<0.001)
Taxable State (Yes=1)	0.056	0.00	0	1	0.091	0.00	0	1	-0.03	(0.101)
Bond Size ($M)	6.3	2.3	0.1	250	3.0	0.7	0.1	3500	3.27	(<0.001)
Bank Qualified (Yes=1)	0.016	0.00	0	1	0.383	0.00	0	1	-0.37	(<0.001)
New Money (Yes=1)	0.711	1.00	0	1	0.434	0.00	0	1	0.28	(<0.001)
General Obligation (Yes=1)	0.147	0.00	0	1	0.468	0.00	0	1	-0.32	(<0.001)
Callable (Yes=1)	0.544	1.00	0	1	0.519	1.00	0	1	0.03	(0.109)
Puttable (Yes=1)	0.000	0.00	0	0	0.001	0.00	0	1	0.00	(<0.001)
CBI Certified Green (Yes = 1)	0.066	0.00	0	1	0.000	0.00	0	0	0.07	(0.029)
Any Certified Green (Yes = 1)	0.117	0.00	0	1	0.000	0.00	0	0	0.12	(<0.001)
Panel B. Corporate										
Rating (AAA=1)	9.26	8.00	2	14	9.10	9.00	1	21	0.17	(0.879)
Maturity (Years)	6.84	7.03	2	10	8.37	7.52	1	30	-1.52	(0.085)
Bond Size ($M)	605	500	250	1,500	487	350	0.1	11,000	118.0	(0.129)

Table 4. Offering yields of green and ordinary municipal bonds. Data on municipal bond characteristics come from Mergent. Corporate bond characteristics are from Bloomberg. Pre-tax yields come directly from Mergent and Bloomberg data. After-tax yields are calculated for a hypothetical investor paying the marginal tax rates prevailing at the highest levels of income; calculations use Mergent data on bonds' tax status and data from the Tax Policy Center on federal tax rates. State-level year-specific tax rates come from the Taxsim model of the National Bureau of Economic Research. Calculations for each bond use the tax rates prevailing in the year of issuance.

	Green			*Ordinary*		
Year	**N**	**Pre-Tax Yield (%)**	**After-Tax Yield (%)**	**N**	**Pre-Tax Yield (%)**	**After-Tax Yield (%)**
2010	116	5.21	3.38	71,643	3.76	3.40
2011	97	4.69	3.00	64,485	3.38	3.30
2012	106	3.12	2.01	92,259	2.39	2.32
2013	78	3.51	2.04	80,666	2.67	2.57
2014	309	2.54	2.39	89,720	2.48	2.41
2015	593	2.52	2.31	116,377	2.37	2.29
2016	784	2.12	2.03	128,149	1.98	1.92
Total	2,083	2.69	2.28	643,299	2.61	2.50

Table 5. Regressions to explain offering yields of municipal bonds. Table presents the results of ordinary least-squares regressions of after-tax bond yields at issue in basis points on green bond indicators and other bond characteristics and fixed effects described in Table 3. Bond size and total issue size categories (across bonds by that issuer, on that day) are deciles. After-tax yields are calculated using Mergent, Tax Policy Center, and NBER data as described in notes to Table 4. "Green" is a dummy variable for bonds that Bloomberg tags as green. "CBI Certified" is a dummy variable for green bonds that also carry Climate Bonds Initiative green certification. T-statistics are reported in brackets.

	Dependent variable: After-Tax Yield			
Variable	**Model 1**	**Model 2**	**Model 3**	**Model 4**
Green	-7.6	-7.0	-5.5	-7.4
	[-9.15]	[-9.75]	[-6.85]	[-11.33]
CBI Certified Green	-18.7	-16.6	-14.4	-8.6
	[-5.88]	[-6.02]	[-5.46]	[-4.01]
R-Squared	0.88	0.91	0.93	0.96
Adjusted R-Squared	0.88	0.91	0.93	0.96
N	614,440	610,485	613,912	609,907
Fixed Effects				
Maturity	Yes		Yes	
Rating	Yes		Yes	
Month	Yes		Yes	
Maturity x Rating x Month		Yes		Yes
Issuer Fixed Effects	No	No	Yes	Yes
Additional Fixed Effects (all specifications)	Bond Size Category, Issue Size Category, Insured, Taxable, Taxable AMT, Taxable State, Bank Qualified, New Money, Code = GO, Callable, Puttable, Use of Proceeds			

Table 6. Regressions to explain offering yields of municipal bonds: Robustness. Table presents the results of ordinary least-squares regressions of after-tax bond yields at issue in basis points on green bond indicators and other bond characteristics and fixed effects described in Table 3. Bond size and total issue size categories (across bonds by that issuer, on that day) are deciles. After-tax yields, used as dependent variables in the second through fourth columns, are calculated using Mergent, Tax Policy Center, and NBER data as described in notes to Table 4. "Green" is a dummy variable for bonds that Bloomberg tags as green. "CBI Certified" is a dummy variable for green bonds that also carry Climate Bonds Initiative green certification. "Any Certified" is a dummy variable for green bonds that are certified by any third party. "Both Types Issued Today" is a dummy variable denoting that both an ordinary and a green bond were issued that day by that issuer. T-statistics are reported in brackets.

	Dependent variable: Offering Yield			
Variable	**Pre-Tax Yield**	**Split Sample**	**CBI vs. Other Certification**	**Overlapping Issue Types**
Green	-2.4		-7.3	-7.5
	[-3.43]		[-10.96]	[-8.12]
Green x (Year = 2010-2013)		-5.7		
		[-4.01]		
Green x (Year = 2014-2016)		-7.6		
		[-10.45]		
CBI Certified Green	-14.0	-8.2	-6.2	-8.6
	[-6.21]	[-3.81]	[-1.68]	[-3.98]
Any Certified Green			-2.5	
			[-0.80]	
Both Types Issued Today				3.9
				[6.16]
Green X Both Types Issued Today				-2.8
				[-2.15]
R-Squared	0.96	0.96	0.96	0.96
Adjusted R-Squared	0.96	0.96	0.96	0.96
N	609,934	609,907	609,907	609,907
Fixed Effects				
Maturity x Rating x Month	Yes	Yes	Yes	Yes
Issuer Fixed Effects	Yes	Yes	Yes	Yes
Additional Fixed Effects (all specifications)	Bond Size Category, Issue Size Category, Insured, Taxable, Taxable AMT, Taxable State, Bank Qualified, New Money, Code = GO, Callable, Puttable, Use of Proceeds			

Table 7. Ownership of green and ordinary municipal bonds. Data are based on combining Mergent data on bond characteristics with Bloomberg data identifying green bonds and eMAXX data on institutional ownership of individual bonds. eMAXX Ownership is the percentage of bond par value accounted for by eMAXX-reporting institutions. Green Fund Ownership is the percentage of bonds owned by a fund that has some green or social investing orientation, based on whether the fund has any of the following strings in its name: CALVERT, CATHOLIC, CHURCH, CLEAN, DOMINI, ENVIRON, ESG, FAITH, GREEN, IMPACT, KLD, PARNASSUS, SOCIAL, SRI, WALDEN. HHI is the Hirschman-Herfindahl Index, calculated as the sum of the squared values of ownership shares. Higher values reflect more ownership concentration, with a value of 1 reflecting a single owner owning all of the bond and 0 reflecting infinite dispersion of ownership. When eMAXX-reporting owners hold less than the total par outstanding, HHI is calculated assuming that the distribution of ownership shares in that universe match what is observed within the eMAXX universe. We require at least 25% eMAXX ownership to calculate HHI. The sample runs from 2014 to 2016 and HHI is calculated for 70,690 ordinary bonds and 436 green bonds with sufficient ownership data and control variables. Standard errors for differenes are clustered by issuer.

	Green				*Ordinary*				*Diff*	
Variable	**Mean**	**Median**	**Min**	**Max**	**Mean**	**Median**	**Min**	**Max**	**Mean**	**P-Value**
eMAXX Ownership	61.9%	67.6%	0.1%	100%	58.6%	58.9%	0%	100%	3.2%	(0.221)
Green Fund Ownership	13.5%	0%	0%	100%	0.6%	0%	0%	100%	12.8%	(0.098)
HHI	0.78	1.00	0.07	1	0.79	1.00	0.03	1	-0.01	(0.541)

Table 8. Regressions to explain ownership concentration of municipal bonds. Table presents results of ordinary least-squares regressions of HHI on green bond indicators and bond characteristics and fixed effects described in Table 3. Bond size and total issue size categories (across bonds by that issuer, on that day) are deciles. T-statistics are in brackets.

	Dependent variable: HHI			
Variable	**Model 1**	**Model 2**	**Model 3**	**Model 4**
Green	0.04	0.03	0.05	0.06
	[3.07]	[2.30]	[2.77]	[2.90]
CBI Certified Green	0.20	0.23	0.09	0.06
	[4.03]	[4.24]	[1.67]	[1.02]
R-Squared	0.24	0.35	0.42	0.52
Adjusted R-Squared	0.24	0.23	0.37	0.38
N	71,126	67,200	69,625	65,546
Fixed Effects				
Maturity	Yes		Yes	
Rating	Yes		Yes	
Month	Yes		Yes	
Maturity x Rating x Month		Yes		Yes
Issuer Fixed Effects	No	No	Yes	Yes
Additional Fixed Effects (all specifications)	Bond Size Category, Issue Size Category, Insured, Taxable, Taxable AMT, Taxable State, Bank Qualified, New Money, Code = GO, Callable, Puttable, Use of Proceeds			

Table 9. Regressions to explain ownership concentration of municipal bonds: Interactions. Table presents results of ordinary least-squares regressions of ownership HHI measures on green bond indicators, interacted with characteristics, and bond characteristics and fixed effects described in Table 3. Bond size and total issue size categories (across bonds by that issuer, on that day) are deciles. T-statistics are in brackets.

	Dependent variable: HHI			
Variable	**Model 1**	**Model 2**	**Model 3**	**Model 4**
Green	0.02	-0.01	-0.05	-0.05
	[0.97]	[-0.32]	[-1.65]	[-1.34]
Green x (Rating = AAA)	0.01	0.05	0.13	0.13
	[0.22]	[1.54]	[3.46]	[2.97]
Green x Not Top Bond Size Quintile	0.08	0.06	0.12	0.15
	[2.14]	[1.45]	[3.09]	[3.15]
CBI Certified Green	0.21	0.27	0.19	0.17
	[4.05]	[4.61]	[3.24]	[2.48]
R-Squared	0.24	0.35	0.42	0.52
Adjusted R-Squared	0.24	0.23	0.37	0.38
N	71,126	67,200	69,625	65,546
Fixed Effects				
Maturity	Yes		Yes	
Rating	Yes		Yes	
Month	Yes		Yes	
Maturity x Rating x Month		Yes		Yes
Issuer Fixed Effects	No	No	Yes	Yes
Additional Fixed Effects (all specifications)	Bond Size Category, Issue Size Category, Insured, Taxable, Taxable AMT, Taxable State, Bank Qualified, New Money, Code = GO, Callable, Puttable, Use of Proceeds			