The Evolution of Pricing Performance of Green Municipal Bonds

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Abstract

Green municipal bonds are a novel way to help unlock finance for investment in sustainable and urban infrastructure in the US, however issuance lags due to negative perceptions of higher cost, lower returns, and greater risk. In this study, we aim to demonstrate that US green municipal bond performance is consistent with the returns of general municipal bonds, which can improve investor confidence and increase demand. The performance of this bond sector is assessed with two different approaches: through the creation of a green municipal bond index and benchmarking its performance against an overall municipal bond index; and by looking for a price difference between green municipal bonds and their conventional counterparts through yield analysis. We found that an index comprised of green muni bonds outperforms the closest equivalent S&P index from 2014-2018, and there is a statistically significant green premium ("greenium") present in the secondary muni bond market of nearly 5 basis points by 2018. There was no conclusive evidence for the presence of greenium at issue in the primary market, however there are some early signs that this could change. Furthermore we do not observe that green muni bonds come to market at a discount. These results are key to encouraging growth in the green municipal bond market, which can help American cities to target ESG and SRI investors and unlock more capital for green and climate-aligned infrastructure projects.

Keywords: green bonds, municipal bonds, sustainability, climate finance, infrastructure, debt capital markets, bond pricing

1 Introduction

Green municipal bonds are a novel way to help unlock finance for investment in sustainable and urban infrastructure in the US, however issuance lags due to negative perceptions of higher cost, lower returns, and greater risk (Chiang, 2017). There are a growing number of municipal bonds being issued in the US as green-labelled bonds, where the use of proceeds is pledged for financing projects with environmental benefits. Projects that are eligible to be financed by labelled green bonds include, "renewable energy, energy efficiency, sustainable waste management, sustainable land use, biodiversity conservation, clean transportation, clean water, and various climate adaptation projects", among others (Saha and D'Almeida, 2017; Climate Bonds Initiative et al., 2015). The first green muni bond was issued by Massachusetts in 2013, and the market has grown rapidly since then (Fulton and Capalino, 2014; OECD, 2017; Shishlov et al., 2016; Chiang, 2017; Saha and D'Almeida, 2017). An S&P Global report (Marin et al., 2018) stated that "volume [...] continues to increase, and market estimates for 2018 suggest that issuance could top $15 billion," up from $10.4 billion in 2017. However, according to the Climate Bonds Initiative (2018a) annual market report, green muni issuance decreased significantly in 2018 due to changes in the tax code.

Green municipal bonds are essentially identical to regular municipal bonds and "to date have been largely identical in structure, risk, and return to regular bonds" (Saha and D'Almeida, 2017). When there is considerable demand for green bonds, this can enable issuers to adjust the terms of their bond issuance to lower the coupon rates, which leads to a better deal for them because it lowers the cost of capital (Zerbib, 2016; Chiang, 2017). In order for this to happen, investors must be willing to accept a lower repayment rate in order to become bond holders. This market dynamic is a crucial focus to this research, since evidence of demand for green bonds can manifest as a pricing premium, where issuers are willing to pay more for less yield, and in subsequent issuances, bond issuers will adjust their terms to leverage this demand.

The green bond pricing dynamic is the primary focus of our research because it helps to overcome some of the perceived or actual expense incurred as part of issuing a green bond (Chiang, 2017). Investors and issuers are keen to discover the presence of a green premium, or "greenium", in the green bond markets, where green bonds price higher, with lower corresponding yields, however evidence so far has been mixed. The presence of a greenium in the primary market would help to lower capital costs for green infrastructure, and a pricing differential in the secondary market could lend pressure to primary market prices, since secondary market prices are an indicator of what the market will bear (Climate Bonds Initiative, 2018b; Zerbib, 2016). Moreoever, any greenium that arises in the market could be attributed to increasing ESG investor demand. As shown by Fama and French (2007), investor appetite for particular assets can have a pricing impact, which we would expect to see with green muni bonds if there is enough demand in the market. Several scholars (Friedman and Heinle (2016); Brodback et al. (2018); Hartzmark and Sussman (2017); Riedl and Smeets (2017)) have found evidence that the personal preferences of investors play a role in SRI investment decisions.

As stated by the Climate Bonds Initiative (2018b), “when green bond curves have a handful of maturity points, they could be used as a reference for pricing new green bonds. If green bonds were trading tighter than vanilla bonds, we would reasonably expect to see a consistent greenium emerging.” Furthermore, Michaelsen (2018) states that, “the true test of a green bond price difference would be to have two identical bonds (i.e. same issuer, tenor, format) pricing on the same day.” However, this is not uncommon in the US municipal market, which is why we chose to focus our analysis on this market in particular.

In order to test our hypothesis of a pricing difference in for green municipal bonds, we followed a twofold approach. First, we used yield analysis in order to detect any differences in yields for the green municipal bonds in our sample, either at issue in the primary market, or after issue in the secondary market. Our sample for this analysis was comprised of green-labelled US municipal bonds that were issued concurrently with non-labelled bonds, so that the issuer, tenor, format, and market timing are identical. Second, we created a bond index in order to facilitate the ability to assess and compare the performance of this sector of the bond market against a sector-wide benchmark. These indices help to examine historical trends because the yield analysis approach does not readily lend itself to detecting the evolution of a potential greenium as time progresses.

At time of writing, no one has published a time-based assessment of the evolution of greenium in the muni market, nor has anyone published any work relevant to the construction or benchmarking of a green municipal bond index as a tool for assessing secondary market prices. Many of the previous studies fail to consider the effects of time on their analysis, grouping their data together in one large amalgamation rather than decomposing it into smaller time periods in order to detect greenium on shorter time scales, which is especially relevant as most have only detected a greenium signal in the past couple of years. Our analysis considers the market prices and yields of green municipal bonds on the scale of months, rather than years, and in the case of the index, the returns are calculated on a daily basis.

We found that there was a clear signal for greenium in the secondary market, both from yield analysis and through index benchmarking. The yield analysis indicates a statistically significant greenium of nearly 4 bp across the sample, increasing to a greenium of nearly 5 bp in 2018, and this was confirmed by outperformance of the green and climate indices in comparison to the market benchmarks, where the climate indices are comprised of unlabelled bonds that would have qualified for the green label, if the issuers had chosen to do so. The green and climate indices exhibited higher annual growth rates along with higher risk-adjusted returns. The results for the primary market were much less conclusive, where we found no significant differences in average yields at issue between the green and vanilla paired bonds. However, we do find some evidence that there may be signs that this could change soon, and we also found that the green bonds do not come to market at a discount, showing that they are at a minimum competitive with their non-labelled counterparts.

This paper is structured as follows: In Section 2, we provide an overview of the existing literature on green municipal bond pricing dynamics. In Section 3, we describe our data collection, and Section 4 discusses the relative liquidity of the bonds in our sample. In Sections 5, we describe our methodologies for both the yield analysis and the index construction and benchmarking. A description of our findings is given in Section 6, and the conclusions are in Section 7.

2 Literature Review

The search for greenium initially started out by looking for differences in yields for corporate green bonds compared with non-green corporate bonds. Recent studies about corporate green bond pricing dynamics include Zerbib (2019), Hachenberg and Schiereck (2018), Kapraun and Scheins (2019), and Bachelet et al. (2019), which use a matched pair analysis method to directly compare the yields of green bonds with conventional counterparts, some of which may be synthetic. All of these studies focus on green bonds that were issued since 2016. Their green bond sample sizes range from 2,000 green bonds in the case of Kapraun and Scheins, 1,000 in the case of Zerbib, and around 65 for Hachenberg and Schiereck and also for Wulandari et al.

In the case of the study of Kapraun and Scheins (2019), there was a greenium of 20-30 bps at issuance for their sample of green bonds issued 2017-2018. They found that for the years 2015-2018, green bonds generally traded 10bps higher in the secondary markets, except for bonds that were traded on exchanges with dedicated green bonds segments traded with yields 20 bp lower, indicating that the possible role of visibility and transparency in generating greenium.

Likewise, Zerbib (2019) found a greenium of 2 bp across his sample from 2017-2018. Over the period of October 2015 to March 2016, Hachenberg and Schiereck (2018) found that A-rated green bonds traded nearly 4 bp tighter than their non-green counterparts in the secondary markets, but the bonds in the other ratings brackets had no statistically significant difference in yields. Wulandari et al. (2018) found a greenium of 70 bp in 2016, and also found that generally green bonds are more liquid than the conventional bonds in their sample. The liquidity was positively related to the yield spread, however this effect has diminished over time. Bachelet et al. (2019) found that the green bonds in their sample had higher yields along with higher liquidity, with lower volatility than their brown counterparts. However, they also found that certified green bonds exhibit a greenium.

Similar analysis has been performed on the U.S. green municipal bond market. One of the first studies was published by Karpf and Mandel (2018), who performed an analysis to look for a price premium in the secondary green muni bond market using fixed effects regression and Oaxaca-Blinder decomposition. Their data set included 1,880 municipal bonds that were labelled green by Bloomberg, along with 36,000 conventional bonds by the same set of issuers from 2010-2016. By using a regression analysis on the yields, they found an overall mean spread of 23 basis points, however they failed to find any greenium signal until 2016.

Baker et al. (2018) performed an analysis of 2,083 municipal bonds defined as "green" by Bloomberg. Their comparison was based on 643,299 conventional municipal bonds, with the data spanning the years 2010 through 2016. Their focus was solely on the yields at issue, or the primary market. Through a linear OLS regression with fixed effects, they found an average greenium of 6 bp. Because their sample included taxable and tax credit muni bonds, they adjusted the yields of these bonds to an effective after tax yield before performing the regression. This crucial step is in contrast to the previous paper, and is in fact why Baker et al assert that Karpf and Mandel (2018) failed to find a greenium in the early years of the sample, since "early green bonds were disproportionately taxable," and state that "our results suggest that this conclusion is incorrect."

A recent paper, Larcker and Watts (2019), has the most similar methodology to our yield curve matched pairs analysis. In a sample of 640 pairs of matched green and non-green municipal bonds, they found a trivial green discount of 0.45 basis points, with the yield differentials being zero in 85% of the matched cases. When their search was expanded to include neighboring bonds, they again found negligible greenium. They also looked into possible differences in liquidity between the green and non-green bonds, lack of institutional ownership, and potential "greenwashing" behavior. They found no significant difference in liquidity or institutional ownership levels. They also observe no pricing difference arising for those green bonds that are third-party certified. Overall, they state that "our results suggest that municipalities actually increase their borrowing costs by issuing Green bonds," and claim that the regression findings from previous works are "insufficient to effectively control for non-linearities and issuer-specific time variation which ultimately leads to spurious inferences."

A drawback of many of these studies is that several of them ran their regressions on the yields to call or maturity without subtracting out the underlying general or municipal bond yield curve. As a result, they potentially exhibit artificially high statistical significance scores due to the fact that the yield curves exhibit a strongly functional form, albeit not linear. Furthermore, their selection criteria for forming bond pairs is not as strict as ours, in that they pair bonds that have the same issuer, coupon, etc. but could have statistically significant differences in time of issue or maturity. In other cases, the comparison bonds are either synthetic, or the yields are interpolated. This difference, especially for bonds that have shorter tenors, can have a marked effect on yields. Finally, many of these studies failed to consider the effects of time on their analysis, grouping their data together in one large amalgamation rather than decomposing it into smaller time periods in order to detect greenium on shorter time scales, which is especially relevant as most have only detected a greenium signal in the past couple of years.

3 Data

With the aim of constructing a green municipal bond index, in cooperation with the Climate Bonds Initiative, we compiled a database of green-labelled and unlabelled but climate-aligned US muni bonds issued in 2014, 2015, and the first half of 2016, with partial coverage for climate-aligned bonds from 2009-2013. One of the key points of labelled green bonds is that the green label aids in discoverability, so that identifying them for inclusion in the database was straightforward. However, labelled green muni bonds make up only a small segment of the climate-aligned muni bond market, therefore in order to get a more comprehensive view of the market, the unlabelled but climate-aligned bonds had to be manually located and checked for eligibility. This data set of muni bonds is unique, because hitherto no other studies have captured a sizeable view of both the labelled and unlabelled US green muni bond market.

In order to capture the non-green-labelled but climate-aligned muni bonds, each potential bond had its use of proceeds declaration checked in its Official Statement. If the use of proceeds indicated that the proceeds from the bond would fund projects that would qualify for the green label according to the Green Bond Principles (GBP) (ICMA, 2016), they were added to the climate-aligned bond database. After the bonds were collected, there were over 4,300 bonds in the database spanning six years and fell into the following categories: water, waste, transport, and energy, as shown in Table 1.

We then created indices to directly compare green municipal issuance against non-green-labelled bonds (which we refer to as “vanilla”) issued at the same time by the same issuers. To do this, we collected all green labelled muni bonds that were issued under the same Official Statement as one or more vanilla bonds. This means that we have collected a unique data set of green and vanilla bonds that were issued at the same time under identical market conditions so that we can best isolate any differences in market performance down to the presence or absence of the green label. Due to the fact that this data set is restricted to issuer-declared green labelled bonds, it spans years 2013 to present, however it does not include all green muni bonds, but rather only those that were issued in tandem with vanilla bonds. As can be seen, the number and amount of issuance in this data set is an order of magnitude smaller than the original green and climate-aligned data, which indicates the need to capture climate-aligned bonds for greater resolution.

The overall characteristics of the bonds in the green and climate aligned index and the S&P US municipal bond index is shown in Table 3. Despite collecting a sizable database of climate-aligned municipal bonds, the number of index-qualifying constituents is significantly smaller in the green (680) and climate aligned (1,200) indices compared with the S&P muni index (180,000), with a corresponding disparity in overall index market value. The Yields to Maturity, Par Weighted Coupons, and Weighted Average Maturities are consistent to within half a percent, or three years, respectively. Because of this equivalency in characteristics, it is an indicator that the green muni indices can be used as valid benchmarks for this market sector. We also broke down the green and

Sector	Amount Issued ($M)	Number
Transport	$19,070	1,127
Water	12,762	2,171
Energy	9,319	2,040
Multi-sector	4,666	367
Waste and Pollution Control	955	185
Total	$46,934	6,168

Table 1: Green and climate municipal bond issuance broken down by sector across all data.

Rating	# Issues	# Green	Amount Issued ($M)
AAA/Aaa	1,846	965	$11,430
AA*/Aa*	5,383	1,552	34,222
A*	1,298	127	15,366
B*	44	44	264

Table 2: Bonds in our data set broken down by ratings bands, based on their S&P and Moody's ratings, where the * indicates any rating in that band.

climate-aligned bonds in the database by their S&P or Moody's ratings, when available, as shown in Table 2.

For the green and vanilla contemporaneous bonds data set, the dates of issuance span June 2013 to December 2018. This data set was also used to create indices to directly compare the returns of the green bonds with the vanilla bonds, the characteristics of which are shown in Table 4. These series of bonds containing both green and vanilla issuance were further narrowed down to 453 matched pairs of green and vanilla bonds which were issued under the same Official Statement, so that they had the same issuer, use of proceeds, issue date, maturity date, and coupon. There was a slight difference in the issue sizes, with the green bonds having a total issue size 10% larger than that of the vanilla bonds, however we performed a sensitivity check on a subset of data with identical sizes, and the results were consistent. This data selection was done so that we could rule out the influence of any differences in credit risk, tax status, duration risk, and liquidity risk as much as possible in order to gain insight into the value of the green label when compared to nearly identical assets in

	Climate + Green	Green-Labelled	S&P IG Muni
# Constituents	1,200	680	97,851
Total Value ($M)	17,751	9,888	1,691,563
Yield to Maturity	2.37%	2.50%	2.98%
Par Weighted Coupon	4.42%	4.53%	4.38%
Weighted Avg Maturity (yrs)	13.8	15.3	12.2
Modified Duration (yrs)	9.7	10.4	6.7

Table 3: Index characteristics for the Climate-Aligned, Green-Labelled, and S&P Investment Grade Muni indices.

	Green	Vanilla
# Constituents	492	550
Total Value ($M)	6,383	8,649
Yield to Maturity	2.90%	2.77%
Par Weighted Coupon	4.53%	4.57%
Weighted Avg Maturity (yrs)	12.3	11.8
Modified Duration (yrs)	7.9	8.1

Table 4: Index characteristics for the Green and Vanilla contemporaneous series muni indices.

the strict pairings case, or at a minimum, contemporaneous assets in the series case.

Finally, because the yields can be considerably different between taxable and tax-exempt bonds, we made sure that we compared like for like in our analysis, and excluded the (few) taxable bonds from our analysis.

4 Liquidity

In order to determine if there is an observable difference in liquidity between the green bonds and the rest of the municipal bond market, the collected bond trade data was used to assess the liquidity of their respective markets (with the climate-aligned and vanilla bonds serving as proxies for the non-green bonds). Similar to the liquidity checks done by Wulandari et al. (2018) and Zerbib (2019), this was done to see if there was a difference in the liquidity of the green muni bonds, as this could have a distorting effect on the prices of those bonds through a liquidity premium.

Since it was not possible to obtain the direct bid-ask spreads in order to determine the liquidity of the bonds in the traditional sense, we used the Index of Martin (IoM) (Gabrielsen et al., 2011) and Amihud's illiquidity measure (Schestag et al., 2016) as volume and price-based proxies for liquidity for the green-labelled vs unlabelled bonds in our sample, in addition to the Zero Trading Days (ZTDs) as a proxy trading frequency.

The Index of Martin is a volume-based liquidity index for a basket of assets, taking the form:

$$\text{IoM}(i,t) = \sum_{i=1}^{N} \frac{(P_{it} - P_{it-1})^2}{V_{it}} \tag{1}$$

where P_{it} is the closing price for asset i on day t, and V_{it} is the trading volume for each asset i on that day t. A higher value for the Index of Martin indicates less market liquidity due to the influence of price dispersion, such that each trade has a larger effect on the day to day prices (Grossman and Miller, 1988).

We use the ratio of ZTDs to the total number of days traded for each bond in our sample in order to determine if there is a difference between the green-

Year	# Green/Vanilla ZTDs	Green/Vanilla Amihud	Green/Vanilla Martin
2015	1.0087	0.445	0.751
2016	1.0086	1.669	1.181
2017	0.9991	1.165	1.050
2018	0.9933	0.798	0.701

Table 5: The Amihud and Martin illiquidity ratios along with the number of active aggregated trading days calculated for the strictly paired green and vanilla bonds in our data set, broken down by year.

labelled and non-labelled bonds, where the lower the ratio, the more liquid. The converse measure, or the number of days where trading actually occurred, is another component of Amihud's illiquidity measure (AI) (Schestag et al., 2016):

$$\text{AI} = \sum_{i=1}^{N} \frac{1}{TD_i} * IoM_i \tag{2}$$

where TD_i is the number of days where each asset was traded, and the IoM corresponds to Eq. 1. This expression weights the Index of Martin for each asset by the number of the bond's "active" days in the market, before summing over all assets.

For each bond, we found the number of ZTDs, and divided this by the total number of potential trading days. This ZTD ratio was compared for the green-labelled bonds against the non-labelled bonds, and the average of these ratios is shown in Table 5. The green bonds in our sample showed only slightly less activity than the vanilla bonds. Using ZTDs as a proxy for liquidity, for the pairs of bonds, there was no statistically significant difference. There was only marginal significance for the green index bonds, which is consistent with our Index of Martin findings.

To look closer at any potential differences between the strictly paired green and vanilla bonds, we looked at the development of the ZTDs, along with the Index of Martin and Amihud illiquidity metrics on an annual basis from 2015 to 2018, as shown in Table 5. This table shows that the green bonds are more liquid in 2016-2017 but less liquid in 2015 and 2018. Overall, there is no significant difference in the liquidity of the green bonds vs non-green bonds in our samples, and these results are stable over the time period considered.

In the next sections, we will first describe the two methods of analysis and then subsequently examine the results.

5 Methodology

5.1 Yield Analysis

For the yield analysis and regressions, we used the dataset that was created as described in Section 3, which was comprised of contemporaneous series of green and vanilla bonds issued in tandem. This data was also refined to create a subset of matched pairs of green and vanilla bonds, which are identical except for the green label and possibly issue size. These bonds were used to construct yield curves in order to investigate whether the green muni bonds in this data set exhibited a green premium ("greenium") or not.

The analysis was done using the initial yields at issue for the primary market, and daily traded market prices to investigate performance after issuance in the secondary market. The yield curves were constructed using the Svensson technique, which is an extension of the Nelson-Siegel method of construction (Svensson, 1994; Nelson and Siegel, 1987). The data that was used for the Nelson-Siegel Svensson (NSS) yield curve modeling consisted of the market traded yields for the set of green and vanilla simultaneous bond issuances, along with the remaining lifetime of the bond at the time of each trade. For the primary market, the initial offering yield was used, and the time remaining was the tenor. All of the bonds issued in each month had their issuance data and market trading prices used to calculate their respective yields to maturity, or in the cases where there the bond has an early redemption option, yield to call. These characteristics of the bonds in our dataset are shown in Table 4.

In order to incorporate a broad view across the full dataset, we constructed yield curves for each month where there were a sufficient number of bonds to do so, as the minimum number of bonds required to generate a NSS best fit curve was five. There were not enough bonds in the data set to consistently create monthly green yield curves for comparison until the beginning of 2015. The bonds were considered in aggregate across all series, and monthly sampling enabled us to build a large enough data set to construct yield curves that were relevant to the market's prevailing conditions (such as interest rate environment) at the time. We considered the primary and the secondary markets separately, and constructed three yield curves per market per month: one for the green bonds only, one for the vanilla bonds only, and one for the two sets of bonds combined. The weighted average of those bonds' time remaining to maturity (or call, where applicable) was calculated, as were the weighted averages of the initial offering yields and coupons.

For both the primary and secondary yield curves, an average monthly spread was found between the green yield curve, the vanilla yield curve, and their differences with respect to the overall aggregate yield curve. It was important to examine the behavior of these bonds on a monthly basis, because the interest rate environment can change from month to month, and also municipal bond prices will respond to political environment, such as tax code changes.

Measuring the green and vanilla spreads separately enables us to decompose their trends individually. The spreads were calculated by iterating over each time to maturity and checking the yields that correspond to that time for the overall curve, the green curve, and the vanilla curve, and taking the differences. These differences were averaged for the month for each type to create an overall monthly average yield spread between the green bonds and the overall yield curve, and the overall monthly average yield spread between the vanilla bonds and the overall yield curve. The difference between the green and vanilla spreads, shown in Fig. 1, reveals any pricing differential, or premium.

For the strict green-vanilla pairs, a more direct approach was used in addition to finding the spreads between NSS yield curves. The actual yields were compared at the same times across the set of bond pairings. This approach was taken because, in this case, we could use actual traded prices rather than yields extrapolated from a best fit Svensson curve, since each bond pairing had the same time to maturity and coupon. The average spread between the green members of the bond pairings and their vanilla counterparts was measured for every month with data available, from the end of 2014 through December 2018. The advantages of this approach that there was no extrapolation or interpolation of prices, and it was based solely upon actual transaction prices.

In addition to the yield curve analysis techniques, we also performed linear regressions on our data set. For the primary market, we did a linear regression on the initial yields against tenor, and for the secondary market we performed panel regressions using the traded yields against outstanding lifetime of the bond at the time of the trade. In order to perform these regressions, we used the following specifications:

$$PrimaryYield_{it} = f(Tenor, Year, GreenBond, Rating, Sector, State, Year, IssueAmount) \tag{3}$$

$$\begin{aligned} SecondaryYield_{it} = f(&RemainingLife, Date, Year, GreenBond, Rating, \\ &Sector, State, Year, IssueAmount, TradeAmount) \end{aligned} \tag{4}$$

In the specifications shown in Eqs. 3 and 4, we captured the green bond status of each bond using a *GreenBond* dummy variable, which was set to "1" for all labelled green bonds, and zero otherwise. *Rating* consisted of a value from 1 to 10 corresponding to the S&P or Moody's credit rating, with 10 corresponding to the highest rating, or AAA/AA+. *Sector* was a value corresponding to the use of proceeds for each bond, where Energy = 1, Multi-sector = 2, Water = 3, Transport = 4, Waste and Pollution Control = 5, and Natural capital = 6. *State* consisted of the two-letter United States postal abbreviation for the issuing state. *Year* is the year in which the bond was issued. *IssueAmount* is the size of the bond in USD. In the secondary market regressions, we also include *TradeAmount*, or the amount of each individual trade, and *Date*, the date the trade was executed.

We used the Bloomberg BVAL municipal yield benchmarks (Bloomberg,

2018) in order to normalize our yield data. By subtracting out the base curve, we linearized our yield data before regressing, which yields more robust results by compensating for prevailing market trends. We subtracted out the BVAL yield for the appropriate tenor or time remaining for each of our yield values before running the regressions. This is a key step that some previous analyses have missed out: unless the yields are normalized in this manner, the regressions are in actuality being run on yield curves, which are, by definition, non-linear. We then performed fixed effects linear OLS regression analysis on the yields at issue for the primary market, and panel regressions (pooled by CUSIP and trade date) on traded yields in the secondary market.

5.2 Index Construction

For the second method employed in our analysis, we created bond indices specific to the green-labelled and climate-aligned municipal bond market to test the competitiveness of the green sector of the muni bond market against the overall muni bond market. The S&P municipal indices were chosen for the methodology and indices for two main reasons: 1) S&P Global Indices share their index methodology publicly (S&P Dow Jones Indices 2017a) so that we could use their methodology with our data for consistency, 2) the size of the S&P municipal indices allow them to stand in as a proxy for the overall muni market. Index benchmarking is one of the best ways to assess the performance of an asset class against the overall performance of a market sector, especially because it enables many-to-many comparison. An index is a time series, so it allows us to assess how the behavior of an asset class evolves over time. Index benchmarking gives most information about the time evolution of secondary market prices by following the fluctuations in traded prices after issuance.

Our objective was to create indices in order to benchmark the performance of the green labelled and climate aligned muni bonds respective to their conventional muni bond counterparts. In order to best be able to rigorously construct and benchmark the green muni market via an index, we chose the S&P indices for benchmarking since their index returns data was available and their methodology was transparent. It is important to compare like with like as much as possible for the purposes of benchmarking, so this approach ensured we used the same calculations on as similar a data set as possible.

Once the green and climate-aligned muni bond data was aggregated and the liquidity was checked as described in Section 4, we were able to construct the green muni bond indices. In order to draw valid comparisons between our indices and the S&P ones, we followed their eligibility criteria for bond inclusion as closely as possible. Following these guidelines, a bond must be issued by a US state or local US government or agency (i.e., must be a municipal bond) "such that interest on the bond is exempt from US federal income taxes" (S&P Dow Jones Indices 2017a), although they do have a taxable muni bond sub-index. The bonds must be denominated in USD, with a minimum issuance size of $2 million.

The end of day price was used for each bond, and if a bond didn't trade on a given day, the last traded end of day price was used, so that a price was established for each bond on each day of its duration until the cut-off of 1 October 2017. In total, over 6 million prices were included in the database for analysis. However, because muni bonds are frequently buy-and-hold securities (Chiang, 2017; O'Hara and SIFMA, 2012), lack of trading frequency created difficulty in selecting the most eligible bonds for the green indices. This translates into a problem of "stale prices", where the price for a bond may not have changed in considerable time due to lack of market activity. As the period of inactivity lengthens, the last traded price may drift from the actual market value of the bond based on its decreased duration.

We addressed the problem of stale prices by selecting only bonds that had recent trading activity and would therefore have more granular pricing histories. To do this, we examined the number of trades for each bond in order to see the overall distribution of trade frequency. In so doing, we determined that 27% (n=1200) of the bonds in the database had been traded on at least 10 days, so these were the ones that we considered eligible for index inclusion. Of these bonds, 40 had been traded on 100 day or more, and the most frequently traded green muni bond had been traded on 417 days. While this technique of filtering by activity mitigates the issue of indexing stale bonds, the price movements for the climate bonds were less frequent compared with the S&P indices, which has an affect of dampening volatility. The primary reason for this is because the S&P indices are based on different pricing data source that uses interpolated matrix pricing for every bond in the index, whereas we are using only actual traded prices due to data availability and because it avoids the controversy over the reliability of bond price data (Kagraoka, 2005).

Once a portfolio of bonds consistent with the eligibility criteria was created, the index calculation methodology was implemented as outlined in the S&P Fixed Income Index Mathematics Methodology (S&P Dow Jones Indices, 2016). This methodology is a market value-weighted index, which consists of calculating the market value for each included security on each day, and then finding a weighted average of the daily market values for all the included bonds in order to calculate the interest return and price return for each asset daily. The daily market values and total returns were combined in aggregate along with the daily cash position (from coupon payments) to obtain an overall index return, which in turn yielded the daily index values. The accrued interest and cash coupon payments were calculated on a 30/360 day count basis, in conformity with the S&P methodology and usual day count convention for US municipal bonds. In particular, we applied the ISDA 2006 date adjustment rules (ISDA, 2006).

For the indices created from the data for the green bonds issued in tandem with vanilla bonds, we did not filter by trade activity because our sample size was already restricted. We did use the general size criteria, such that only bonds larger than $2 million in size were indexed. All other criteria and construction rules are consistent with the climate and S&P indices, and like the benchmark indices, our constructed indices were rebalanced monthly.

We based our returns calculations on the time frame spanning 2014 to end of year 2018, since this span is much more active than previous years due both to

Year	Coefficient(bp)	Std. Error	t-value	Pr(> $\|t\|$)	r^2
PRIMARY					
ALL	0.853	1.032	0.826	0.408920	0.7273
2014	4.015	3.047	1.318	0.194	0.5576
2015	0.239	2.374	0.100	0.920137	0.7422
2016	0.400	1.646	0.243	0.808116	0.8279
2017	0.605	1.716	0.352	0.724695	0.695
2018	-0.115	1.780	-0.082	0.934	0.8843
SECONDARY					
ALL	-3.7070	0.3924	-9.4462	<2.2e-16 ***	0.26615
2014	-1.9305	3.7509	-0.5147	0.60707	0.2853
2015	-1.4338	1.0173	-1.4094	0.158818	0.1685
2016	-1.7500	1.1912	-1.4691	0.141860	0.1898
2017	-2.9180	0.6508	-4.4833	7.417e-06 ***	0.323
2018	-4.7796	0.5272	-9.0645	<2.2e-16 ***	0.2924

Table 6: Annual regressions for the green and vanilla pairs yields.

data availability and also to the number of eligible bonds issued and traded. We benchmarked against the S&P Investment Grade Municipal Bond index because it has similar credit rating and tenor profile as our set of bonds (see Tables 2 and 3). First, we evaluated the Compound Annual Growth Rate (CAGR) for each of the indices based on the daily logarithmic returns. We also calculated the annual rates of return for each of these years on a rolling basis.

When a regression was performed on the excess returns of the climate index with the excess returns of the benchmark index, the Security Characteristic Line (SCL) linear equation that resulted is of the form:

$$R_i = \alpha i + \beta I R_B(t) + e_i(t) \tag{5}$$

where $R_i = r_i - r_f$ are the excess index returns, r_f is the risk free rate, $R_B = r_B - r_f$ are the benchmark excess returns, β is the systematic risk, and e_i are the residuals (Bodie et al., 2011).

With all of these values, we can then compare the performance of the climate indices with their S&P counterpart, which we discuss in Section 6.

6 Results

6.1 Yield Analysis

Looking at the strictly paired green and vanilla bonds, the average initial offering yield, price, and issue amount, there was a 10% difference in the issue amounts, which was the only other difference besides the green label in the characteristics of these bonds, as the issuers, issue dates, maturity dates, and coupons were identical between the pairs. For all of the aggregated bonds, we saw an average

Year	Green #	Vanilla #	Green Spread (bp)	Vanilla Spread (bp)
2014	0	0	0	0
2015	0	8	0	8.75
2016	0	1	0	1.0
2017	18	16	4.89	3.88
2018	6	1	3.00	6.00

Table 7: The number green bonds per year that were issued at yields lower than their paired vanilla counterparts, and vice versa. The spreads represent the average difference between the offering yields of the bonds issued at premium and the offering yields of their pair counterparts.

greenium at issue of 0.1bp, with a corresponding price difference of just over 1 cent. This is consistent with the regression findings shown in Table 6, which only showed a signal for a greenium of -0.115 bp in 2018, with very low statistical significance.

Investigating the offering yields for any differences in primary market prices for the green and vanilla pairs, we observed the number of green bonds that were issued with yields lower than their vanilla counterparts, and vice versa, as shown in Table 7. This table also shows the average spread at offer between those green bonds that were priced differently than the vanilla bonds, and vice versa. In 2017 in particular, 18 green bonds were issued at a premium compared with their vanilla paired counterparts, with an average greenium of nearly 5bp. This is compared with 16 vanilla bonds that were issued at an average of a nearly 4 bp premium. In 2018, despite issuance decreasing overall, 6 green bonds issued at a premium compared with only 1 vanilla bond. While the data for paired issuance is still sparse, rather than looking at the aggregated view, or regressing over data for multiple years, it could be that looking deeper into the data could show indications of what some call "green shoots" (Brett and Teague, 2016; Climate Bonds Initiative, 2018b), which in this case could be taken as preliminary evidence for the potential rise of a greenium in the primary green muni bonds markets.

Furthermore, Table 8 shows the average initial offering yields for the green and vanilla pairs by year, and a very small greenium is seen to emerge in 2017 and 2018, however it is not statistically significant. The very slight greenium appears as the sample size grows larger, such as in the primary series regressions, where a statistically significant greenium of over 5 bp is observed at issue in 2017, which is also the year with the largest sample size. We have also broken down the pairs regression by month for 2017 and 2018, as shown in Table 9. The only months where there was an actual average difference in yields at issue were November 2017 and December 2018, and this table shows the wide variability in both the regression results and sample size from month to month.

The two months that exhibited a signal for greenium at issue correspond to the months where a series of bonds was issued where the green bonds were issued with lower yields than their vanilla counterparts. There are four series in total where one or more of the bonds in that issue came to market with higher prices than their vanilla partners. Three of these issues originated in the San Francisco Bay Area (for the financing of the San Francisco Transbay Transit Center, water management for the San Francisco Public Utilities Commission, and park improvements for the East Bay Regional Park District), and one originated in Bloomington, Indiana for storm sewer improvements. In two of these examples, the green bonds were slightly larger in issue amount, but in the other two cases, they were smaller, so it cannot be concluded that the pricing difference arose from issue size difference. Furthermore, these issues span different sectors of project activity, so the greenium in the primary markets so far have not been concentrated to one area, i.e. water. Because there are so few issuances so far that exhibit a greenium at issue, we are limited in the conclusions we can draw from this sample, except to observe that these bonds were issued towards the end of the year, and greenium has a higher concentration in Californian municipal bonds than elsewhere.

Overall, previous studies that have analyzed their data in aggregate over all the years that green labelled municipal bonds have existed are missing out on these details which could hint at the development of a greenium in the primary market, such that it only very recently becomes discernible as a pricing differential at issue. The sample size may be an important factor, such that increasing numbers of green bonds coming to market may provide data that exhibits more significant signals for greenium at issue. As shown, straightforward regression in aggregate is not sufficient for the pairs analysis to uncover any significant differences, because as of yet, there is not a large enough sample size to draw clear conclusions.

These limitations don't apply to the secondary market trades, which despite low liquidity, still have a larger set of observations. The data for the secondary markets shows a much clearer greenium signal. We found an overall greenium that exists across the sample, as shown in Fig. 1. The regression results shown in Table 6 also indicate a statistically significant greenium of nearly 4 bp across the sample, increasing to a greenium of nearly 5 bp in 2018.

Despite the data limitations, these results show that greenium signals have different sensitivities in the muni bond markets. In particular, the secondary market appears to be more sensitive to environmental preferences than the primary market, which in turn confirms an increase in ESG investor activity, as described by Fama and French (2007); Friedman and Heinle (2016); Brodback et al. (2018); Hartzmark and Sussman (2017), and Riedl and Smeets (2017).

These results are consistent with the index benchmarking analysis, which we discuss in the next section.

6.2 Index Benchmarking

In order to form as comprehensive view of the market as possible, we performed a benchmarking analysis on the climate indices compared with the S&P investment grade municipal index, since that is the index that was closest to our bond portfolio on the basis of credit profile (see Table 2). Furthermore, we

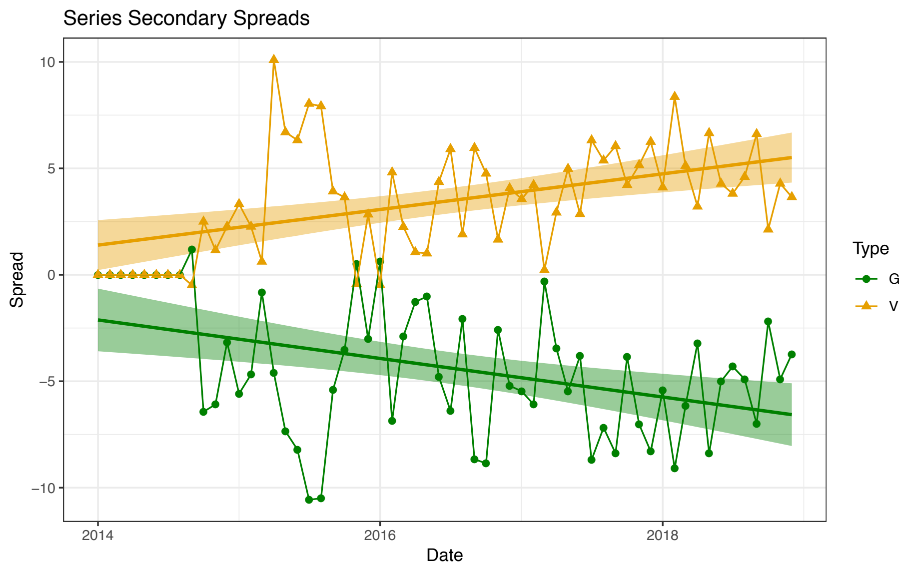

Figure 1: The trends in the secondary spreads between the monthly yield curves generated from green bonds and the vanilla bonds that were issued in contemporaneous series from 2014-2018.

Year	Green	Vanilla	Difference	N
2014	2.138 ± 0.770	2.138 ± 0.770	0.0	21
2015	2.518 ± 0.836	2.502 ± 0.856	0.016	43
2016	2.213 ± 0.696	2.213 ± 0.696	0.0	93
2017	2.416 ± 0.716	2.418 ± 0.723	-0.002	191
2018	2.726 ± 0.557	2.727 ± 0.557	-0.001	103

Table 8: Annual average yields for the primary market for the strictly paired green and vanilla muni bonds. N is the number of pairs issued for each year.

Month	Greenium (bp)	Std. Error	t-value	$\Pr(>\|t\|)$	r^2	N
January 2017	-0.2701	3.503	-0.077	0.93881	0.78	30
March 2017	-0.9395	4.449	-0.211	0.8336	0.63	45
April 2017	-8.960	9.078	-0.987	0.3316	0.81	17
June 2017	-1.206	4.316	-0.280	0.794	0.39	4
November 2017	-0.8774	0.7526	-1.166	0.25513	0.87	31
December 2017	1.701	3.602	0.472	0.637	0.15	75
April 2018	4.494	2.343	1.918	0.0613 .	0.90	25
June 2018	-0.1080	2.316	-0.047	0.963	0.88	24
August 2018	1.429	1.710	0.836	0.410	0.91	17
November 2018	-9.766	4.627	-2.110	0.102448	0.99	4
December 2018	-3.271	2.834	-1.154	0.253195	0.87	31

Table 9: Monthly regressions of primary offering yields for the combination green and vanilla bond series in 2017 and 2018 for the months where data is available. The Column N shows the number of pairs issued that month. The months in bold exhibit an actual greenium at issue based on initial yields.

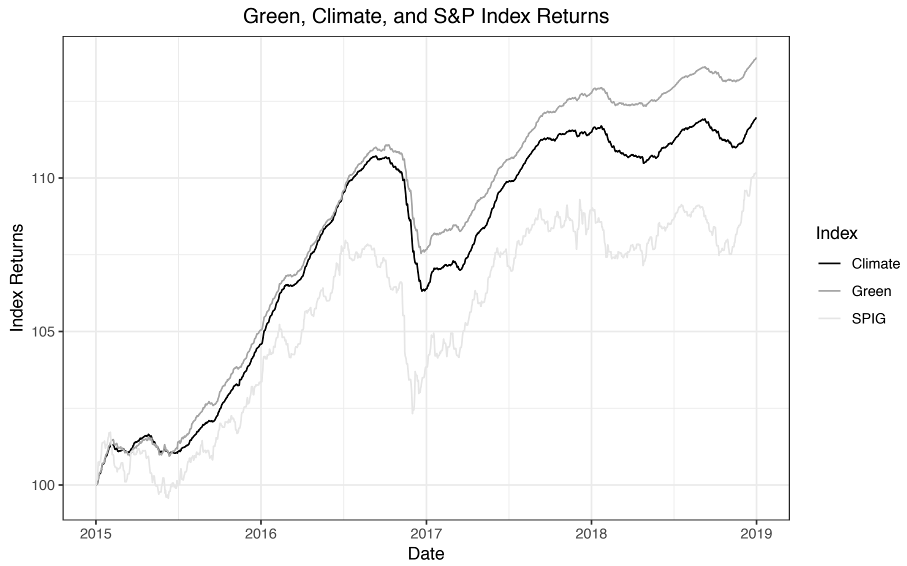

Figure 2: The returns of the climate-aligned and green-labelled municipal bond indices for 2015-2018 in relation to the S&P Muni index. Rebased so that 2015-10-01 = 100.

also benchmarked the green labelled index against the broader climate-aligned index, and indices resulting from the green series bonds that were issued at the same time with the vanilla series bonds. Using only traded prices enables us to check for trading activity and to filter out bonds that do not appear to have much liquidity. The disadvantage is that our prices do not fluctuate as much as matrix prices since they are based on actual trades, which in turn makes our volatility look abnormally low compared with the S&P data.

The performance chart showing returns relative to the first day of the benchmarking period is depicted in Figures 2 and 3. A summary of annual returns in the form of CAGR for the different indices is shown in Table 10. The climate indices exhibit the same directional movements and trends as the S&P benchmarks, and the annualized volatilities are comparable on an index-by-index basis. Also, the returns and trends are robust across the indices, since these are calculated solely upon price movements rather than any volatility measures, so they are directly comparable. On a returns and trends basis, the climate indices have consistently outperformed their S&P counterparts, as shown in Tables 10 and 10. As can be seen, the index constructed from green bonds issued before 2016 ("Green Labelled") had a CAGR of 3.31%, and the index constructed from the green bonds issued at the same time as vanilla bonds from 2015-2018 had a CAGR of 3.17%. These compare favorably with the S&P Investment Grade index CAGR, which was 2.45%.

Table 10 shows the risk-adjusted relative returns in the form of the alpha of each climate index compared with their corresponding benchmarks, calculated from the logarithmic returns for the timeframe spanning 1 January 2015 to

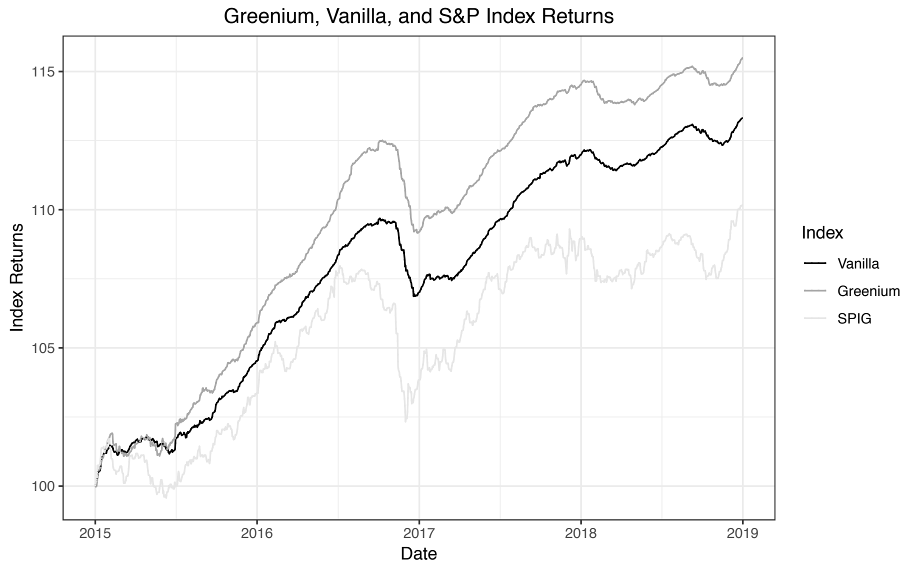

Figure 3: The returns of indices created from the green and vanilla muni bond series that were issued contemporaneously, in relation to the S&P Muni index. Rebased so that 2015-10-01 = 100.

Climate Index	CAGR	Volatility	Tracking Error	α	β
Climate Aligned	2.86%	0.73%	0.41%	2.52%	0.11
Green Labelled	3.31%	0.87%	0.86%	2.98%	0.10
Green Series	3.67%	0.87%	1.22%	3.30%	0.10
Vanilla Series	3.17%	0.87%	0.72%	2.85%	0.09
S&P Investment Grade	2.45%	1.82%	-	-	-

Table 10: Compound Annual Growth Rate and annualized volatilities for the period spanning 2015 to 2018, along with the tracking errors of the climate indices compared with the S&P, along with the alphas and betas of the climate indices found with respect to the indicated benchmark indices. All of these values resulting from the regressions were found to be statistically significant.

31 December 2018. As consistent with the CAGRs, the pre-2016 green index exhibited $\alpha = 2.98\%$ when benchmarked against the S&P Investment Grade index, and the green bonds issued in tandem with vanilla bonds showed an alpha of 3.30%. Furthermore, when we benchmark the green-labelled bonds against their climate-aligned or vanilla counterparts, we find that they still outperform, with alphas of 2.95% and 3.29%, respectively. Overall, the index returns indicate the presence of greenium in the secondary market, which is consistent with the results of our yield analysis.

The index benchmarking also lends support to the presence of a greenium in the secondary markets. We found that the green labelled indices outperformed the S&P Investment Grade municipal index over the years for which we had data, 2015-2018. The green indices exhibited stronger performance both in terms of growth rates (Table 10) and in terms of risk-adjusted returns (Table 10). Furthermore, the green labelled indices also outperformed indices constructed from their climate-aligned peers, or their vanilla counterparts that were issued simultaneously.

7 Conclusions

The main focus of this research was to benchmark the performance of the green municipal bonds against the prevailing conventional municipal bond market in order to test if a greenium is present. Two techniques for analysis were used to perform this benchmarking: index analysis and yield curve analysis. We also performed a liquidity comparison between the labelled green bonds and their unlabelled counterparts, and found that the results were similar.

Across a set of over a thousand bonds, 548 of which were green and 667 were vanilla, spanning the years 2014 through 2017, we found strong evidence for greenium in the secondary markets (shown in Fig. 1 and Table 6), but less clear evidence for greenium in the primary markets (see Table 6). However, one key observation is that we did not see any signs that green muni bonds were coming to the market at a discount compared to their vanilla paired counterparts, which indicates that the green bonds are competitive with their unlabelled peers. Furthermore, when we look at the number of green bonds being issued with a greenium compared with the number of vanilla bonds being issued with a premium, we find signs of a trend where recently more green bonds are being issued at a premium than vanilla, as shown in Table 7. This is further confirmed by looking at the actual average spreads at issue for the green against vanilla pairings, shown in Table 8, where a very small but actual greenium is shown in 2017 and 2018. More definite signs of greenium in the primary market could arise as the sample size grows.

One reason that it could be difficult to discern a greenium in the primary market could be because of the green halo effect, where the issuance of green bonds causes the overall yield curves of bonds from that issuer to lower, rather than just the green bonds (Hale, 2018). As stated by Basar and Krebbers (2019), "The entire green debt curve trades at tighter spreads than a non-green curve," so comparing green against non-green issuances from the same issuer may not currently give enough resolution to detect a greenium at issue.

The reasons for a rising greenium after issue could be that bond traders are better at leveraging the resale secondary market for higher prices on green bonds due to relative scarcity of available green bonds. Furthermore, it could be that the issuers of green muni bonds and the banks constructing their offering deals have not had sufficient data yet to achieve similar levels of performance in their offers. This is supported by the fact that any sign of greenium at issue did not appear until 2017 in our analysis. Future work in this area could include tracking the green municipal bond markets as issuance increases, since a larger amount of data would more clearly reveal pricing behavior. Also, in the case of the few issues that did come to the market with a greenium it would be useful to interview the issuers and underwriters to ascertain the reasons that any greenium arose.

While our analysis did not reveal a large greenium at issue for green municipal bonds issued in recent years, we did find some signs that this could change, especially if the number of green bond issues increases. However, both of our yield curve and our index pricing analyses show a greenium present in the secondary market for green municipal bonds, where the index findings are a novel way to quantify this secondary greenium. Furthermore, we found a few instances of greenium at issue in the primary market amongst like-for-like paired bonds, in contrast with previous studies, which could be the very beginnings of a larger trend, although there is still too little data to tell. The difference in greenium in the secondary market as opposed to the primary could arise from the fact that the primary issue market for municipal bonds is relatively closed, and the secondary market is more accessible to smaller investors. Overall, our analysis demonstrates that green municipal bonds price competitively against their vanilla counterparts in the primary market, and experience a greater price uplift in the secondary market after issue.

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