The Creation and Benchmarking of a Green Municipal Bond Index

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Abstract

As the green bond market grows, many are wondering if there is a pricing difference between green bonds and conventional bonds. In order to explore these ideas, we created bond indices specific to the green-labelled and climate-aligned municipal bond market, primarily to test the competitiveness of the green sector of the muni bond market against the overall muni bond market. We used the S&P municipal bond index construction methodology in order to compare like with like, and benchmarked the green and climate indices against their counterpart S&P municipal indices. We find that the green and climate muni indices showed CAGRs of 4.5% from 2014 to 2017, compared with 3% for the S&P Investment Grade Municipal index. We also created several sector and state sub-indices, which also outperformed their S&P counterparts.

1 Introduction

A growing number of municipal bonds are being issued in the US as green-labelled bonds, where the use of proceeds is pledged for financing projects with environmental benefits. 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). 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. In the 2016 Climate Bonds Initiative State of the Market report, they stated that "2015 saw significant growth in the labelled green muni bond market, with $4.7bn in issuance, up by 47% over 2014", making a total of $9.7 bn outstanding and an additional $20.6 bn in unlabelled but climate-aligned bonds (Climate Bonds Initiative, 2016). An S&P report published in 2016 said that "we believe the market for U.S. municipal green bonds could be significantly larger" due to the large amount of climate-aligned bonds that haven't been labelled green. In 2017, a Bloomberg New Energy Finance report stated that the US was likely to sell more than $10 bn in green municipal bonds in that year, an increase over the $6.8 bn issued in 2016. Saha and D'Almeida (2017) state that, "of last year's [2016] $41.8 billion of green bond issues, over $5 billion came from regional governments or municipalities, making this the third-largest category of issuer after development banks and corporations." Furthermore, according to Bloomberg, "U.S. State and local governments have issued $7.5 billion of green-labelled bonds since 2010, with a record issuance of $3.8 billion in 2015 – a 55 per cent increase over 2014." The Climate Bonds Initiative released findings in late 2017 that "annual US green municipal bond issuance reached a new record in 2017, passing the symbolic $10bn mark," and forecasted that 2018 issuance should grow to $20 bn.

Similarly, the S&P Global report titled "2018 U.S. Municipal Green Bond & Resiliency Outlook" (Marin et al., 2018) states, "volume [...] continues to increase, and market estimates for 2018 suggest that issuance could top $15 billion," up from $10.4 billion in 2017. They found that the majority of the labelled green muni bonds are for "water, green buildings, and transportation projects". 64% of issuance from 2013-2017 was from New York, California, and Massachusetts, and growth has been seen in issuance from Connecticut and Colorado, but overall most green muni bond issuance is in the more urban areas and states.

While the New York City Comptroller's Office was exploring the feasibility of a green muni bond programme for the city (Stringer, 2014), they found that institutional investors "expressed an unwillingness to accept lower yields" in exchange for positive environmental externalities, indicating that the market demands that green bonds remain competitive with conventional bonds (Stringer, 2015). Nevertheless, Saha and D'Almeida (2017) state that green muni bonds can help leverage demand to achieve better bond terms. Because demand for green bonds currently outstrips supply, green bond issuances are usually oversubscribed. As a result, "the issuer can try to leverage this demand to seek more favourable terms," and that "some issuers have achieved a better price (cheaper debt) through green bonds." The authors also state that "there is also anecdotal evidence to suggest that green bond investors may be willing to accept a longer term to maturity (i.e., a later principal repayment date)."

Against this context, the objective of this paper is to test the competitiveness and aggregate performance of green municipal bonds in relation to the overall conventional municipal bond market. In so doing, we aim to verify the need for a green municipal bond market which could address different needs than the conventional municipal bond market.

There is a growing body of support for the need for and implementation of green bonds and green municipal bonds (Fulton and Capalino, 2014; OECD, 2017; Shishlov et al., 2016; Chiang, 2017; Saha and D'Almeida, 2017). Nonetheless, it has been difficult to benchmark the performance of green municipal bonds against prevailing market trends to see if their returns are competitive with conventional bonds. The majority of green municipal bond performance has focussed on yield curve analysis, a thorough discussion of which can be seen in our related paper (Partridge and Medda, 2018).

In order to test our hypothesis of the necessity of green municipal bonds, we created a bond index is to facilitate the ability to assess and compare the performance of this sector of the bond market. An index allows the market performance of many assets to be reduced down to a single time-series, which can be used as an indicator of the overall average performance of the assets included in that index. Indices allow one to take a broader view on the performance of a market sector, and also to be able to compare the returns of one index with other indices in order to assess their competitiveness. Overall, "bond indices are used by bond funds to benchmark individual issuances and measure their relative performance" (Clean Energy Group and Croatan Institute, 2014). Therefore, indexes are important for encapsulating historical market data and price trends. They enable an investor to view the overall performance of a market sector in aggregate and how that performance has evolved over time.

At present, there are a few green corporate bonds indices, including Bank of America Merrill Lynch, Barclays/MSCI, and S&P, which the Croatan Institute states is "clear evidence of a swiftly maturing market" (Clean Energy Group and Croatan Institute, 2014). While there are also municipal bond indices, such as the S&P, there is to date no index specific to the green or climate-aligned sector of the municipal bond market. Therefore, one major objective of this work is to create an index for the green municipal bond sector in order to be able to benchmark its performance relative to the overall municipal bond market. A primary way to motivate ESG investment in green infrastructure is to demonstrate that the performance of green assets is comparable to the overall market. To this end, our objective is 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 the next section, we describe our data collection and some preliminary analysis. In Section 3, we perform a preliminary liquidity comparison between our green and vanilla bonds, and in Sections 4 and 5 we describe our index construction methodology. A description of our benchmarking analysis is given in Section 6. The results of the performance benchmarking are given in Section 7 along with a discussion of these findings. The conclusions are in section 8.

Year	Amount Issued ($M)	Number	Labelled
2106 Q1-2	$6,242	651	240
2015	14,661	1,853	617
2014	9,362	1,352	230
2013	776	150	3
2012	228	117	0
2011	148	115	0
2010	474	127	0
2009	11	12	0

Table 1: Green and Climate issuance by year, including the number of green labelled bonds.

2 Data

With the aim of constructing a green municipal bond index, we worked in cooperation with the Climate Bonds Initiative to compile 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 (see Table 1), 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 is a key distinguishing feature of our data set.

In order to capture the non-green-labelled but climate-aligned muni bonds, several key word searches were performed, and 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. In order to be included in the climate-aligned category of the database, the official statements of each bond issuance were scrutinised to ensure that the use of proceeds disclosed therein fell within the guidelines laid out by the Green Bond Principles (GBP). We used the GBP as the criteria because we wished to conform to an external standard of what constitutes "green" rather than to rely on a subjective internal interpretation. Because the GBP largely address green infrastructure standards, the bonds that qualified for inclusion fell into the following broad categories: water, waste, transport, and energy, as shown in Table 2.

After the bonds were collected, there were over 4,300 bonds in the database spanning six years. Because US muni bonds are typically issued in series, each individual issuance is broken down into series of bonds with different coupons and maturities. The same official statement covers each series of bonds, so the use of proceeds across a given series of bonds is consistent.

As can be seen in Table 1, the number and amount of issuance has grown

Sector	Amount Issued ($M)	Number
Transport	$18,631	1,062
Water	6,676	1,558
Energy	3,969	1,379
Multi-sector	2,034	280
Waste and Pollution Control	591	98
Total	$31,902	4,377

Table 2: Green and climate municipal bond issuance broken down by sector.

State	Num Issues	Total Amount $M	Num Green	Green Amount $M
CA	548	3,286	114	1,447
MA	346	2,776	193	2,441
NY	535	10,269	173	1,543
TX	327	1,887	6	254
WA	187	2,665	61	1,196

Table 3: The number and amount of green and climate-aligned issuances by the top five most active states 2009-2016.

consistently year on year, however it is also evident from this table which years (2009-2013) have incomplete data discovery for the climate-aligned but non-labelled bonds. Eligible bonds that were issued before 2014 were inconsistently captured in the data for reasons explained previously, and so there are more extant than the data reflects, except for a subset of tax credit energy bonds that were consistently identified across all years due to CREBs (Certified Renewable Energy Bonds) and QECBs (Qualified Energy Efficiency Bonds) (Clean Energy Group and Croatan Institute, 2014) being easily identified as qualifying clean energy-related bonds.

The green muni bond database allows us to show which states have been most active in the green bond market over the considered time period, as shown in Table 3. We also broke down the green and climate-aligned bonds in the database by their S&P or Moody's ratings, when available, as shown in Table 4.

In terms of the time to maturity of the green and climate aligned bonds, Figure 1 shows that most of these bonds were issued with 10 to 20 year durations, followed by 5 to 10 years. This is in alignment with the relatively long-term nature of green infrastructure investment.

The overall characteristics of the bonds in the green and climate aligned index, the labelled green index, and the S&P US municipal bond index is shown in Table 5. Despite collecting a sizeable database of municipal bonds that were issued for the purposes of financing sustainable infrastructure, 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. Because the index methodology normalized the indices by market cap, the trends of the smaller

Moody's Rating	Amount Issued ($M)	Number
Aaa	$4,526	542
Aa	3,863	952
A	69	79
Baa	16	1
S&P Rating	Amount Issued ($M)	Number
AAA	$0	0
AA	4,005	697
A	95	106
BBB	177	23

Table 4: Green and climate muni bonds broken down by Moody's and S&P ratings.

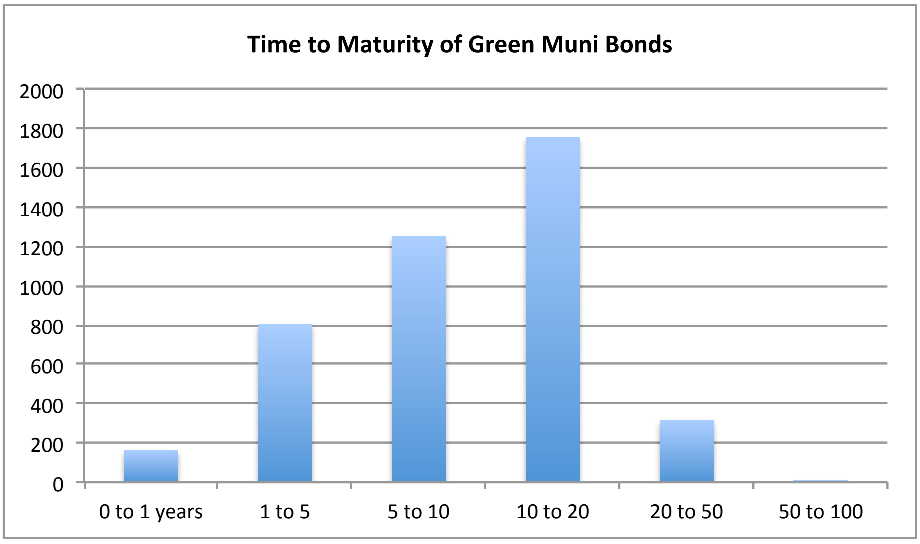

Figure 1: The tenor breakdown of green and climate muni bonds.

	Climate + Green	Green-Labelled	S&P 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

Table 5: Index characteristics for the Climate-Aligned, Green-Labelled, and S&P Muni indices.

green indices would still be expected to be similar to the larger S&P index. As can be seen, 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.

In addition to the creation of the climate-aligned and green-labelled indices, we also created sub-indices in order to benchmark each of the following sectors: energy, water, and transport. Five state green muni indices were also created for California, Massachusetts, New York, Texas, and Washington. We were constrained by paucity of data before 2014 since the muni bond survey has not yet reached into prior years to search out relevant climate-aligned but unlabelled bonds. Therefore, in the older non-energy data, we are restricted to labelled green bonds, which didn't have market activity until 2013. In particular, the water index wasn't active until mid-2014, and this is why our benchmarking time frame starts on 1 October 2014 and not earlier, and also allows us to more easily annualise our returns by ending the benchmark on 1 October 2017.

3 Liquidity

In this section we aim to test the liquidity in the green municipal bond market compared with with conventional municipal bond market. We base the measure of liquidity of the market on the Index of Martin, a price and volume based metric. This is done in order to determine whether or not there is a difference in liquidity between the two markets, which could cause a liquidity premium to arise.

Because it was not possible to obtain the direct bid-ask spreads in order to determine the liquidity of the markets in the traditional sense, we used the Index of Martin (Baker and Filbeck, 2015) as a volume and price-based proxy for liquidity for the green-labelled vs unlabelled bonds in our sample. In order to check for differences between the green muni bonds and the unlabelled muni bonds, the climate-aligned bonds were used as a proxy for the non-green bonds.

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. The reason that we used the Index of Martin rather than the more common liquidity ratio is that the Index of Martin is "a suitable index for the market as a whole, while the liquidity ratio is best suited for a single asset" (Gabrielsen et al., 2011). 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.

The green index bonds ($n = 944$) had an Index of Martin of 18.47 compared with the climate-aligned bonds ($n = 2,486$), which had an Index of Martin of 37.92. When these values are divided by the issue amount in each set in order to normalise, the resulting indices are 1.92 and 1.72, respectively. The ratio of these values (green/climate) for the overall index data set is 1.11. The raw Index of Martin is lower for the green bonds in the index dataset, but when normalised by total issue amount, the climate-aligned ratio is lower. Trading volume has limitations for representing market liquidity, nevertheless these Martin ratios indicate near parity for the liquidity of green muni bonds compared with the overall muni market, and therefore support the relevance of the green and climate aligned indices to serve as a valid benchmarks.

4 Green Muni Bond Index Construction

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 with the overall muni bond market. We used the S&P bond index construction methodology in order to compare like with like. The S&P municipal indices were chosen as for the methodology and indices for three 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 indices allow them to stand in as a proxy for the overall muni market, 3) the S&P has also created many muni subindices (i.e., by state, by sector, etc.) that also allow subsector comparisons with the green muni data to determine relative performance by geography and by sector.

Once the green muni bond data was aggregated and the liquidity was checked as described in Section 3, we were able to construct the green muni bond indices. In order to draw valid comparisons between our green muni bond 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 (or \$1 million in the case of the ARRA index).

The ARRA index had two of the selection criteria lifted: they were not subject to the trading frequency conditions, and they were also exempted from the $2 million lower size threshold. This is because there were only 632 CREBs and QECBs in total in the database, and their average issue size was $1.99 million, with 504 of those bonds under $2 million. Therefore, in order to have a sufficient sample size, and one that reflects the fact that QECBs in particular were issued in smaller sizes by smaller issuers, we loosened the index selection criteria. With this in mind, we have compared them against the S&P Build America Bonds (BAB) index, which has similar issue size (the minimum size is $1 million for this index), infrastructure sector relevance, and tax credit characteristics (S&P Dow Jones Indices, 2017).

Next, market price data for each bond for each trading day was acquired in order to be able to gauge the price performance. For this, we used the end of day price 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 4 million prices were included in the database for analysis. However, lack of trading frequency created difficulty in selecting the most eligible bonds for the green indices, because frequently muni bonds are buy-and-hold securities (Chiang, 2017; O'Hara and SIFMA, 2012). 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. Based on this analysis, we determined that 27% (n=1200) of the bonds in the database had been traded at least 10 times, so these were the ones that we considered eligible for index inclusion. Of these bonds, 40 had been traded 100 times or more, and the most frequently traded green muni bond had been traded 417 times. As can be seen from the relative infrequency with which these bonds are traded, it was essential that the index only included the most frequently traded assets in order to prevent the use of prices that had become out-dated due to lack of activity, and similar approaches of filtering index inclusion by trading activity have been taken by other bond indices (FTSE, 2017).

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). Additionally, because our index is specifically focussed on green infrastructure muni bonds, the pool of eligible bonds was much more restricted than the S&P indices, which is reflected in Table 6, which shows the number of bonds

Index	#	Par value $M	Avg Asset Size $M
Climate	919	$17,751	$19
Green	680	9,888	15
Energy	344	3,456	10
Transport	903	20,394	23
Water	556	5,589	10
ARRA	481	1,209	3
CA	126	1,689	13
NY	236	6,203	26
MA	78	1,206	15
TX	77	1,302	17
WA	110	3,004	27
S&P Investment Grade Muni	97,851	$1,691,563	$17
S&P Public Power	3,146	59,664	19
S&P Transport	10,273	229,948	21
S&P Water/Sewer	5,604	80,547	14
S&P BAB	6,933	148,244	21
S&P CA	27,033	367,918	13
S&P NY	12,794	264,340	20
S&P MA	4,518	68,506	15
S&P TX	22,467	210,721	9
S&P WA	6,382	64,348	10

Table 6: The number of constituents and par value of the green and climate-aligned national and sector municipal bond indices, along with the number of constituents and par value of the S&P national and sector municipal bond indices as of mid-2017.

in each index along with their total market values.

Like the S&P indices, the green muni indices were rebalanced monthly on the first of the month. Bonds that are added to the index at rebalancing must have a date of issue within three months of the rebalancing date, and must have at least one month in duration remaining before maturity. S&P also require the bonds that they include to be held by a mutual fund, however this restriction is not one that we imposed largely due to lack of data and also because it would have potentially been too restrictive on the eligible pool of green muni bonds.

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).

5 Index Methodology

In order to construct our market value weighted indices, we followed the S&P methodology (S&P Dow Jones Indices, 2016). The bond issue and trading price data was loaded into the database, and then we calculated the daily market value for each bond based upon their closing prices for each day. Once the market values for each asset were calculated for each day, these valuations were used to calculate the interest returns and price returns for each asset on each day. Then, these values were used to create an overall index return for the aggregated assets in the index.

The total index returns are created so that they begin at a value of 100 at the beginning of the index ($t = 0$), and this value is adjusted upwards or downwards according to the movements in the market valuations and any bond coupon payments that arise on an iterative day-to-day basis. This total return value enables us to encapsulate the overall performance of the collection of the green and climate-aligned bonds, so that they can be compared with other indices. Once we had calculated the index returns for each day for the green-labelled bonds, we did the same with the climate-aligned bonds in combination with the green-labelled bonds. From there, we created sub-indices where the same methodology was applied to bonds specific to a sector or issued by a particular state.

The climate indices were constructed from the 1,200 most frequently traded bonds, which were narrowed down by including those with issuance size of at least \$2M, which amounted to 919 green and climate-aligned bonds. For each trading day, any bonds that were "active" on that day (bonds that were issued before the day being considered, and that matured at least a month after the day being considered) had their end of day trading price and accrued interest used to create their market values for that day. These market values, along with any coupon payments that day, were used to calculate the index return, price return, and total returns on each day. These values were summed across all active assets on each day to calculate the overall index returns and these returns were used to find the overall index values. This same method was repeated on the same set of bonds, but narrowed down even further to look at the green-labelled bonds only.

Similarly, sub-indices were created for the climate energy, water, and transport sectors. These sub-indices were created by selecting the relevant bonds for each sector, then ensuring that the same criteria that applied to the national climate muni index also applied to the sub-indices, namely that the issue size was at least \$2 million, and that the bonds included had at least 10 trades. We also created five sub-indices, one each for each of the top five largest green muni bond issuing states: California (CA), Massachusetts (MA), New York (NY), Texas (TX), Washington (WA) as shown in Table 6.

6 Analysis

In order to ensure that our indices are comparable to the S&P indices, we compare some of the overall characteristics of the bonds that made up our indices. The descriptive characteristics that are commonly used for bond indices are: overall yield to maturity, par weighted coupon, weighted average maturity, and modified duration (Brown, 1994; Goltz and Campani, 2011).

In order to calculate the yield to maturity (Bodie et al., 2011) for the index data, we gathered all of the bonds issued in each month and used their issuance data and market trading prices to calculate their respective yields to maturity, or in the cases where there the bond has an early redemption option, yield to call. In order to calculate the yield to maturity/call, we used the following equation with the last traded price for each asset per day, then performed an optimisation using Newton's technique (Weiming, 2015). In order to calculate the weighted average overall yield to maturity (or call) for the index constituents, we used the traded yields (which correspond to the yield to worst, or call, from the traded prices as disclosed by EMMA) along with the trade amounts as the weightings to calculate the weighted average per day.

We use a similar approach to calculate the weighted average coupon and maturity for each day, but weighted by the initial issue amount, in order to establish values for the overall par weighted coupon and maturity. The weighted average coupon gives an indicator of the overall coupon rates that are being offered by the bonds in the index, and the weighted average maturity gives an indication of how long it will be on average before the bonds in the index mature.

The modified duration is a measure of percentage change in the price of a bond in response to a percentage change in yield. Our programmatic approach follows that of Weiming (2015), where we calculate the modified duration based upon the bond's par, time remaining to maturity, coupon, and frequency of coupon payments (twice annually). Having calculated the modified duration for each bond on a given day, we can then calculate a weighted average based on either initial issue amount or trade size in order to obtain a weighted average modified duration for the entire index.

Once these values are calculated for the bonds making up each index and sub-index, we compared them with the S&P index values to see if they are consistent (as shown in Table 5). This step ensures that we are comparing similar baskets of securities with similar yields and maturities. Once this check was completed, we then moved on to benchmark the returns of our climate muni indices against those of the S&P muni indices.

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 also 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 secondary market prices, by following the fluctuations in traded prices after issuance.

In particular, we were interested to see how green muni bonds performed compared with the overall muni bond market. To this end, 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 deliberately chose the S&P indices for benchmarking since their index returns data was available and their methodology was transparent. It is of utmost importance in the process of benchmarking to compare like with like as much as possible, so this approach ensured we used the same calculations on as similar a data set as possible.

We based our returns calculations on the time frame spanning October 2014 to October 2017, since this span is much more active than previous years due both to data availability and also to the number of eligible bonds issued and traded. We used the daily index values for our indices and the S&P indices in order to perform a benchmark analysis of the returns. 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 4 and 5).

First, we calculated the Compound Annual Growth Rate (CAGR) over the time period spanning 1 October 2014 to 1 October 2017 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 from October to October.

Then, we used the daily returns to calculate two common values that are used to benchmark the performance of an asset or a collection of assets: the Sharpe Ratio and the Information Ratio (Kidd, 2011). We compare the Sharpe Ratios of the climate indices with their S&P counterparts in order to check the relative performance of the indices in comparison with the risk free rate. The higher the Sharpe Ratio, the greater the expected excess returns. And like the Sharpe Ratio, higher values for the Information Ratio indicate stronger performance.

We also used the daily returns to calculate the excess returns and the relative returns. We used monthly 3-month Treasury Bill (T-Bill) data as provided by the Federal Reserve Bank of St Louis (2018), and the average of these values over the relevant time period was used as the risk-free rate, r_f, and this was subtracted from the overall returns in order to establish the excess returns. Similarly, the relative returns were found by taking the difference between the returns of the climate indices and the returns of their respective benchmarks. The excess returns were used to calculate the Sharpe Ratio, and the relative returns were used to calculate the Information Ratio. The risk free rate, r_f, is also used in the alpha calculations (Eq. 2). From the index data, we specifically measured the historical realised volatility, rather than the implied or forecast volatility.

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:

$$R_i = \alpha i + \beta IR_B(t) + e_i(t) \tag{2}$$

Climate Index	S&P Index
Climate	S&P Investment Grade Muni
Green	S&P Investment Grade Muni
Energy	S&P Public Power
Transport	S&P Transport
Water	S&P Water/Sewer
ARRA	S&P BAB
NY	S&P NY
CA	S&P CA
MA	S&P MA
TX	S&P TX
WA	S&P WA
Green	Climate

Table 7: The pairs of the climate indices with their S&P muni index benchmark counterparts.

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).

In summary, the daily returns values were used to perform a regression for each pair of indices in order to find the alpha and beta from the SCL (Eq. 2). The volatility, Sharpe, and Information Ratios were also calculated for each index/pair from the log returns. The daily log returns were also used to calculate the CAGR. With all of these values, we can then compare the performance of the climate indices with their S&P counterparts, which we discuss in the next section.

7 Results and Discussion

In order to form as comprehensive view of the market as possible, we performed a benchmarking analysis on the climate indices and sub-indices compared with their closest equivalent S&P muni index. Furthermore, we also benchmarked the green labelled index against the broader climate-aligned index, with the pairings as shown in Table 7. Nevertheless, using only traded prices enables us to check for trading activity and to filter out bonds that do not appear to have much liquidity (see Section 3). 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. Unfortunately, this introduces an element of inconsistency into our benchmarking comparison, however it does not change the fact that the overall percentage returns and trend characteristics are still directly comparable.

The performance chart showing returns relative to the first day of the benchmarking period is depicted in Figure 2. A summary of annual returns in the form of CAGR for the different indices is shown in Table 8. The overall climate-

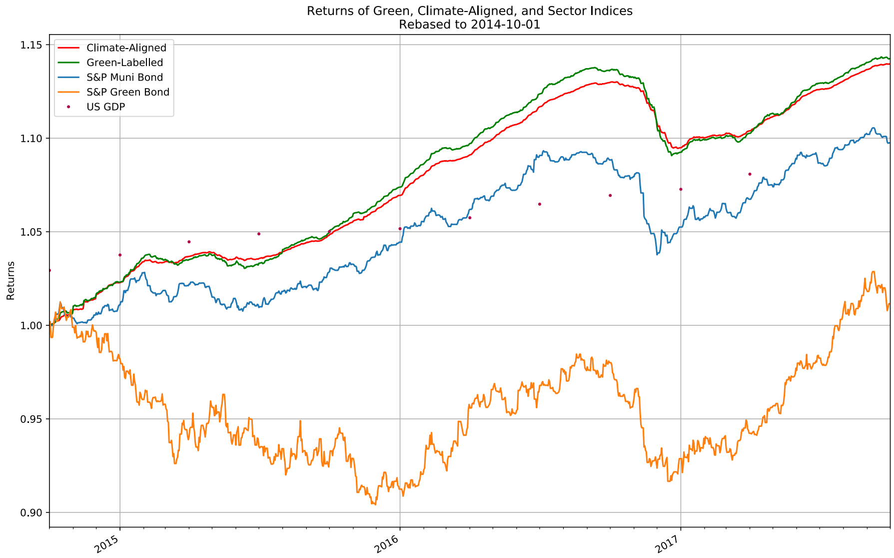

Figure 2: The returns of the climate-aligned and green-labelled municipal bond indices for 2014-2017 in relation to the S&P Muni index and the S&P Green Bond index. Rebased so that 2014-10-01 = 100; GDP for reference.

related indices (across all sectors) plus the climate-aligned sector indices for water, energy, and transport are shown in Figure 3, and the returns for the state indices for California (CA), New York (NY), Massachusetts (MA), Washington (WA), and Texas (TX) in Figure 4.

The climate indices exhibit the same directional movements and trends as the S&P benchmarks, and the annualised 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 Figs 3 and 4, and Table 8. As shown in the tracking errors (Table 9), the climate energy index showed the highest tracking error, outperforming its S&P Public Power benchmark by 3.2%, and the ARRA index most closely tracked its benchmark, the S&P BAB index, with a tracking error of only 0.34%.

All of the indices being considered, both climate-related and S&P, show positive growth over this timeframe. However, a key point of creating the climate-related muni indices was to enable us to benchmark their performance against the closest equivalent S&P muni indices. Table 10 shows the risk-adjusted relative returns in the form of the information ratio and the alpha of each climate index compared with their corresponding S&P muni benchmarks. The information ratio was calculated using the mean and standard deviation of the logarithmic returns of the climate indices and the S&P benchmarks for the timeframe spanning 1 October 2014 to 1 October 2017.

Climate Index	CAGR	Volatility	S&P Muni Index	CAGR	Volatility
Climate Aligned	4.50%	0.73%	S&P Investment Grade	3.05%	1.89%
Green Labelled	4.54%	0.87%	S&P Investment Grade	3.05%	1.89%
Energy	6.16%	0.90%	S&P Public Power	2.96%	1.98%
Transport	4.99%	1.04%	S&P Transport	3.71%	2.20%
Water	5.32%	2.34%	S&P Water & Sewer	3.36%	2.10%
ARRA	5.60%	0.44%	S&P BAB	5.26%	6.09%
CA	6.17%	1.56%	S&P CA	3.47%	2.07%
NY	5.31%	1.37%	S&P NY	3.22%	1.87%
MA	4.48%	1.08%	S&P MA	2.84%	1.86%
WA	5.90%	1.31%	S&P WA	2.82%	1.98%
TX	4.49%	1.37%	S&P TX	3.08%	1.94%

Table 8: Compound Annual Growth Rate and annualised volatilities for the period spanning October 2014 to October 2017.

Climate Index	S&P Muni Index	Tracking Error
Climate Aligned	S&P Investment Grade	1.45%
Green Labelled	S&P Investment Grade	1.49%
Energy	S&P Public Power	3.20%
Transport	S&P Transport	1.28%
Water	S&P Water & Sewer	1.96%
ARRA	S&P BAB	0.34%
CA	S&P CA	2.70%
NY	S&P NY	2.09%
MA	S&P MA	1.64%
WA	S&P WA	3.08%
TX	S&P TX	1.41%

Table 9: Tracking errors in the returns of the climate indices compared with their respective benchmarks over October 2014 to October 2017.

Index vs Benchmark	Information Ratio	Alpha%	Beta
Climate vs S&P Muni IG	0.75	4.0%	0.12
Green vs S&P Muni IG	0.80	4.0%	0.15
Energy vs S&P Public Power	1.39	3.8%	0.20
Transport vs S&P Transport	0.56	2.9%	0.10
Water vs S&P Water & Sewer	0.47	3.3%	0.12
ARRA vs S&P BAB	0.01	5.3%	0.01
CA vs S&P CA	0.95	3.4%	0.00
NY vs S&P NY	0.83	3.1%	0.02
MA vs S&P MA	0.70	2.8%	0.02
WA vs S&P WA	1.20	2.8%	0.01
TX vs S&P TX	0.53	3.1%	0.01

Table 10: The risk-adjusted relative returns (information ratio), excess returns (alpha), and correlations (beta) of the climate indices compared to their corresponding S&P benchmarks for the time span 1 October 2014 - 1 October 2017.

The biggest source of discrepancy between our climate indices and the S&P indices is that the volatilities appear to be markedly different. This is primarily attributable to the difference in the source of our pricing data: S&P prices will have come from a pricing data service, who provide constantly updated market prices. Where a bond may not have been traded for a while, these services provide matrix prices, which are fixed income prices based upon an asset's characteristics and surrounding similar assets, interpolating the relevant prices to provide a best estimate of a market price. By contrast, due to data availability, and also because we wanted to create the most rigorous index possible, we used actual transactional prices from EMMA, which are trades that have been executed, rather than interpolated prices (Kagraoka, 2005). There is also the additional difference that the climate indices are comprised of a much smaller number of constituents as compared with their S&P counterparts, which could lead to less opportunities for prices to move as there are fewer bonds trading on a day to day basis.

As shown in Table 10, the pair with the highest information ratio was the Climate Energy sector index compared with S&P Muni Public Power, with a ratio of 1.39 for October 2014 to October 2017, and a corresponding alpha of 3.8%. Climate-aligned Transport also had an information ratio of 0.56 relative to the S&P Muni Transport index, with an alpha of 2.9%. The overall climate-aligned index had a information ratio of 0.75 ($\alpha = 4.0\%$) against the S&P Muni, and the Green-Labelled index had a ratio of 0.80 ($\alpha = 4.0\%$) against the same. In terms of the state indices, the California Climate index was the strongest performer with 6.17% CAGR, with an information ratio of 0.95 ($\alpha = 3.4\%$) relative to its S&P counterpart. In terms of tracking errors, all of the climate indices posted returns greater than their benchmarks, as shown in Table 9, with the energy index showing the greatest difference from its S&P Public Power benchmark.

Table 11 shows the three-year annualised returns for the climate and green

	Climate + Green	Green only	S&P
2017-2014	4.10%	4.70%	3.40%
2016-2013	4.60%	6.90%	3.80%
2015-2012	4.80%		3.30%
2014-2011	5.80%		5.70%
2013-2010	7.00%		6.00%
2012-2009	7.90%		7.60%
Overall	5.70%	5.20%	4.90%

Table 11: Three-year annualised returns for the Climate and Green indices, along with their S&P counterparts.

indices along with the S&P Municipal Investment Grade index. The green muni index does not have three-year returns prior to 2013 since that is the year that green-labelled muni bonds entered the market. The earlier years showed stronger performance across the board, both for the climate indices and the overall muni bond market.

Overall, similar to the national muni indices, the sector sub-indices demonstrate performance that is competitive with their respective S&P counterparts. These sector subindices are quite small in terms of constituents, however their index characteristics are nevertheless comparable to their S&P benchmark counterparts (see Table 12). In terms of drawdowns (see Table 13), the overall S&P muni index experienced a 6.13% drawdown in the aftermath of the Presidential election, while the climate-aligned and green-labelled indices only incurred 3.97% and 4.62% in losses, respectively, which indicates some additional resilience against policy risk in the overall climate indices. However, the index that incurred the largest drawdown of 10.93% was the climate energy index, compared with only 5.5% for the S&P Public Power index. This is unsurprising that the climate energy index saw the largest drawdowns (see Table 13) when considered in the context of expected changes in green energy policies as a result of the Trump administration coming to power. Overall, however, the other sector indices exhibit drawdowns greater than their S&P benchmarks, indicating that investing in more sustainable infrastructure via green and climate-aligned muni bonds can in some contexts expose the investor or issuers subject to additional losses from increased policy risk. Interestingly, the aggregated overall indices show resilience against this, exhibiting smaller drawdowns.

Figure 5 shows the rolling information ratio calculated for the climate-aligned and green-labelled indices benchmarked against the S&P muni index. There is a considerable increase in the information ratios at the end of 2016, which corresponds to the only period of time at which these indices experienced significant losses within the timeframe being considered. Inspection of the index returns plots (Figures 2, 3, and 4) shows that this corresponds with a downturn in the overall market that occurred at the time of the presidential election in early November 2016. The entire municipal bond market was affected by these election results, however we were interested to compare the drawdowns across the climate indices with their S&P counterparts.

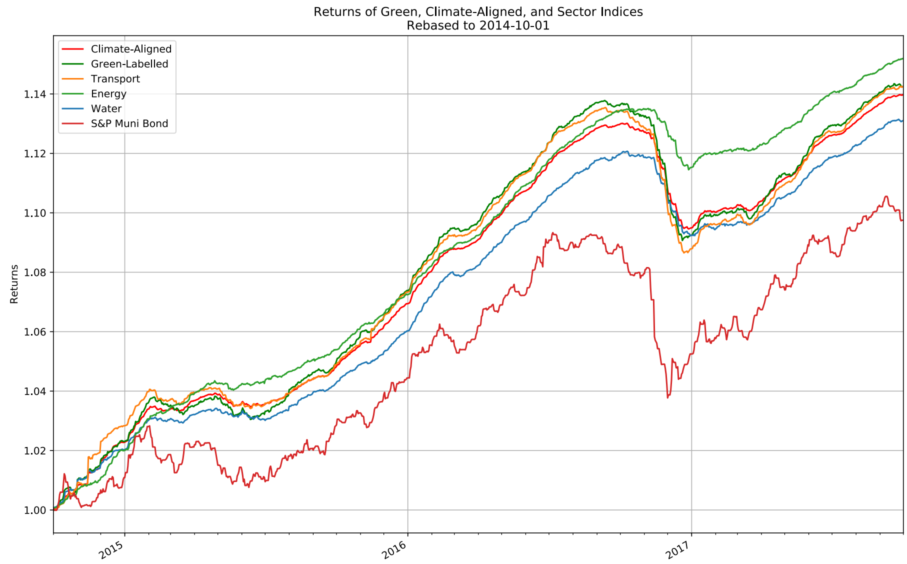

Figure 3: Green municipal indices by sector for Energy, Transport, and Water, along with the overall climate-aligned and green-labelled muni indices, and the S&P municipal index.

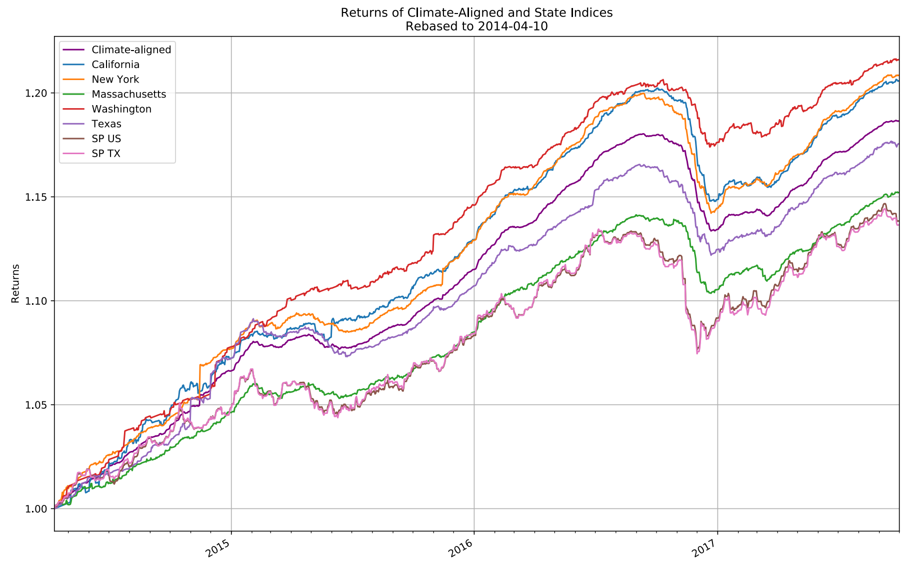

Figure 4: Green municipal indices by state, and their corresponding state S&P municipal index.

	Energy	Water	Transport	ARRA
# Constituents	147	214	456	632
Total Value ($M)	1,259	2,540	11,453	9,888
Yield to Maturity	3.28%	2.98%	2.50%	2.50%
Par Weighted Coupon	4.73%	4.68%	4.53%	4.97%
Weighted Avg Maturity (yrs)	15.32	14.8	13.58	16.14
	S&P Power	S&P Water	S&P Transport	S&P BAB
# Constituents	4,442	10,937	10,273	6,684
Total Value ($M)	61,701	107,831	229,948	147,811
Yield to Maturity	3.02%	3.20%	3.35%	4.04%
Par Weighted Coupon	4.68%	4.61%	4.50%	6.06%
Weighted Avg Maturity (yrs)	11.61	14.75	14.57	17.99

Table 12: The climate sub-sector index characteristics along with their S&P counterparts.

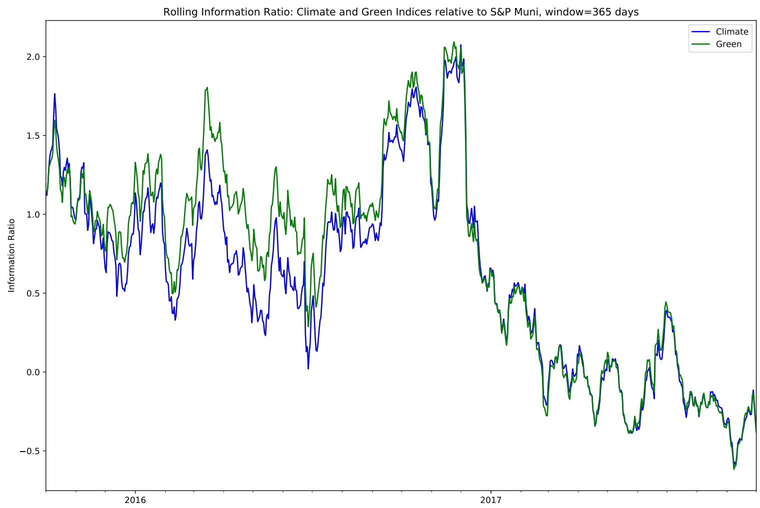

Figure 5: Rolling information ratio for the climate-aligned (blue) and green-labelled (green) indices benchmarked against the S&P Investment Grade Municipal index with a window size of 365 days.

Index	Drawdowns
Climate	3.97%
Green	4.62%
Energy	10.93%
Transport	8.01%
Water	5.28%
ARRA	5.68%
S&P Muni	6.13%
S&P Public Power	5.50%
S&P Transport	7.11%
S&P Water and Sewer	6.68%
S&P BAB	8.00%
Average	6.46%

Table 13: Drawdowns experienced in the aftermath of the Presidential election in the last quarter of 2016.

Table 13 shows the drawdowns that occurred in the aftermath of the election for the fourth quarter of 2016. The overall S&P muni index experienced a 6.13% drawdown, while the climate-aligned and green-labelled indices only incurred 3.97% and 4.62% in losses, respectively. However, the index that incurred the largest drawdown of 10.93% was the climate energy index, compared with only 5.5% for the S&P public power index.

Due to the fact that green bonds and green municipal bonds are such a new asset class, it is unfortunately not possible to investigate their long-term performance over a timeframe beyond five years. It is also worth noting that all of the assets in the green muni and fossil fuel muni indices have long maturities, so no portfolio allocation analysis or rebalancing was performed. This was done explicitly so as not to introduce any investment strategy or optimisation in order to get a broad and unbiased view of market activity. If the index portfolios were actively managed or optimised, they would be likely to produce higher returns.

As a caveat, we need to observe that this analysis via index benchmarking only gives insight into the secondary market rather than into the primary issuance market. Nevertheless, if green muni bonds are trading at higher prices in the secondary markets, that indicates that the buyers may be willing to accept lower primary yields in return for greener investments, which leads to a cheaper cost of capital for issuers. As stated by Chiang (2017), "pricing reflects supply and demand, and any developments that fuel demand could cause green bond yields to fall." We explore this issue in depth in our complementary paper, Partridge and Medda (2018), the findings of which are consistent with the results of our index benchmarking. Additionally, this work supports the previous findings of a green secondary premium in the corporate green bond market (Preclaw and Bakshi, 2015; Beaumont and Kinmonth, 2017; Bos et al., 2018) and in the municipal market (Baker et al., 2018). On the issuer side, if a green premium can be found in the primary markets, this could lead to a cheaper cost of borrowing and therefore save taxpayers money (Stringer, 2015; Chiang, 2017).

There is more work to be done to explore any correlations between bond activity and local employment rates and/or state GDP. In particular, there has been extensive discussion about linking green infrastructure development with "green collar" jobs (Yi, 2013; United Nations Environment Programme, 2008; United States Dept. of Energy, 2017). The stimulus of a new skilled employment sector could be a positive externality from investing in green infrastructure, along with improvement in sustainability and resilience for American cities.

8 Conclusion

In this analysis, we have argued that green municipal bonds could be one of the best possible ways to increase the momentum of ESG (Environmental, Social, and Governance) investment (Fulton and Capalino, 2014; The New Climate Economy, 2016; Saha and D'Almeida, 2017). However until recently it has been impossible to benchmark their performance due to lack of data. Furthermore, the uptake of green muni bonds in the US is currently hampered by a "combination of sporadic deal flow, small offering size, index ineligibility, illiquidity, and lack of standardization that limits market activity" (Chiang, 2017). Therefore, we undertook a survey of the market and the construction of green and climate-aligned municipal bond indices to investigate whether, over the considered time period, the green sector of the muni bond market is competitive with the conventional muni bond market.

The findings from this work demonstrate that green and climate-aligned municipal bonds in the US are competitive in the secondary markets with traditional non-climate-aligned muni bonds, and in our benchmarking analysis, actually outperformed the market. The Climate and Green indices both saw returns of 4.5% from 2014 to 2017, compared with a CAGR of 3% from the S&P Investment Grade Municipal Bond Index. The Energy, Transport, and Water sector subindices posted similar returns of around 5% over this timeframe, compared with about 3% from the S&P sector indices (see Table 8). The state climate indices also outperformed their S&P state index counterparts by about 2% on average. When the climate indices are benchmarked directly against their S&P counterparts in order to calculated their Information Ratio, the resulting values range from 0.01 to 1.39, with alphas ranging from 2.8 to 5.0%, as shown in Table 10. The overall climate indices also exhibited smaller drawdowns than the S&P index, however as shown in Table 13, the sector subindex drawdowns were greater.

The limitation of our risk-adjusted returns is based on the fact that our index is based on actual transaction prices rather than matrix pricing, which leads to the appearance of lower volatility in our climate indices, however their trends and overall performance can still be compared. There is additionally a need to update all of the pricing data for the bonds in the data sets, and also to update the data sets with green and climate muni bonds that have been issued since 2016, along with back filling the climate-aligned bonds for the years prior to 2014.

Notwithstanding, given the infrastructure gap that is present in the United States (American Society of Civil Engineers, 2016), and the particular need for sustainable infrastructure in American cities, the conclusion that can be drawn from our analysis is that the green municipal bond market may be an important and effective financial mechanism to allow investors to foster sustainable development without sacrificing financial returns.

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