Green Premium in the Primary and Secondary US Municipal Bond Markets

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Abstract

Green municipal bonds are a growing segment of the US municipal bond market. As they face increasing demand, there have been questions about the performance of green muni bonds relative to their conventional counterparts. In this paper, we perform yield curve analysis on a selection of green-labelled muni bonds that were issued at the same time as conventional muni bonds by the same issuers. We further refine this down to a pair-wise analysis to check the yield differential between pairs of bonds that are identical except for the green label. We find that there is a growing trend towards green premium in both the primary and secondary markets in both the series trend analysis and in the pair-wise analysis.

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).

At present, investors and issuers have increasingly become aware of perceived or actual additional costs incurred as part of issuing a green bond. The

presence of a green premium, or "greenium" in the green bond markets could help compensate for these costs. A green premium occurs when a green bond is priced higher, with lower corresponding yield, than equivalent conventional "vanilla" bonds.

Greenium is essential to some market players, since on the issuance side, higher prices and lower yields at time of issue translate to lower costs of capital, thereby offsetting some or all of the additional expenses of disclosure. On the investor side, a greenium may reduce the yields for the bond holder, but rising prices in the secondary market mean that they could more easily sell the green bonds on at profit. However, the Climate Bonds Initiative (2018) pricing report explains that "intuition suggests that a bond being green should not influence its price. Green bonds rank pari passu (on equal footing) with bonds of the same rank and issuer. There is no credit enhancement to explain pricing differences, and issuers of green bonds do incur minimal additional costs."

The presence of a greenium in the secondary market could lend pressure to primary market prices, since secondary market prices are an indicator of what the market will bear. As stated in the latest CBI pricing report (Climate Bonds Initiative, 2018), "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," however, "a secondary green curve does not guarantee a greenium." Nevertheless, "the secondary market structure seems to have the potential for increasing the green bond issuance and offering a primary yield which is slightly lower than that observed on the conventional bond curve" (Zerbib, 2016). Greenium is fundamental for making or breaking the green bond market, and that is why this research focuses on the detection of greenium in the US municipal bond market through yield curve analysis.

The important information that a yield curve gives is a snapshot of the performance of a particular set of bonds at a specific time, which enables one to see which bonds are selling at a discount (falling above the yield curve, since prices are inversely proportional to yields), and which ones are selling at a premium (falling below the yield curve). For this reason, in this work we have used yield curve analysis to look for trends in how green muni bonds perform, and in particular whether or not they exhibit a green premium, or "greenium", both at time of issue in the primary market and later on for seasoned bonds in the secondary market.

In the next section, we briefly review other pricing studies which have examined the green bond market and the green premium. and in Section 3, we describe our data collection and some preliminary analysis. In Section 4, we perform a preliminary liquidity comparison between our green and vanilla bonds, and in Section 5 we describe our yield curve analysis methodology. The results of this analysis are given in Section 6, and the discussion and conclusions are in sections 7 and 8.

2 Green Bond Market Review

While 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), 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. At time of writing, no publications were available that provided an assessment of greenium in the primary muni market. Because this particular area of research is very new, there is a paucity of literature in the academic context, however there are a few reports that have been published stating that they have found a greenium signal in the secondary green bond markets. Preclaw and Bakshi, from Barclays (2015) found that, at the time the report was issued, "green [corporate] bonds trade a statistically significant 17bp tighter in OAS after accounting for their other characteristics". Overall, they state that "investors are currently paying a premium to acquire green bonds, at least in the secondary market [...] which we see as partly attributable to opportunistic pricing based on strong demand from environmentally focused funds." The implications of these findings are that "investors and their sponsors will need to consider exactly how much they are willing to pay to be green."

Another early report about green bonds released by Natixis (2014) also disclosed a potential primary greenium of "between 2bp and 6bp over the secondary spreads of these same issuers for similar maturities". Moreover, they also checked the volatility and found that green bonds were equivalent to the non-green. Then, in 2016, Zerbib found a green bond premium across 118 bonds issued from early to late 2016, especially in bonds with a rating strictly below AAA (-6.70%) and those emitted in Euros (-8.47%)" (Zerbib, 2016). This paper raises a particularly interesting point in that "while a negative premium favors the issuing of green debt, it subdues the appetite of investors that are not compelled to dedicate part of their balance sheets to the purchase of green assets. If the equivalent conventional debt gives greater yields, green debt will be forsaken by those investors who do not have to meet any green investment obligations."

In 2018, NN Investment Partners issued a report titled "Unravelling the Green Bond Premium" (Bos et al., 2018), where they found a greenium in the secondary market of 11bps. Additionally, the Climate Bonds Initiative has released a series of reports about green bond pricing in the primary market, the most recent of which was released in February 2018 (Climate Bonds Initiative, 2018) and found that in a sample of 12 green bonds, 2 bonds exhibited a greenium at issue, 4 bonds exhibited lack of a new issue premium (or possible greenium), and 6 bonds had neither. Their previous report from Q2 2017 (Climate Bonds Initiative, 2017) found that 2 bonds exhibited a greenium, 2 lacked a new issue premium, and 6 had neither.

There are only two papers or reports that have been published so far that deal with green premiums in the green municipal bond market. The first was published by Karpf and Mandel (2018), who performed an analysis to look for

a price premium in the secondary green muni bond market by looking at the yield spreads between green and conventional muni bonds. They found that "the overall mean spread in returns between conventional and green bonds is 0.23; that is, 23 basis points." 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. Their pricing data came from the same source that we used in our analysis: the EMMA MSRB database (Municipal Securities Rulemaking Board, 2018). The drawbacks to their method are that their data is not as comprehensively or rigorously screened as our dataset for "greenness", and in particular they do not consider climate-aligned but unlabelled bonds at all. Furthermore, they analyse the yield spreads on an annual average basis, but this loses much of the intraday pricing movements and trends, rendering any nominally annualised yield trends less significant because the timeframe of the analysis is not granular enough.

Baker et al. (2018) looked at 2,083 green municipal bonds along with 643,299 conventional municipal bonds, all issued between 2010 and 2016. As in the previous paper, their green labeled bonds come from Bloomberg, and they do not provide any breakdown for climate-aligned bonds. However, they focused on performing a fixed effects regression on the green muni bonds to determine whether or not there was a green premium in the primary market, and indeed found a greenium of about 6 bp at issue.

In our previous work (Partridge and Medda, 2018), we describe the creation and performance analysis of a green and climate-aligned municipal bond index. This work found that over the period spanning October 2014 - October 2017, the green and climate municipal bond indices outperformed their counterpart S&P municipal bond indices in terms of returns. We also found that the green and climate indices experienced smaller drawdowns than the S&P indices in the aftermath of the 2016 presidential election.

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 – something few issuers would be willing to do." However, this is not uncommon in the US municipal market, which is why we chose to focus our analysis on this market in particular. None of the previously mentioned pricing studies have used the data available to compare green labelled bonds with their "vanilla" direct counterparts. Our analysis focuses on like-against-like pricing comparisons across a collection of green muni bonds and their unlabelled contemporaries issued at the same time by the same issuer..

3 Data

In order to explore the pricing difference between green and unlabelled ("vanilla") muni bonds, we constructed a data set that was comprised of all the green-labelled municipal bonds that have ever been issued in the US in conjunction with vanilla bonds. Unlike the rest of the global green bond market, it is not uncommon for US municipal bonds issuances to be a mix of "green" and "vanilla".

This means that our dataset gives us the unique ability to quantitatively and rigorously check for greenium in this market.

Because municipal bonds are generally issued in series, with the same official statement and use of proceeds covering each series of bonds, this aspect of the market gave us the unique opportunity to be able to compare the yields of green bonds with their direct vanilla counterparts. Therefore, we collected a set of muni bonds from EMMA (the Electronic Municipal Markets Access database run by the MSRB (Municipal Securities Rulemaking Board, 2018)) where an issuer has issued one or more green bonds in the same series (at the same time) as one or more vanilla bonds, where they are covered by the same Official Statement. This enables us to compare like with like, because the bonds are grouped into green/vanilla series with the same issuer, same credit rating, and same time of issue. Within those series, the individual bonds will have different issue amounts, coupons, and tenors, along with their differing green statuses. We found 50 series of muni bonds issued between June 2013 and January 2018 that include both green and vanilla bonds, covering a total of 1,530 bonds, 716 of which were green. The green/vanilla pairs and their containing series are all investment grade, as shown in Table 2. The tenors of these bonds are shown in Table 3, and the amount of issuance by sector is shown in Table 4.

Overall, 1,215 bonds were located where there were more than five vanilla and green counterparts within the same issue, totalling 42 separate bond issues. Within these bonds, there were 548 green bonds, and 667 vanilla. Of the 1,215 bonds, 56 green bonds exhibited a premium at issue (10.22% of the green bonds), compared with 29 vanilla bonds (4.35% of the vanilla bonds). The average initial price for the greenium bonds was 118.08 ± 4.52, and for the bonds with vanilla premiums, it was 117.63 ± 4.30. Overall, there were twice as many green bonds issued with a premium compared with the vanilla bonds. Furthermore, their price premium was slightly higher, however only by one cent.

This data set (Table 1) was further restricted down to 521 pairs of green and vanilla bonds where the pairs had the same issuer, use of proceeds, issue date, maturity date, and coupon. This enabled us to be able to directly compare the yields of green and vanilla bonds and eliminate differences in credit and duration risk. However, there was a slight difference in the issue sizes, with the green bonds having a total issue size 108% that of the vanilla bonds. Nevertheless, this data set is the only known green bond data set of this size and homogeneity which allows our pricing analysis to have an unusual degree of rigour, most since the other pricing studies are restricted by lack of comparable issuance. 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 the strict pairings case or at a minimum, contemporaneous assets in the series case.

It was important to ensure that the bonds in the data set had the same tax status, because tax advantages are frequently given to muni bond issuances, which influences their effective yields: what may look like a higher yield tax-exempt bond may end up having the same effective yield as a taxable bond

Bond Data Set	Number	Issue Amt $M
Green Series Bonds	548	5,279
Vanilla Series Bonds	667	8,255
Green Bonds from Pairs	521	3,081
Vanilla Bonds from Pairs	521	2,846

Table 1: The number of bonds and their volumes in the data sets spanning January 2015 to October 2017.

Rating band	Num Pairs	Num Bonds
AAA/Aaa	191	664
AA+/Aa1	224	612
AA/Aa2	260	714
AA-/Aa3	185	429

Table 2: The ratings bands for the green/vanilla muni bond pairs, and for the total green/vanilla data set, of which all are at least A-rated. All of the bonds in this data set have been rated, and some bonds have both S&P and Moody's ratings so they could appear twice in the totals.

once these discounts are included in the lifetime cashflow of the bond. Therefore, 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 the yield curve analysis.

4 Liquidity

As a check 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 bonds serving as proxy for the non-green bonds). While 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

Tenor	Num	Issue Amt $M
<1	31	112
1-5	251	1125
5-10	405	2040
10-15	345	2600
15-20	281	2187
20-25	130	2206
25-30	57	2530
30-35	31	1347

Table 3: The tenors by number of bonds and amount of issuance broken into five year bands.

Sector	Amount Issued ($M)	Number
Transport	$438	65
Water	5,458	509
Energy	5,358	664
Multi-sector	2,153	119
Waste and Pollution Control	415	94
Natural Capital	161	79

Table 4: Issuance broken down by sector.

Bond Data Set	Issue Amt $M	Index of Martin	Normalised	Green/Vanilla Ratio
Green Series Bonds	5,279	7.31	1.28	
Vanilla Series Bonds	8,255	9.98	1.21	1.06
Green Bonds from Pairs	3,081	4.55	1.48	
Vanilla Bonds from Pairs	2,846	4.38	1.54	0.96

Table 5: The volumes of the bonds in the aggregated data sets spanning January 2015 to October 2017. The Index of Martin has also been normalised by the total issue amount of assets in each basket, and the ratio of these values for each green/vanilla paired dataset is shown.

(Baker and Filbeck, 2015) as a volume and price-based proxy for liquidity for the green-labelled vs unlabelled bonds in our sample.

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

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

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.

As can be seen from Table 5, the Index of Martin value is lower for the green series bonds that we used to calculate the yield curves. For the green + vanilla series bonds, the number of bonds are evenly divided between green ($n = 712$) and vanilla ($n = 779$). In this set of bonds, the green bonds had a lower Index of Martin of 7.31 compared with 9.98 for the vanilla bonds. After normalising by total issue amount, the green/vanilla ratio is 1.06, nearly at parity. When we focus only on the strict green/vanilla pairs of bonds within this dataset, the green bonds have a slightly higher Index of Martin value of 4.55, whereas the vanilla bonds have 4.38. When normalised by issue amount, the green/vanilla ratio is 0.96. In this dataset, the bonds in each basket are identical except for the label status, and the average issue amount of the green bonds is 8% larger than the vanilla bonds.

5 Yield Curve Analysis

We used the dataset that was created as described in Section 3, comprised of contemporaneous green and vanilla bonds, to construct yield curves in order to investigate whether the green muni bonds in this data set exhibited a green premium ("greenium"). The hypothesis to test is if there is a pricing difference between this set of green municipal bonds and a set of their conventional "vanilla" equivalents. If a green bond has a greenium, it has lower yields, and correspondingly higher prices, than the "surrounding" vanilla bonds, indicating that investors are willing to make a tradeoff between yield and a green label. In this data set, the green and vanilla bonds in each series are issued at the same time by the same issuer and covered by the same Official Statement, which is important since this makes them more directly comparable.

Once the relative liquidity of the green vs conventional muni bond markets was established as described in Section 4, we then used the aggregated yields to construct yield curves for both green and vanilla bonds. This was done with the initial yields at issue for the primary market, and by using secondary market prices to investigate performance after issuance. The yield curves were constructed following established practice using the Svensson technique, an extension of the Nelson-Siegel method of construction (Svensson, 1994; Nelson and Siegel, 1987).

The data that we used for the NSS yield curve modelling consisted of the traded market price yields for the set of green + vanilla simultaneous bond issuances. We first used the strict green-vanilla pairs so that we were comparing like with like to the greatest extent possible in order to perform a preliminary matched pair analysis. However, because this pair data set is more limited than the overall green-vanilla series data set, we also performed the same yield curve analysis on the wider series data. There were a total of 50 green+vanilla series, however eight of these series had too few bonds to be able to model a Svensson yield curve, which requires at least 5 points in order to perform a best fit. While some of the series yield curves did indicate that some green muni bonds were issued with prices inside their yield curves, they were not sufficient to give an overall view of the market.

In order to incorporate a broader view across the full dataset, we then constructed yield curves for each month where there were a sufficient number of bonds (greater than 5) to do so. It was more relevant to sample the bonds for each month rather than for each series because the financial environment (i.e., interest rate environment) at issue is likely to change over time, and monthly sampling enabled us to build a large enough data set to construct the yield curves.

Each bond was considered in turn and had its time remaining and yield added to an aggregate list of all monthly issuances. If the bond was green labelled, it was added to a list of green issuances, otherwise it was added to a list of vanilla issuances. These lists were sorted by the time remaining and then used to create monthly yield curves using the Svensson methodology. For each month between June 2013 and January 2018, we gathered all of the bonds

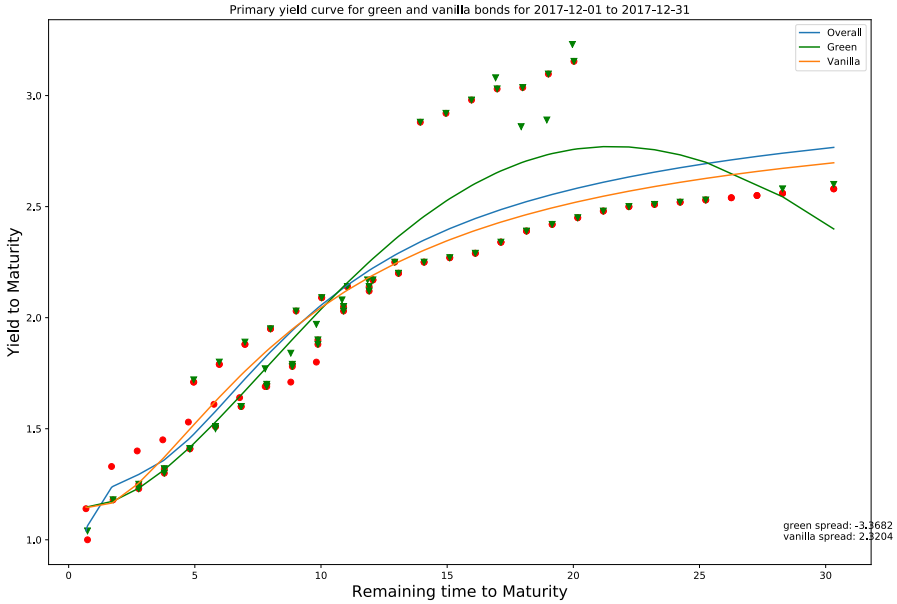

Figure 1: The aggregate primary market yield curve for December 2017.

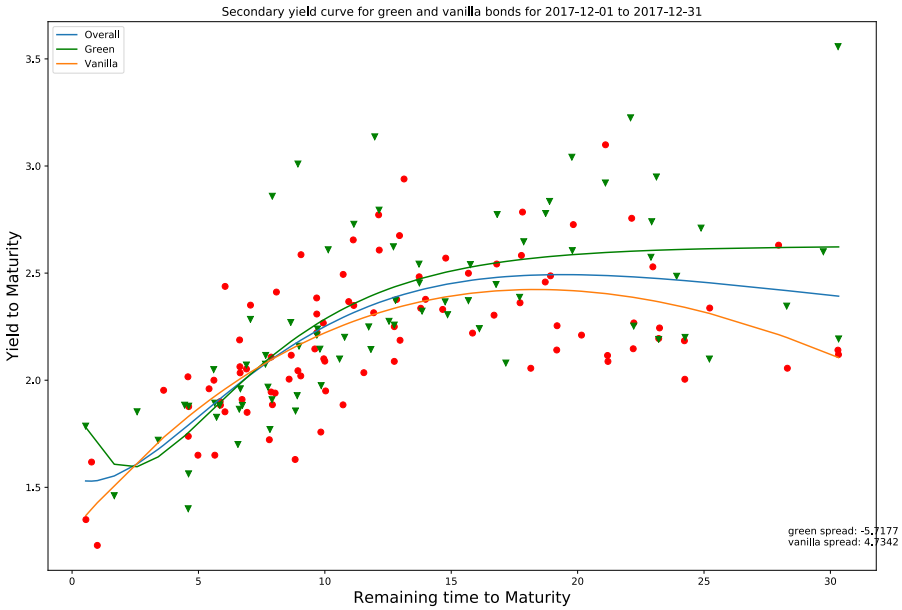

Figure 2: The yield curve for the secondary market for December 2017.

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. 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. The amount of each bond's issuance was used to weight these averages. A monthly yield curve (as shown in Figure 1) was constructed from the entire bond data set for that month, both green and vanilla, and then curves were created for the green bonds only, and the vanilla bonds only, where sufficient data ($N >= 5$) was available. There were not enough bonds in the data set to consistently create monthly primary green yield curves for comparison until the beginning of 2015.

The secondary yield curves were constructed using the final trading price of each bond per day, or the last closing price available, along with the remaining times to maturity of the bonds. We used the same method as used for the primary market, but for the secondary market we used the size of the trades to weight the average yields and time remaining. Like the primary yield curves, an overall curve was fitted for the combined green and vanilla data (as shown in Figure 2), and then green and vanilla curves were overlaid separately where sufficient data was available. The difference was found between the green yield curve and the overall yield curve, and then the vanilla yield curve and the overall yield curve, in order to quantify the yield spreads between the green and vanilla bonds. Similar to the primary yield curves, there was not enough bond data available to reliably generate monthly yield curves until the beginning of 2015.

For both the primary and secondary yield curves, we have generated an average monthly green and vanilla spread between the green yield curve for each month, the vanilla yield curve for each month, and their differences with respect to the overall aggregate yield curve. The spreads are calculated by iterating over each available 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 are then averaged for the month for each type (green, vanilla, overall) 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.

For the strict green-vanilla pairs, a more analytical approach was used rather than finding the spreads between NSS yield curves. Instead, 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. It was not possible to use this approach for the the larger series datasets, since in the case of this dataset, the pairs could be matched up by the time remaining on the bond and coupon, whereas similar bonds making up each series in the larger dataset may have identical time remaining, but different coupons, which is why they could not be included in the strict pairings.

We first compared the initial yield at each for each pair to see which bond had the lower yield, green or vanilla. We collected all the bond pairs issued in each

	Number	Modified Duration	Maturity	Tenor
Green + Vanilla Series	1,532	7.9	15.0	15.9
Green + Vanilla Pairs	1,062	8.0	16.3	17.5
Green-only Partners	521	7.9	16.3	17.5

Table 6: Weighted average characteristics for the green+vanilla series issuances and the strict green+vanilla pairings.

month, and then calculated the average initial yield weighted by issue size to see which class of bonds had the overall premium for each month. The difference in the average yields between the green bonds and the vanilla bonds in the pairings was measured as a spread in basis points. 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. This spread represents the total difference in price between the green bonds and the vanilla bonds, rather than measuring the distance between the green yields and the aggregate yields, and then the distance between the vanilla yields and the aggregate yields. This is because for pairs of bonds, the average would split the difference, so it is more straightforward to represent these spreads with one number, the magnitude, and a sign, representing the direction with negative indicating a stronger greenium signal (because the green yields would be lower in that case).

The advantages of this approach that there was no extrapolation or interpolation of prices, and it was based solely upon actual transaction prices. Also, it was a simple analytic approach, made possible because of the amount of green muni bond issuance data that we had available. The pair data set was smaller than the overall series data, meaning that it was not possible to generate monthly yield curves in a majority of months since they did not have the required minimum of 5 issuances, however, this technique enabled us to still be able to measure the spreads in the bond yields since even one bond pairing could have their yields compared. Additionally, this technique was equally applicable to the secondary market traded prices so that we could also examine any trend in their spreads.

6 Results of Yield Curve Analysis

Of the 1,532 bonds in the green + vanilla series data set, 47% ($n = 716$) are green bonds. 94% ($n = 1,445$) of the vanilla bonds at some point traded at a premium (where their yield to maturity is less than their coupon), and 95% ($n = 683$) of the green bonds traded at a premium. When looking at the initial offering yield, 75% of the green bonds where sold at a premium, compared with 80% of the vanilla bonds. Looking only at the bonds issued in 2017, 820 bonds were issued in this data set, 420 of which were labelled green. Of these bonds, 73% of the vanilla bonds were issued at a premium, and 69% of the green bonds were issued at a premium.

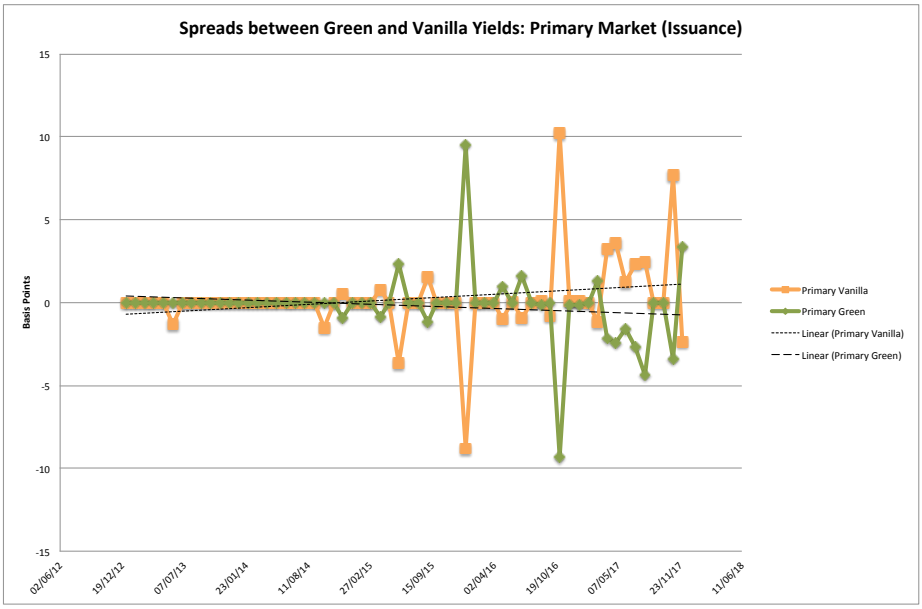

Figure 3: Spreads between the green and vanilla aggregate yield curves in the primary market.

If we narrow our view to the strict pairings of green bonds with their vanilla counterparts from the same series such that they have the same issuer, issue date, maturity date, credit rating, and coupon. The only difference between these bond pairs is that one is labelled green, and potentially the size of the bond issuance is different (although we found them to be within 8% of each other). The overall characteristics of this data set is shown in Table 6.

For these bonds, we created monthly average yield curves for all of the bonds issued in a given month, and then made yield curves for the green bonds within that set, and then the vanilla bonds in that set. This enabled us to see the overall aggregate trend in yields for each month, and then to compare the behaviour of the green bonds and the vanilla bonds with respect to the aggregate yield curve. For this analysis, the spreads are measured as the distance between the green yield curve and the aggregate yield curve, and then the vanilla yield curve and the aggregate yield curve.

The overall spread between the green and vanilla yield curves can be found by combining these spreads, since the aggregate yield curve is a combination of the two and therefore generally lies in between the green and vanilla curves. The green spreads and the vanilla spreads are averaged for each month, as shown in Table 8. The annual average spreads in the primary market show that from 2014-2016, the vanilla had the overall premium, while the green bonds were sold at a discount, whereas in 2017, the signs flipped, such that the green bonds sold at a premium of 1bp. The annual average results from the secondary market also show a trend of increasing greenium from 2015 onwards, with a difference of over 6bp in 2017.

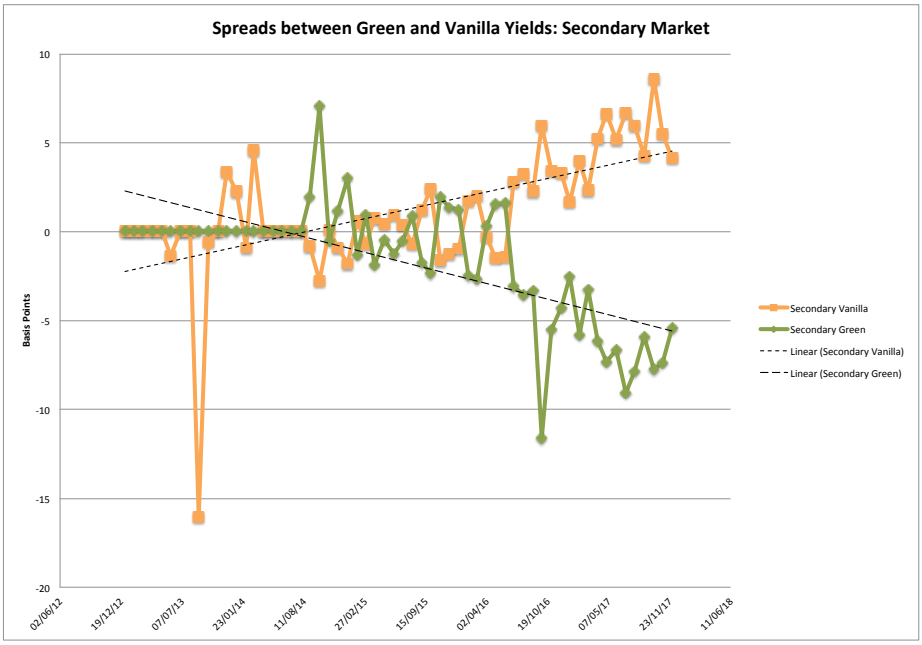

Figure 4: Spreads between the green and vanilla aggregate yield curves in the secondary market.

Year	Primary Green All	Primary Vanilla All	Primary Green Pairs	Primary Vanilla Pairs
2013	3.57%	2.12%	-	-
2014	2.63	2.12	2.26	2.20
2015	2.49	2.33	2.30	2.30
2016	2.27	2.10	2.22	2.16
2017	2.23	2.34	2.24	2.23

Table 7: The weighted average initial offering yields for the tax exempt green and vanilla bonds in the data set.

When we inspect the trend plots of the monthly average spreads in primary yields as develop over time in Figure 5, it can be seen that there is an increasing greenium price signal at issuance, especially since late 2016. Overall, the green spread trend line is relatively flat, but the vanilla trend line is sloping slightly upward, leaving room for an increasing greenium at issuance in the markets from 2018 onwards, assuming the trend holds.

The average initial yields from 2013-2017 for the full green + vanilla data set is 2.36% for the green, 2.27% for the vanilla. For 2017 only, it is 2.23% for the green, and 2.34% for the vanilla, a potential average greenium of 11bp. Looking only at the strict green+vanilla pairs (where their tenor and coupon match), the overall average initial yield is 2.29% for the green, 2.24% for the vanilla. However, for 2017 only, it is 2.24% for the green, and 2.23% for the vanilla, a difference of only 1bp.

Year	Primary Green	Primary Vanilla	Secondary Green	Secondary Vanilla
2014	0.08	-0.08	0.80	-0.14
2015	0.03	-0.11	-0.11	0.07
2016	0.21	-0.08	-2.65	1.72
2017	-1.00	1.42	-6.25	5.02

Table 8: The green and vanilla average average monthly spreads, measured as the difference between the aggregate yield curve and the green and vanilla yield curves in basis points. A negative spread indicates a premium (as in distance below the aggregate yield curve).

Year	Primary	Secondary
2014	0	0
2015	-1	8
2016	-4	5
2017	-7	-3

Table 9: The monthly weighted average spread between the green and vanilla strict pairings in basis points.

For the strict green + vanilla pairs, as shown in Table 7, the primary green bonds have exhibited a slight average greenium since data was available (2015 onwards). However, it is a fairly small difference of less than a tenth of a basis point in the annual averages. Furthermore, as can be seen in Fig. 5, the trend for this greenium for the pairs is relatively flat across time with a slope of only 0.0002. This is not a large difference, however for this set of bonds, everything about each pair is identical except for the green label and possibly the issue size. When looking at the spreads in the secondary market, there is a downward trend in the spreads present from the beginning of 2015, as shown in Figure 6, indicating a trend towards increasing greenium.

7 Discussion

We used yield curves to assess the performance of seasoned green labelled muni bonds in the secondary market relative to their vanilla counterparts. We also examined the differences in their initial offering yields compared with the yields at issue for the green and vanilla bonds in the primary market. If yields are on average lower at issuance, this would indicate the presence of greenium in the primary market, which could translate into a cheaper cost of capital for issuers. One of the points of friction for green bond issuance is the transactional costs involved in doing the additional paperwork for green assessment and reporting transparency, and issuers frequently ask if there is a pricing advantage that would help them to offset this additional cost. This is why the search for greenium has been of such importance in the corporate bonds markets, however they are hampered by lack of comparable bonds and overall lack of data.

The sheer number of muni bonds, and green muni bonds in particular, en-

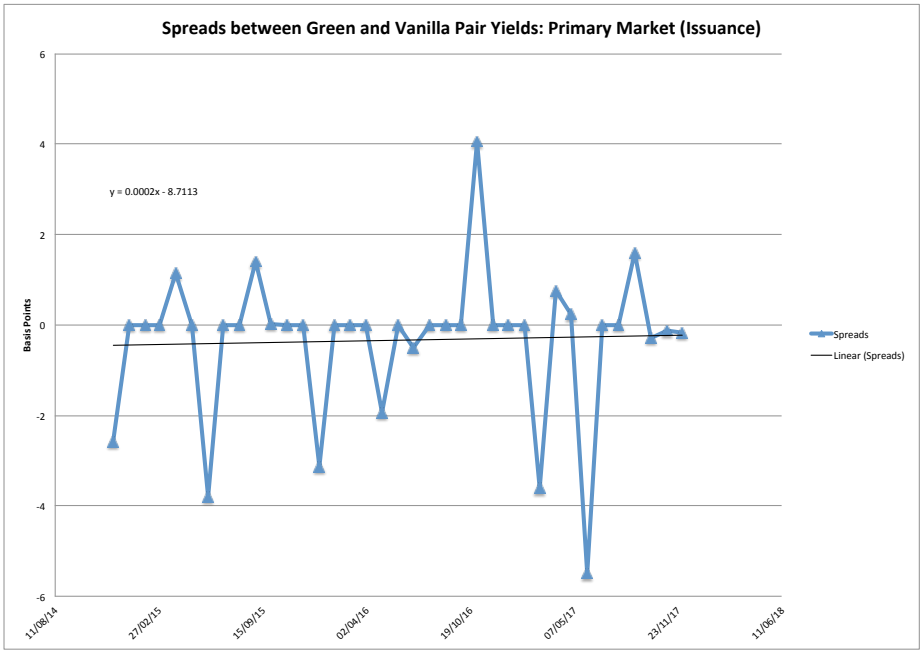

Figure 5: Spreads between the green and vanilla pairs in the primary market.

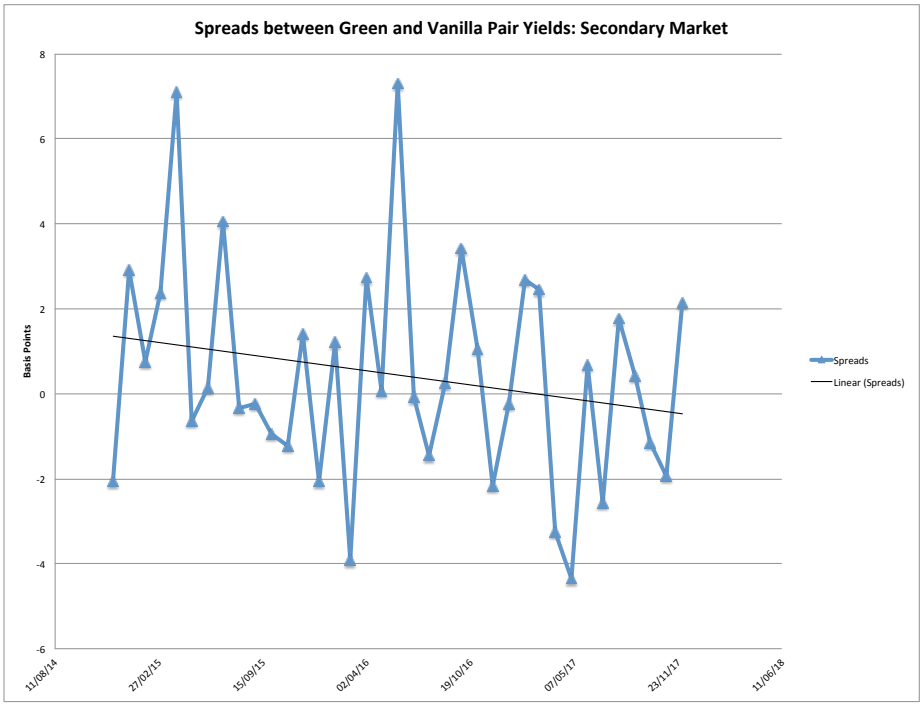

Figure 6: Spreads between the green and vanilla pairs in the secondary market.

abled us to undertake the most rigorous survey of green bond premiums so far. The volume of muni bond data also allowed us to perform a comparison of liquidities between the green and vanilla muni markets, something else that has been difficult to do in the corporate bond market due to lack of data.

When looking at the spreads in the green muni market, there is a downward trend in the spreads present from the beginning of 2015, as shown in Figures 3 and 4. It is also of note that the linear regression line crosses the x-axis, indicating an overall average greenium, in early 2017, which is also indicated in Table 8. This is consistent with our previous yield curve findings, which generally have shown a clear greenium signal from 2017 onwards. These findings are also consistent with the performance of the green and climate indices, which show especially strong returns with respect to the overall market after the presidential election in late 2016. At minimum, these spreads indicate that so far investors have been willing to pay a little more for the green labelled bonds at time of issue, or at least they have not bought them at a discount.

As stated by Michaelsen (2018), "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", which he asserts is rare. However, because of the number of issuances and sheer amount of activity in the US muni bond market, we were able to identify several instances of these, which is indeed a singularity for research in this sector. Indeed, this study is a new contribution to the literature since we completed a like-for-like analysis of green vs vanilla bonds, although a similar approach has been used for BABs (Luby, 2012). This means that our dataset gives us the unique ability to quantitatively and rigorously check for greenium in this market.

We looked specifically at the green+vanilla pair yields, where the issuer, tenor, and format are the same. For both the primary and secondary markets, we find that yields for green muni bonds are slightly lower than their vanilla counterparts. At issue in the primary market, there was an weighted average overall greenium of 4 bp, which has been increasing year on year (see Table 9. The greenium signal in the secondary market is less clear cut due to greater monthly and yearly fluctuations, however as shown in Figure 6, there is a trend towards greenium from the beginning of the data set, with an actual greenium signal materializing in late 2016. By constrast, the trend of the green spreads in the primary market as shown in Figure 5 is relatively flat, however it has consistently remained below the x-axis, indicating small but consistent greenium at issue.

Overall, the green and vanilla bond series data generally indicates a small greenium in the primary markets, and a greenium in the secondary markets that has been noticeable and increasing in the past two years, which is consistent with our findings from the green and climate indices. In the secondary markets, there appears to be an inflection point in 2015 where the overall yields for the green bonds first dipped lower than the vanilla bonds yields, and a greenium has been present since. Although the number of years of data is limited, leaving aside the strict pairings, the primary market trends seems to lag behind the secondary market trends by two years, such that 2017 is the first year on record with

a measurable greenium in the green muni markets. As this is the end of our collection of data, it remains to be seen what will happen in 2018, but if it holds consistent with the trends of the past couple of years, there could be a primary greenium of 3-5 bp. However, this could be thwarted or amplified according to surrounding policy: the tax code was changed in 2018, and the interest rate environment could change further.

The presence of a greenium in the primary market would help to lower capital costs for green infrastructure, and pricing in the secondary market could lend pressure to primary market prices, since secondary market prices are an indicator of what the market will bear. As stated in the latest CBI pricing report (Climate Bonds Initiative, 2018), "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," however, "a secondary green curve does not guarantee a greenium." Nevertheless, "the secondary market structure seems to have the potential for increasing the green bond issuance and offering a primary yield which is slightly lower than that observed on the conventional bond curve" (Zerbib, 2016).

However, conversation with practitioners has shed light on a possible shift of demand away from green bonds if there a consistent greenium does arise. This point was also brought up by Zerbib (2016), stating that "while a negative premium favors the issuing of green debt, it subdues the appetite of investors that are not compelled to dedicate part of their balance sheets to the purchase of green assets. If the equivalent conventional debt gives greater yields, green debt will be forsaken by those investors who do not have to meet any green investment obligations." This observation echoes the concerns of issuers and investors: they are almost frightened of an obvious greenium coming into the market dynamics as it could potentially trigger a flight to yield, acting as a deterrent for green bond investment.

Therefore, while at present, the existence of greenium could help foster more green bond issuance, which is key towards helping develop green and sustainable infrastructure, the market can only realistically bear a small greenium, if any, long-term. Rather than investors paying more for green bonds, if there is sufficient supply of unlabelled climate-aligned bonds, they could simply do a little more research and buy those instead at a relative discount rather than sacrifice yield for the green label. If demand is lessened for green bonds because their prices are higher, then investors will be forced to look elsewhere for more suitable investments and the prices would come down again.

8 Conclusion

Green municipal bonds could be one of the best possible ways to increase the momentum of ESG investment and close the sustainable infrastructure gap in American cities, 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 limits market activity" (Chiang, 2017). Therefore, we undertook a survey of the market and the construction of green municipal bond yield curves 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 overall findings from this work demonstrate that green and climate-aligned municipal bonds in the US are competitive with the conventional municipal bond market. Overall, the yield curve analysis indicated a small but growing greenium in both the primary and secondary markets. This yield curve analysis spanned the years 2015 to 2017, and compared green labelled muni bonds that were issued at the same time by the same issuers as conventional vanilla bonds. This enabled us to perform a like against like comparison of their yields to determine if there were any differences between the green bond prices and the vanilla bonds prices. This yield curve analysis was performed for both the primary and the secondary markets. As shown in Fig. 3, the primary market exhibits a small average greenium at time of issue compared with the vanilla bond cohort. The greenium in the secondary market, shown in Fig. 4, is even more pronounced, with a difference of about 5 bp. We also performed a like for like comparison between green muni bonds that had direct vanilla counterparts with the same terms and same issuer, and found that these bonds also exhibited an overall average greenium in the primary and secondary markets.

References

Baker, H. K. and Filbeck, G. *Investment risk management*. Oxford University Press, Oxford, UK, 2015. ISBN 9780199331963. URL https://global.oup.com/academic/product/investment-risk-management-9780199331963.

Baker, M., Bergstresser, D., Serafeim, G., and Wurgler, J. Financing the Response to Climate Change: The Pricing and Ownership of U.S. Green Bonds. *Brookings Institution*, 2018. URL https://www.brookings.edu/blog/up-front/2018/07/16/municipalities-could-benefit-from-issuing-more-green-bonds/.

Bos, B., Meinema, A., and Houkes, E. Unravelling the Green Bond Premium. Technical Report January, NN Investment Partners, London, 2018. URL https://www.nnip.com/market-matters/view/Unravelling-the-Green-Bond-Premium.htm.

Chiang, J. Growing the U.S. Green Bond Market, Volume 1: The Barriers and Challenges. Technical report, California State Treasurer, Sacramento, CA, 2017. URL http://treasurer.ca.gov/news/releases/2017/01/23_03.asp.

Climate Bonds Initiative. Green Bond Pricing in the Primary Market: Q2 2017. Technical Report January 2016, Climate Bonds Initiative, London, 2017. URL https://www.climatebonds.net/files/files/CBI-Green-Bond-Pricing-Q2-2017.pdf.

Climate Bonds Initiative. Green Bond Pricing in the Primary Market: Q3 2017. Technical Report February 2018, Climate Bonds Initiative, London, 2018. URL https://www.climatebonds.net/files/reports/greenium_q3-final-20180219.pdf.

Climate Bonds Initiative, CDP, C40 Cities, NRDC, Ceres, and As You Sow. How to Issue a Green Muni Bond: The Green Muni Bonds Playbook. Technical report, Climate Bonds Initiative, London, 2015. URL http://www.gogreenbonds.org/.

Fulton, M. and Capalino, R. Investing in the Clean Trillion: Closing the Clean Energy Investment gap. Technical Report January, Ceres, 2014. URL https://www.ceres.org/resources/reports/investing-in-the-clean-trillion-closing-the-clean-energy-investment-gap/view.

Gabrielsen, A., Marzo, M., and Zagaglia, P. Measuring market liquidity: An introductory survey. pages 1–37, 2011. ISSN 1556-5068. doi: 10.2139/ssrn.1976149. URL http://arxiv.org/abs/1112.6169.

Karpf, A. and Mandel, A. The changing value of the 'green' label on the US municipal bond market. *Nature Climate Change*, 2018. ISSN 1758-6798. doi: 10.1038/s41558-017-0062-0. URL http://dx.doi.org/10.1038/s41558-017-0062-0.

Luby, M. J. Federal Intervention in the Municipal Bond Market: The Effectiveness of the Build America Bond Program and Its Implications on Federal and Subnational Budgeting. *Public Budgeting and Finance*, 32(4):46–70, 2012. ISSN 02751100. doi: 10.1111/j.1540-5850.2012.01023.x.

Michaelsen, J. An underwriter's reflections on green bond pricing. *Environmental Finance*, pages 1–4, jun 2018. URL https://www.environmental-finance.com/content/analysis/an-underwriters-reflections-on-green-bond-pricing.html.

Municipal Securities Rulemaking Board. EMMA: Electronic Municipal Markets Access, 2018. URL https://emma.msrb.org/.

Natixis. Green & Sustainable bonds: growth with staying power? Technical Report December, Natixis, 2014. URL https://www.research.natixis.com/GlobalResearchWeb/Main/GlobalResearch/GetDocument/gFJtD_SaaSQK4sMICntHsA==.

Nelson, C. R. and Siegel, A. F. Parsimonious Modeling of Yield Curves. *The Journal of Business*, 60(4):473–489, 1987. URL http://www.jstor.org/stable/2352957.

OECD. *Mobilising Bond Markets for a Low-Carbon Transition*. Green Finance and Investment. OECD Publishing, April 2017. ISBN 9789264272316. doi: 10.1787/9789264272323-en. URL http://www.oecd-ilibrary.org/environment/mobilising-bond-markets-for-a-low-carbon-transition_9789264272323-en.

Partridge, C. C. and Medda, F. R. The Creation and Benchmarking of a Green Municipal Bond Index. *SSRN*, pages 1–29, 2018. URL https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3248423.

Preclaw, R. and Bakshi, A. The Cost of Being Green. Technical Report September, Barclays, New York City, 2015. URL https://www.environmental-finance.com/assets/files/US_Credit_Focus_The_Cost_of_Being_Green.pdf.

Saha, D. and D'Almeida, S. Green Municipal Bonds. In Kamiya, M. and Zhang, L.-Y., editors, *Finance for City Leaders*, pages 98–150. UN Habitat, 2nd edition, 2017. ISBN 9789211327663. URL http://financeforcityleaders.unhabitat.org/.

Shishlov, I., Morel, R., and Cochran, I. Beyond transparency: unlocking the full potential of green bonds. Technical Report June, Institute for Climate Economics, Paris, 2016. URL http://www.i4ce.org/wp-core/wp-content/uploads/2016/06/I4CE_Green_Bonds.pdf.

Svensson, L. E. Estimating and Interpreting Forward Interest Rates: Sweden 1992 - 1994. Technical report, National Bureau of Economic Research, 1994. URL http://www.nber.org/papers/w4871.pdf.

Zerbib, O. D. The Green Bond Premium. *SSRN*, 2016. URL https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2889690.