Green Municipal Bonds and the Financing of Green Infrastructure in the United States

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I, Candace C. Partridge, confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the work.

Abstract

Green municipal bonds are a novel way to help unlock finance for investment in sustainable and urban infrastructure in the US. However, issuance lags in the US market due to negative perceptions such as high cost, low returns, and greater risk. In this study we aim to demonstrate that US green municipal bond performance is consistent with the returns of general municipal bonds, which can improve investor confidence and increase demand. The performance of this bond sector is assessed through two different means: through the creation of a green municipal bond index and benchmarking its performance against an overall municipal bond index; and by looking for a price difference between green municipal bonds and their conventional counterparts through yield curve assessment. Increased investment in this sector could be triggered by showing that the green municipal bond sector performs similarly to, or better than, conventional municipal bonds. We found that an index comprised of green muni bonds outperforms the closest equivalent S&P index from 2014-2017, and there is a statistically significant green premium ("greenium") present in the secondary muni bond market of at least 3 basis points in 2017. There was no conclusive evidence for the presence of greenium at issue in the primary market, however there are some signs that this could change, and furthermore we do not observe that green muni bonds come to market at a discount. These results are key to encouraging growth in the green municipal bond market, which can help American cities to target ESG and SRI investors and unlock more capital for green and climate-aligned infrastructure projects.

Impact Statement

The research that was undertaken for this thesis focused on green municipal bonds, which are bonds that are used to finance sustainable infrastructure. This work is inherently beneficial to society because it shows examples of where these types of bonds are being used effectively to create more sustainable development and cut emissions. It also performs a survey of this market to uncover the depth of the market and trends in market development. Finally, it explores any pricing differential between these green bonds and conventional bonds to show that investment in sustainable urban infrastructure via these mechanisms does not necessarily have to cost bond issuers more, and if anything, could potentially save them (and taxpayers) money through a cheaper cost of capital.

The market survey and findings, along with the overview of policy mechanisms, are all of practical use to both policy makers and to investors who are interested in increasing their sustainability platform. For policy makers, the business cases demonstrate workable financial models that can be adapted for use in many contexts. For investors, the findings show that they may, in the end, have to pay a bit more for green bonds, however this also demonstrates that these bonds have held their value over time, and can be more resilient to market downturns.

This is one of the first complete overviews of the green bond market, and more specifically the green municipal bond market. It uses multiple techniques to analyse the data set, which is uniquely comprehensive and curated to best reflect the state of the market. The unique contributions of this work include the creation of a green municipal bond index, along with a yield curve analysis that has not been undertaken to such depth for this segment of the market until now.

This thesis could potentially help to encourage more green bond issuance for sustainable urban infrastructure by demonstrating that this is a market that is seeing solid growth and gains, with benefits both for issuers and investors, and therefore to the world at large.

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List of Abbreviations

ABS.......Asset-Backed Security

ARRA.......American Recovery and Act Reinvestment Act of 2009

BAB..Build America Bond

bp..basis points, 1bp = 0.01%

CREB.......................................Certified Renewable Energy Bond

ESG..Environmental, Social, Governance

ESCO..Energy Services COmpany

EMMA..................Electronic Municipal Markets Access website

GBP..Green Bond Principles

MUSH............Municipal, University, School, Hospital (buildings)

PACE..Property Assessed Clean Energy

QECB...................................Qualified Energy Conservation Bond

SREC......................................Solar Renewable Energy Certificate

SRI..Socially Responsible Investment

ZTDs...Zero Traded Days

Chapter 1

Introduction

In 2007, the Stern Review stated that climate change was the single biggest market failure. This report delivered the stark message that failing to act on climate change would result in a 20% reduction in global economic growth, and calculated that, at that time, every tonne of CO_2 being emitted caused damage valued at over $85 (Stern, 2007).

These findings helped to pave the way to the Paris Agreement in 2016, when 195 countries committed to keeping the increase in global temperature to within 2C above pre-industrial levels. Furthermore, it signals their commitment to "making finance flows consistent with a pathway towards low greenhouse gas emissions and climate-resilient development" (UNFCCC, 2017). This agreement was groundbreaking because it was the first time that a many nations committed to reducing their carbon emissions in an attempt to slow the pace of global warming and mitigate the worst effects of climate change.

However, in 2017, the then-new Trump administration withdrew the United States from the Paris Agreement, stating that it would render the US non-competitive in economic terms (Rucker and Johnson, 2017). The withdrawal caused much consternation both in the US and internationally due to the fact that the US has one of the largest carbon footprints of any nation in the world and is responsible for nearly 15% of global CO_2 emissions (The World Bank, 2018). In reaction to the statement to withdraw, several American cities and institutions banded together and announced that they would still independently meet their Paris Agreement commitments, under organizations such as We Are Still In and The United States Conference of Mayors (We Are Still In, 2017; United States Conference of Mayors, 2017; Bloomberg and Pope, 2017).

Localized commitment by cities to climate action could conceivably enable the US to honor the spirit of the Paris Agreement by cutting emissions on a local, rather than national, level. This movement demonstrates the power that federalism still has in the US, where frequently legislation is driven by bottom-up rather than top-down political will (Rabe, 2018). Even more importantly, this form of climate federalism in the US further demonstrates the rise of power of cities in an increasingly urbanised world. Rather than being dictated to by what they perceive to be an increasingly out-of-step national regime, individual American cities and states are instead creating their own mandates for sustainable development.

Accordingly, the Fourth National Climate Assessment recently issued by the US Global Change Research Program (2018) states that "cities across the United States are leading efforts to respond to climate change." This report warned that if climate change is allowed to happen unchecked, then the resulting damage will cost the US as much as 10% of the national GDP by 2100, which is more than double the losses incurred in the Great Recession of 2008, with damages including "$141 billion from heat-related deaths, $118 billion from sea level rise and $32 billion from infrastructure damage by the end of the century, among others." Overall, almost two million labor hours are forecast to be lost every year by 2090 due to temperature extremes, which will cost $160 billion in lost wages by 2050. In agreement with the Stern Report, this report concludes that without a significant effort to cut emissions and improve climate mitigation and adaptation, "substantial losses to infrastructure and property would impede the rate of economic growth over this century."

The Climate Assessment (2018) dedicated an entire chapter to the vulnerabilities of and effects of climate change to cities in the US. It states that climate change can "exacerbate existing challenges to urban quality of life, including social inequality, aging and deteriorating infrastructure, and stressed ecosystems," and that "damages from extreme weather events demonstrate current urban infrastructure vulnerabilities."

At present, over half of the world's population lives in urban areas with this proportion expected to increase to 66% by 2050 (United Nations, 2014). The US is already one of the most urbanised regions with 82% of North Americans living in urban areas (United Nations, 2014). At the same time, cities are the source of around 75% of carbon emissions from energy use (Seto et al., 2014). Due to the energy intensive nature of cities, reports have stated that we can cut global carbon emissions by 30% if we invest in energy efficiency, demand reduction, and sources of renewable energy for urban areas (Gouldson et al., 2015). Cities are very frequently situated on coastlines or other bodies of water, which leaves them most vulnerable to the primary effects of climate change, notably rising sea levels and increasingly severe impacts from major storms. Furthermore, the interconnected nature of urban infrastructure means that there is a need for "reliable infrastructure that can withstand ongoing and future climate risks," because damage to these systems will "adversely affect urban life" (US Global Change Research Program, 2018). Therefore, while it is in the world's interest for cities to cut their emissions, it is particularly in the interest of the cities themselves to try and stave off climate change, because they will be among the first and most severely impacted.

More sustainable infrastructure (also known as "green infrastructure" in this work) for cities that addresses the issues of energy and water consumption, along with cutting emissions and improving resilience against natural disasters, is key to mitigating climate change. In 2016 in the United States, transportation was the source of over 28% of greenhouse gas emissions, and electricity generation was responsible for another 28.4%, so decarbonizing these two sectors alone would make a considerable impact on the carbon budget (US Environmental Protection Agency, 2018). The IEA estimates that "an additional $36 trillion in clean energy investment is needed through 2050 or an average of $1 trillion more per year compared to a 'business as usual' scenario over the next 36 years" (OECD, 2017b; IEA, 2016). A New Climate Economy report (2016) states that it will take $93 trillion to decarbonize global infrastructure, with $8 trillion needed in the U.S. alone (Heal, 2016).

In 2017, the OECD stated that "recent estimates suggest that approximately USD 93 trillion in infrastructure investment will be needed in the next 15 years in a 'low-carbon' scenario" (OECD, 2017a,b).

Currently the majority of infrastructure in the United States is outdated and was not built with sustainability or resilience in mind. Every four years, the American Society of Civil Engineers publishes a report card that gives a quality rating for each sector of existing infrastructure. Overall, in 2017, they rated the infrastructure in the US as a D+, one grade above failing, meaning it is generally "poor and at risk" with a "strong risk of failure" (American Society of Civil Engineers, 2017). As stated in their latest report, "most electric transmission and distribution lines were constructed in the 1950s and 1960s with a 50-year life expectancy, and the more than 640,000 miles of high-voltage transmission lines in the lower 48 states' power grids are at full capacity," and this is all while facing "increasing demand, as well as increasing storm and climate impacts." Transit, a sector that particularly has an impact on both emissions and livability of the urban environment, was rated as D-, because "the nation's transit systems have been chronically underfunded resulting in aging infrastructure and a $90 billion rehabilitation backlog."

Globally, infrastructure has been underfunded, resulting in a situation known as the infrastructure gap (Inderst, 2013; Subacchi et al., 2014). In the United States specifically, there is a $5 trillion USD shortfall in infrastructure investment through 2040 (American Society of Civil Engineers, 2016), and failing to address the problems arising from increasingly dilapidated infrastructure will cost the US economy nearly $4 trillion in GDP by 2025. In addition to mitigation of climate change and emissions reduction, investment in more sustainable infrastructure will also help to improve work force efficiency and living standards (McNichol, 2017). However, most cities barely have the resources to maintain their infrastructure, much less invest in new. The 2018 budget that was approved by the Trump administration consisted of "tax credits to private-sector investors, which would boost investment in projects that will generate revenue like tolls or user fees (such as new roads and bridges) but leaves out maintenance of existing roads, bridges, and water lines, and

Cumulative Infrastructure Needs by System Based on Current Trends Extended to 2025 (dollars in 2010 billions)

Infrastructure Systems	Total Needs	Estimated Funding	Funding Gap
Roads, Bridges, & Transit[1]	$2,042	$941	$1,101
Electricity[1]	$934	$757	$177
Schools[2]	$870	$490	$380
Public Parks & Recreation[3]	$114	$12	$102
Airports[1,4]	$157	$115	$42
Dams, Levees, Waterways & Ports[1,5,6]	$162	$38	$124
Water & Wastewater[7]	$150	$45	$105
Rail[8]	$154	$125	$29
Hazardous & Solid Waste[7]	$7	$4	$3
Total	$4,590	$2,526	$2,064

Source: American Society of Civil Engineers (ASCE) 2017 Report Card for American Infrastructure
1 Data taken from ASCE Failure to Act Series published 2011-16.
2 These numbers are based on the latest available national data collection and brought to current market dollars.
3 Total needs and estimated funding include all costs associated with parks and recreation. Funding gap is capital needs only.
4 Airport needs and gap include anticipated cost of NextGen: $20 billion by 2020 and $40 billion by 2040.
5 Total needs number is based on discussions with the National Committee on Levee Safety.
6 Total needs are federal and non-federal high-hazard dams.
7 Funding only includes publicly funded remediation, not funds from private sector.
8 These numbers are based on market projections and current investment trends.

Figure 1.1: Needs for infrastructure investment in the United States to 2025 in billions of dollars. Source: McNichol (2017).

construction of public schools and many public transit projects" (McNichol, 2017).

The infrastructure investment amounts cited above do not even include energy efficiency measures in building stock, whether in encouraging the construction of more efficient new construction, or the retrofitting older buildings. Yet building emissions are a significant part of the problem, since in some cities, over half of carbon emissions result from the construction and use of buildings and transportation systems (BPIE, 2011; Merk et al., 2012). Overall, heating and cooling buildings accounts for about 40% of total energy consumed, with 70% of this energy coming from fossil fuel sources. As a result, building climate control is estimated to have been responsible for 30% of CO_2 emissions in 2012 (International Energy Agency, 2015).

This is why investment in infrastructure for cities must include a multi-faceted approach, which involves improved water management, expansion of public transport, decentralised energy generation, significant deployment of renewable sources of energy with intelligent distribution and demand response, and energy efficiency measures for new and existing building stock. By investing in clean energy for cities in particular, the world benefits not only from lowered carbon emissions and improved climate change mitigation, but also from a more resilient and ultimately more affordable energy supply.

Additionally, financing green infrastructure would help to build a green economy (United Nations Environment Programme, 2008), and localized investment could trigger economic growth on a national level. In particular, there has been extensive discussion about linking green infrastructure development with "green collar" jobs (Yi, 2013; United States Dept. of Energy, 2017; Gessesse et al., 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. Otherwise, retaining a "business as usual" approach rather than investing in a greener future, cities could face consequences later, both physically in terms of climate disaster mitigation, and fiscally in terms of damages and depressed economic prospects that arise from a lack of resilient and robust infrastructure.

Green bonds can help to unlock financing for green and sustainable infrastructure. Green bonds are a subset of bonds which are "intended to encourage sustainability and to support climate-related or other types of special environmental projects. More specifically, green bonds finance projects aimed at energy efficiency, pollution prevention, sustainable agriculture, fishery and forestry, the protection of aquatic and terrestrial ecosystems, clean transportation, sustainable water management and the cultivation of environmentally friendly technologies" (Investopedia, 2018). Despite their beginnings in the private sector in the form of corporate bonds, green bonds are now also increasingly being issued by public governmental bodies, both in the form of sovereign and sub-sovereign debt. This intersects with the fact that one of the largest sub-sovereign debt markets in the world is the municipal bond market in the US, currently with over $4 trillion in debt outstanding for a million different projects, and $445.8 billion issued in 2016 alone (SIFMA, 2018; Lambert, 2014). As stated by Saha and D'Almeida (2017), "Green municipal bonds are an important area for future growth as cities and other sub-national entities look to low-cost and long-term sources of capital to finance climate mitigation and adaptation infrastructure requirements.” The New Climate Economy sustainable infrastructure report (2016) also says that “with the right approach, green bonds can be powerful instruments and play a tremendous role in facilitating sustainable infrastructure investment and growth.”

Green bonds are important for closing the infrastructure gap because they help to “broaden the universe of highly-rated fixed-income products (bonds) attached to clean energy, thereby making it easier for investors to increase allocations to clean energy within existing liquidity/creditworthiness constraints” (Fulton and Capalino, 2014). However, against the background of increasing ESG (Environmental, Social, and Governance) investment, the question is whether such these green bonds are competitive with respect to the overall market, which is necessary in order to prove appealing to investors who are subject to fiduciary duty, in that they are mandated to put profits before all other investment criteria. If, however, it can be shown that green assets can give returns as good as, or better than, their conventional counterparts, then investors can comply with their fiduciary duty and help invest in sustainability at the same time (Sandberg, 2011)

Another challenge facing the development of sustainable infrastructure is lack of access to institutional capital, despite the fact that socially responsible investors (SRI) are continually searching for investments that meet their ESG criteria (Fulton and Capalino, 2014). The sustainable investment sector is best situated for leveraging capital to close the infrastructure gap via green bonds. At present, there are $22.89 trillion of assets under SRI management, which is an increase of 25% since 2014, and accounts for 26% of all managed assets (Global Sustainable Investment Alliance, 2016; US SIF, 2016). Also, there are more than $60 trillion in assets under management by signatories to the Principles for Responsible Investment (OECD, 2017a).

This is relevant at a time where ESG investing is becoming increasingly important (Chandler, 2018), and where the demands of the socially conscious retail investors are starting to influence the mandates of the larger institutional investors. As stated by Amy O'Brien, head of responsible investment at TIAA Investments Napach (2017),"we're seeing the political climate actually act as a catalyst for ESG and impact investing solutions".

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. As long as the impression persists that ESG investing means taking a hit in terms of profitability (Köb, 2018), then most investors (both retail and institutional) will shy away from ESG investing. However, it is not necessarily true that ESG investing is less profitable, and now that there is beginning to be enough data to explore this issue (Barclays Research, 2016, 2018), the best way to trigger more ESG-guided investment into sustainable infrastructure is to show that it is a good investment in terms of financial returns in addition to being a good investment in terms of climate or moral returns. Indeed, the best way to help grow the market is to show that sustainable investing does not have to be a compromise. To this end, we don't actually have to demonstrate the that green investments outperform the conventional market, but rather it is sufficient to show that they perform equivalently, so that the need to balance ESG returns against financial returns is negated.

The motivation of this work is to explore financial methods that can help to meet the challenges of sustainability, resilience, and chronic underinvestment in the infrastructure in American cities. We focus on the advancement of green (sustainable) infrastructure in cities, from the perspective that financial instruments like green bonds can be used to kick start sustainable urban investment in a way that is currently lacking in the scope of traditional finance. As stated by Mathews and Kidney (2010), "many renewable energy projects are rendered uncompetitive not because of technical inadequacies but because funding sources are limited to loans from very conservative banks." In particular, the main stumbling block for clean energy finance is the reluctance of investors to invest in new technologies and/or business models, especially when their revenues are sensitive to policy risk.

This could arise from market conditions where many investors are put off by novel financial instruments, especially after the collapse of the CDO (Collateralized Debt Obligation) and ABS (Asset-Backed Securities) markets during the subprime crisis of 2008. Fortunately, there is already an existing financial instrument that has been used for over 200 years to finance infrastructure in the United States: municipal bonds. In particular, green municipal bonds are an increasingly popular way for American cities to finance green infrastructure (Sanders et al., 2013). Against this background, this work seeks to explore the behavior of green and climate-aligned municipal bonds in the United States with a specific focus on green infrastructure.

This work focuses on the United States municipal bond market because this market is the largest and most active municipal bond market in the world with almost $5 trillion in assets outstanding, and municipal bonds are financial instruments that are commonly used in the US for investment in infrastructure for cities, towns, and states (Garrett, 2008). Because the US municipal bond market is the largest of its kind, it means that it is also the largest aggregation of green and climate-aligned municipal bond data, and no other bond market has the depth of data available in terms of infrastructure-related bonds that the US muni bond market does. While there is a growing corporate green bond market, these bonds are not issued in the same numbers as US municipal bonds, so in order to obtain the largest possible homogeneous data source, we focus our investigation specifically on the US municipal bond market. This also ties in with our initial motivation of investigating ways to accelerate access to capital for sustainable urban infrastructure, since municipal bonds are implicitly vehicles for financing urban infrastructure.

The US saw $11 billion in green municipal bonds issued in 2017, the largest year ever, however these represent only about 2% of the overall US muni bond market. For the green municipal bond market to scale up and effectively address the infrastructure investment shortfall, investors need to know that buying green bonds does not expose them to greater losses than buying into conventional muni bonds. Moreover, if the green muni bond market showed a green premium, or “greenium”, this would show that some investors are willing to pay more for these bonds.

In order to investigate the performance of these green and climate-aligned municipal bonds, we collected the relevant bonds into an aggregated data set which includes all green-labelled municipal bond ever issued in the US, along with a large sample of climate-aligned bonds, which are bonds that would qualify for the green label, however for whatever reason they have not been formally declared as green bonds. We also capture a segment of so-called “vanilla” bonds, or conventional non-climate-related bonds, that have been issued concurrently with green bonds. This data allows us to assess the performance of the green and climate municipal bonds against the prevailing conventional municipal bond market via two methods: the creation and benchmarking of a green and climate-aligned municipal bond index, and yield curve spread analysis between contemporaneous green and vanilla municipal bonds.

Demonstrating that the green municipal bond market is competitive with, or outperforms, the conventional municipal bond market could help to alleviate some of the perceived market risks for green municipal bonds and unlock more capital for investment in sustainable infrastructure. Therefore, our overarching objective is to assess the competitiveness of the green and climate-aligned municipal bonds as compared with the prevailing municipal bond market. The techniques used to accomplish this are twofold:

1. To create an index for this asset class and benchmark its performance against conventional municipal bonds; and

2. To investigate whether there is any significant greenium in the market for new green municipal bond issuances via yield curve analysis.

This work makes several contributions to the current state of the art. First of all, the bond data that has been collected is uniquely comprehensive and well-formed. No other work has collected the depth of homogenous and manually checked and cleaned data that is used in our analysis, which is crucial to any study that investigates the performance of green assets, particularly when so many question what actually constitutes “greenness”. In terms of the analysis, no one else has created an index specifically for green and climate-aligned municipal bonds. There are commercially available municipal indices and corporate green bond indices, but there is no extant green municipal bond index in order to benchmark the performance of that market sector. Furthermore, while there have been yield curve analysis for corporate green bonds, and yield curve analysis for the secondary market performance of green municipal bonds, there has been no yield curve analysis for the primary market performance of green municipal bonds. Finally, this work includes a pairwise like for like analysis between green muni bonds and their vanilla counterparts, which has not been done before.

The reason that we focus on green municipal bonds is because they are crucial to helping cities build and retrofit greener, more sustainable infrastructure. However, in order for the green municipal bond market to scale up – and be able to effectively address the infrastructure investment shortfall – investors need to know that buying green bonds will not expose them to greater losses than buying conventional municipal bonds. If the green municipal bond market showed a green premium, or "greenium", this could encourage a more diverse pool of investors to enter the market and potentially push down the cost of capital for municipalities looking to finance green and sustainable infrastructure projects.

This work is structured as follows: In Chapter 2 we provide background and context for what green bonds are and the state of the global green bond market. Chapter 3 focuses specifically on the green municipal bond market in the United States, and provides a history of this market along with giving several case studies of where municipal bonds have been used to finance sustainable infrastructure in the US. Chapter 4 focuses on the search for "greenium", or a premium in the pricing of green bonds as compared to conventional bonds, and also introduces the two main tools for market performance analysis that we use in our research. Chapter 5 describes how we collected our data and describes how we assessed the comparative liquidity of our data. Chapter 6 pertains to the construction and benchmarking of our green and climate indices as a way of benchmarking the performance of this market. Chapter 7 describes the construction and spread analysis of the yield curves for the green municipal bonds compared with the conventional ("vanilla") municipal bonds. Chapter 8 brings together our findings from the index benchmarking and yield curve analysis and gives context for the implications of these findings.

Chapter 2

Green Bonds

This chapter will provide an overview of the green bond markets, with a particular focus on applications for investment in green infrastructure. We will set the context for the the research by describing the background and history of green bonds, describe some of the literature where they are featured, and discuss some of their disadvantages.

2.1 Green Bonds

Bonds have always had an essential role in financing infrastructure, and with the increasing urgency behind developing more climate-resilient and sustainable infrastructure, there is a burgeoning new asset class that is specifically targeted towards financing green infrastructure: green bonds. Green bonds are "debt instruments used to finance green projects that deliver environmental benefits" (OECD, 2017a). The issuers of these bonds are bound by commitments to use the proceeds that they raise solely to finance or refinance green and sustainable projects, business activities, or assets. The Green Bond Working Group defines a green bond as "one for which the issuer declares that the proceeds will be applied (either by ring-fencing, direct project exposure or securitization) towards climate and/or environmental sustainability purposes" (Bank of America Merrill Lynch and Citi, 2013).

Green bonds have some significant advantages that lend themselves towards increasing the size of the market and therefore the capital available to green infrastructure. Shislov et al (2016) outline some of these advantages in their report titled

"Beyond transparency: unlocking the full potential of green bonds". One key advantage is that labelling a bond as green has been shown to increase the pool of potential lenders and diversify the investor base. As the report states, "issuing a green bond can be a way for these organizations to gain visibility, and thus attract more attention from investors," which has led to many green bonds being oversubscribed. Of particular note within the context of the green muni bond market, "the green bond issued by the State of Massachusetts in 2013 was 30% oversubscribed, while the regular bond was undersubscribed" (KPMG, 2015). Furthermore, Shislov et al (2016) state that "at some point, a larger base of investors may also lead to a greater ability to reach long term lenders and thus have access to longer maturities," and that green bonds also serve as a "way [for companies and municipalities] to communicate on their sustainability strategy and thus enhance their reputation." A side effect of this is that green bonds can "help build stronger sustainability awareness within the issuing organization and reinforce ties between financial and sustainability departments" and, in turn, "help develop and enable the basis for an improved understanding and integration of climate-related issues in the financial decision-making process."

Green bonds are generally labelled as such by the issuers and/or independent reviewers, and "labelled green bonds are no different from normal bonds in the wider market; the difference is that proceeds are transparently channelled for climate-friendly purposes" (Financing the Future Consortium, 2015). In addition to labelled green bonds, there are many bonds whose use of proceeds are also for sustainable and climate-friendly uses and would qualify for the green label, however for whatever reason, these bonds are not labelled. In this work (in alignment with others (OECD, 2017a)), we refer to these bonds as "climate-aligned bonds", or just "climate bonds". Climate bonds are the super-set of all bonds whose use of proceeds finance green and climate-friendly infrastructure, and green bonds are the sub-set of the climate bonds that are "officially" labelled as green bonds. Ultimately, both climate bonds and green bonds serve the same goal. The relationship between green bonds, climate bonds, and municipal bonds is shown in Figure 2.1.

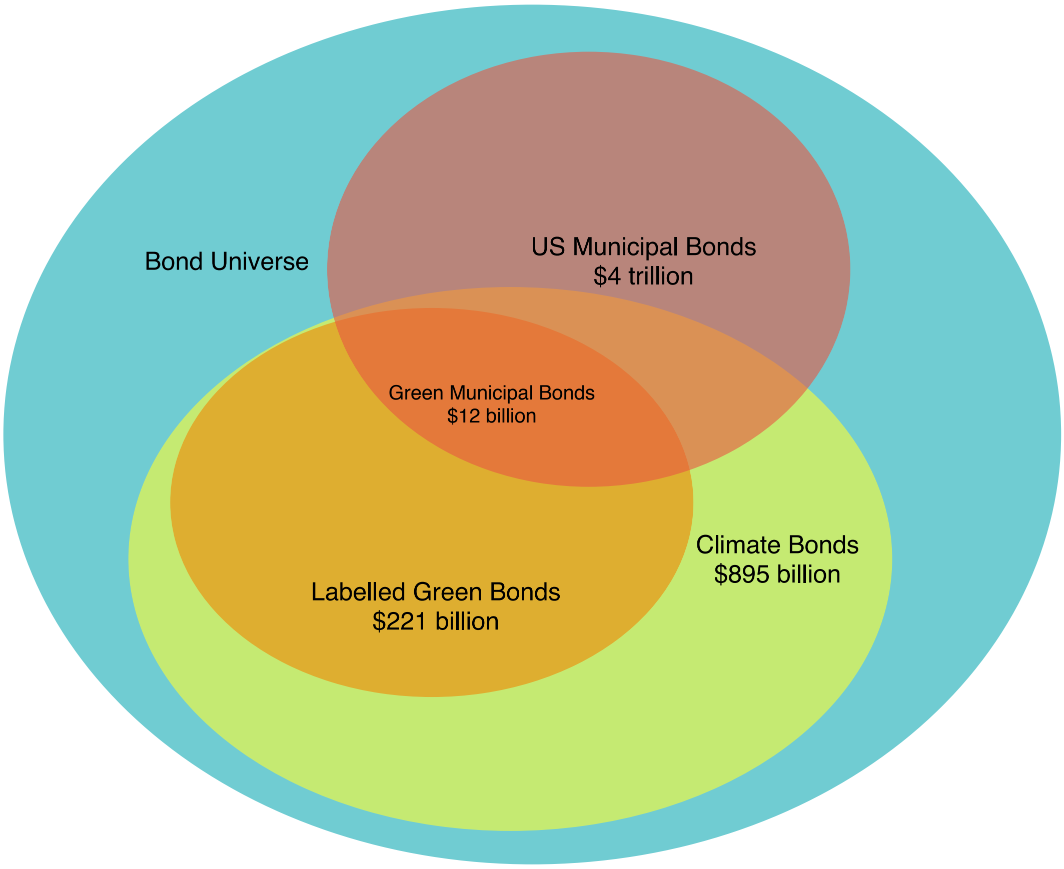


Figure 2.1: A Venn diagram (not to scale) showing the relationship between green bonds, climate bonds, and municipal bonds.

The European Investment Bank (EIB) and World Bank first started issuing what they call "climate bonds" in 2007 (European Investment Bank, 2015). Since then, the multilateral lenders have continued to champion green bonds, and in 2013 the first corporate green bonds were issued by EDF, Bank of America, and Vasakronan. The largest corporate green bond issued to date is a EUR2.5 billion offering from GDF Suez in March 2014 (Climate Bonds Initiative, 2015b). One of the main points for the increasing adoption of the green bond is that they were intended from conception to be identical to the pre-existing types of bonds in all ways except in their labelling and use of proceeds (Mathews and Kidney, 2012). The reason for this is that it keeps the barriers to entry into the green bond market as low as possible since they can use already existing legal and financial frameworks, which was considered to be more efficient than creating an entirely new financial instrument. One of the main reasons for the success of green bonds is that "investors do not have to choose between financial returns and environmental benefits, as green bonds offer the same financial terms as other bonds, with the added bonus that their green label enables investors to identify them as environmentally beneficial investments" (Climate Bonds Initiative et al., 2015).

As opposed to (unlabelled) climate bonds, labelled green bonds have gone through the process of the issuers agreeing to the Green Bond Principals (GBP) (ICMA, 2016). The GBP states that use of bond proceeds must go towards eligible projects, specifically those that fulfil environmental objectives. In addition, the issuers also agree to provide periodic reports in order to ensure accountability and transparency, and also enable the stated objective of having third party auditing and/or certification (frequently from CICERO). Issuers that agree to the GBP and fulfil the criteria can then refer to these bonds as labelled green bonds. However, as stated previously, there is a larger universe of bonds that are issued for climate-friendly projects that are unlabelled. These bonds can be referred to as unlabelled green bonds or climate-aligned bonds. One of the main objectives of the green label is to serve as a "discovery tool" (Climate Bonds Initiative, 2016), which has the potential "to reduce friction by allowing investors to find environmentally sustainable securities while minimising transaction costs incurred through the diligence and research normally required to find and compare unlabelled bonds in the broader market." In short, one of the main advantages of the green label is that it makes green bonds easier to identify for investors that are specifically looking for green investments.

2.1.1 Green Bond Standards

There are a number of different frameworks and taxonomies that deal with the project definitions of what is eligible for the green bond label, but the two major international standards are the aforementioned Green Bond Principles (GBP), and the Climate Bonds Standard (CBS), both of which are described below.

The Green Bond Principles (GBP) (ICMA, 2017) are voluntary guidelines that "recommend transparency and disclosure and promote integrity in the development of the Green Bond market by clarifying the approach for issuance of a Green Bond."

The GBP recognises “several broad categories of eligibility for Green Projects with the objective to address key areas of environmental concern such as climate change, natural resources depletion, loss of biodiversity, and air, water or soil pollution.” The framework includes but is not limited to: renewable energy (including production, transmission, appliances and products); energy efficiency (such as in new and refurbished buildings, energy storage, district heating, smart grids, appliances and products); pollution prevention and control; environmentally sustainable management of living natural resources and land use; terrestrial and aquatic biodiversity conservation; clean transportation; sustainable water and wastewater management; climate change adaptation; circular economy adapted products; and green buildings. The basis for the labelling of a green bond as green according to the GBP is that the use of proceeds for a bond must go to green projects, “which should be appropriately described in the legal documentation for the security. All designated Green Projects should provide clear environmental benefits, which will be assessed and, where feasible, quantified by the issuer.” Furthermore, “The net proceeds of the Green Bond, or an amount equal to these net proceeds, should be credited to a sub-account, moved to a sub-portfolio or otherwise tracked by the issuer in an appropriate manner, and attested to by the issuer in a formal internal process linked to the issuer’s lending and investment operations for Green Projects,” and green bond issuers should issue regular (annual) reports on project progress and information on the actual use of proceeds. The GBP are voluntary guidelines with no means by which to enforce compliance with their standards, nor are their standards rigorously defined or intended to serve as a legal framework.

The Climate Bonds Standards (CBS) (Climate Bonds Initiative, 2017a) builds on the GBP, but goes a step further in seeking third party verification for green claims. As of 2017, the CBS is in full alignment with the GBP, and similarly requires “clear mandatory requirements for use of proceeds, tracking, and reporting and specific eligibility criteria for low carbon and climate resilient projects and assets. However, it also provides “an assurance framework with independent verifiers and clear procedures” and furthermore encourages “certification by an independent Climate Bonds Standard Board." This certification by an external third party addresses potential greenwashing worries and "allows investors, governments and other stakeholders to prioritise green bonds with confidence that the funds are being used to deliver a low carbon and climate resilient economy." However, certification is still voluntary under the CBS. Advantages of going through the certification process are described as the prevention of investors "having to make subjective judgements or do expensive due diligence on the green attributes of certified investments." This, in effect, puts the onus on the issuer to go through the certification process, which while it may open the pool of interested SRI investors, could add to transaction costs due to the time and effort required. Furthermore, the CBS are separated into pre-issuance and post-issuance requirements, the former for a bond to gain certification, and the latter are reporting requirements to retain certification. While the types of projects that could be financed by a CBS certified green bond are in alignment with those covered by the GBP, the requirements for capital accounting and reporting on use of proceeds is much more proscriptive. Also, the sector-based requirements for green eligibility are still under development for many sectors. The CBS take a more rigorous legal approach and address what to do when a bond's actual use of proceeds ends up falling outside of the "green" category.

2.1.2 Advantages of Green Bonds

Green bonds are beneficial because they deepen the pool of available investors, help address maturity mismatches between long-term projects and short-term financing, and potentially offer cost advantages amongst other things. In particular, institutional investors with long investment horizons, such as pension funds and insurance companies, are increasingly interested in investing in green infrastructure in order to help hedge against long term climate risks inherent to their current investment portfolios (Shishlov et al., 2016). They also provide "much-needed diversification" for investment portfolios while at the same time providing stable returns (Climate Bonds Initiative, 2015c). However, the market faces challenges in the form of lack of awareness, added transactional costs, and lack of standardisation (OECD, 2017a). In order to overcome some of these challenges, many ESG investors and issuers are looking for a green premium, or "greenium". This would provide evidence that green bond buyers are willing to pay more for green bonds, a point that this research explores in detail.

Furthermore, the green label helps to give a "green halo" (Hale, 2018) effect to the issuer, in that "the green label provides a good indication that, all things being equal, the given issuer has a stronger focus on governance, which in turn lowers the overall credit risk" (Michaelsen, 2018). Issuing green bonds helps to lower the cost of capital for an issuer because the "value ascribed to green bonds are not exclusive to the bond itself but is rather issuer-specific, such as improved governance and stronger strategic alignment towards a sustainable agenda, which also benefits non-green bonds." A study done by NatWest also reported these findings, stating that "green bond issuance helps attract a broader sustainability-focused investor base to the company's debt as a whole, thereby putting downward pressure on the entire [yield] curve" (Hale, 2018).

This green halo effect can also positively impact the bottom lines of the companies that have issued green bonds. Flammer (2018) found that the stock market responded positively to news of corporate bond issuances, finding a 0.67% in the cumulative abnormal return in a company's stock price around the times of announcements of green bond issues. The issuance of corporate green bonds was also associated with an increase in long term company value along with an increase on the return on assets. In addition to positive associations with book value, green bond issuance also correlated positively with an increase in the company's environmental score and a decrease in their CO2 emissions.

2.2 State of the Market

Over the past decade, a growing market for green bonds has emerged in the wake of pioneering early issuers. The size of the green bond market grew from $3 billion in 2011 to $95 billion in 2016 (OECD, 2017a). Between 2008 and 2013, the World Bank (2013) issued approximately $4 billion in green bonds, and uses the proceeds raised for eligible projects that meet their project selection criteria, which include

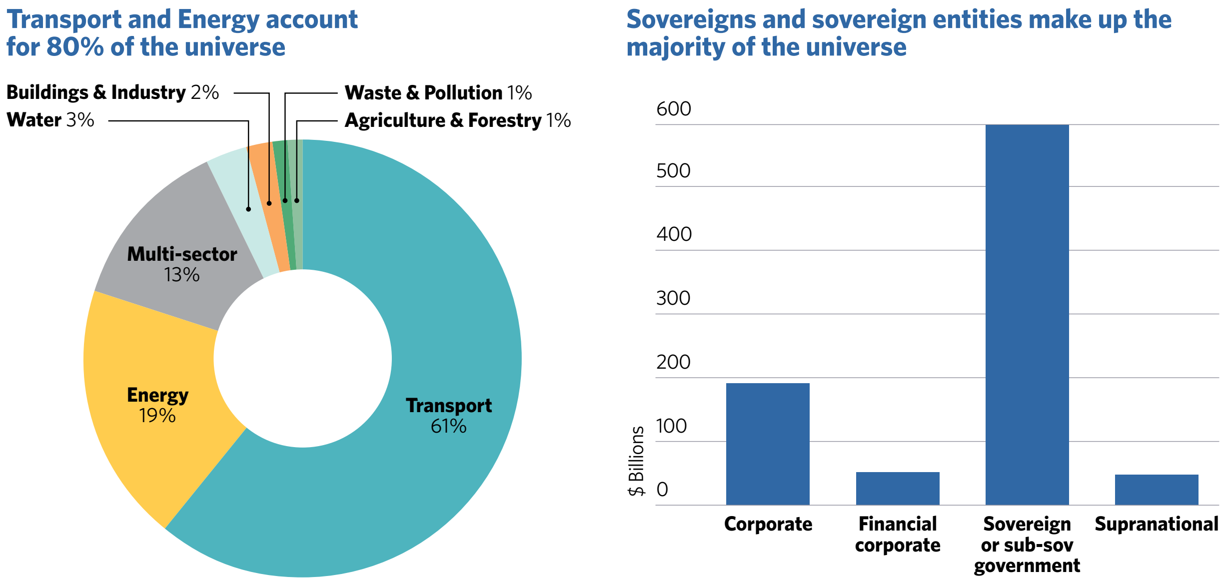


Figure 2.2: A breakdown of global green bond issuance by sector and by type of issuer. Source: Climate Bonds Initiative (2017d).

mitigation projects such as solar and wind generation, along with efficiency, among others. As of mid-2015, there were $40 billion in labelled green bonds issued, and $532 billion of unlabelled climate bonds (Climate Bonds Initiative, 2015b). However, in the American context, green bonds (both corporate and municipal) make up only 0.061% of the total US bond market, which, percentage-wise, is much lower than "China, India, and South Africa, and an order of magnitude below the share in the Nordic countries, Germany, the Netherlands, and France" (Chiang, 2017).

In their 6th annual State of the Market report in 2017, the Climate Bonds Initiative (2017d) estimated the size of the global climate-aligned bond market to be worth just under US$895 billion, $221 billion of which are labelled green bonds, and includes 3,493 bonds from 1,128 issuers. The largest sector for bond issuances is transport, specifically rail, however clean energy is the second largest sector with 21% of issuances (see Figure 2.2). This is likely due to the developed nature of the rail bond market, and to the "greenness" inherent to rail transport that makes it relatively easy for these bonds to be labelled as green. Over $600 billion in green bonds are issued by sovereign or sub-sovereign governmental entities (which in-

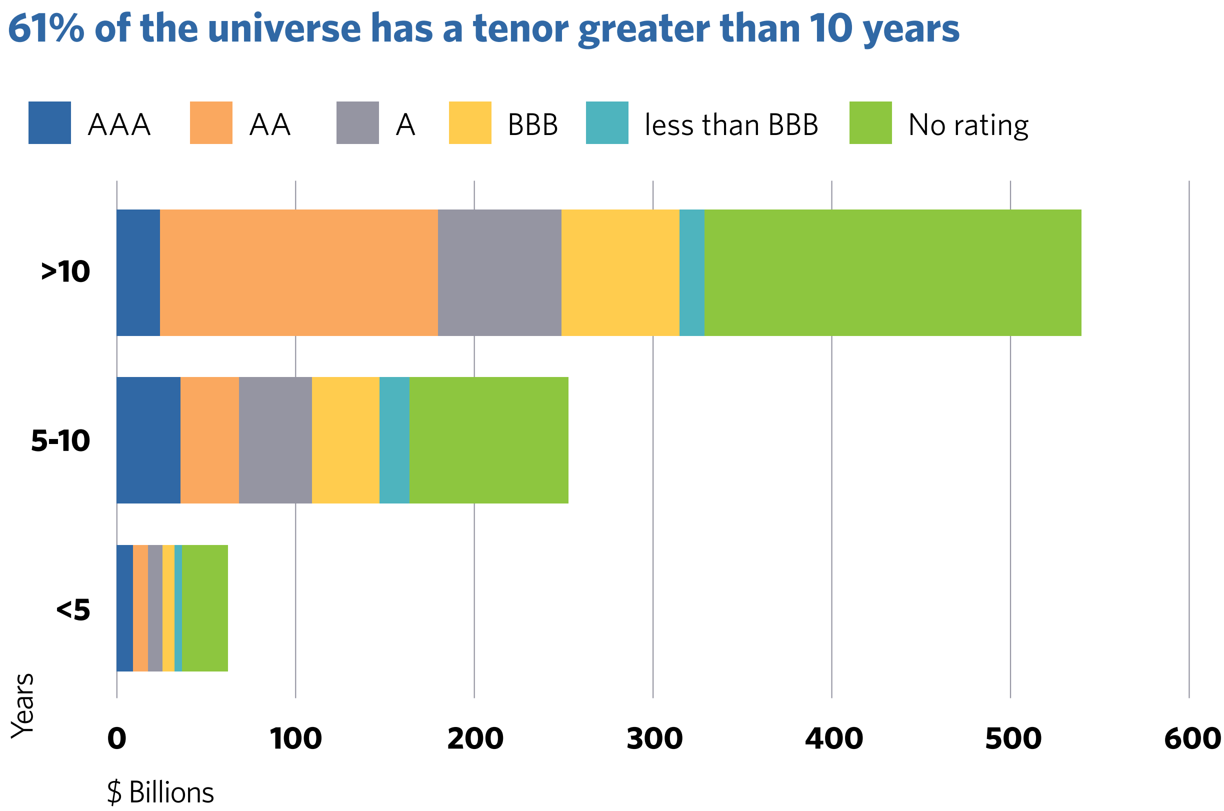


Figure 2.3: A breakdown of global green bond issuance by tenor and rating. Source: Climate Bonds Initiative (2017d).

cludes municipal bonds), also as shown in Figure 2.2.

This State of the Market report also found that the majority of the climate bond universe is investment grade (rated BBB- or above), and most green bonds issued are $10 to $100 million in size, however the average bond size is $262 million. This could be due to influenced by the municipal bond market, which features many smaller issue bonds rather than large monolithic ones, but there is also a pipeline of large benchmark size green bonds that would explain the high average. A breakdown of the relationship between tenor and rating is shown in Figure 2.3, which shows that 61% of issued green bonds have a tenor longer than 10 years, which is in alignment with the long term nature of infrastructure investment. This report states that the amount of bond issuance in the global debt capital markets in Q2 2017 was $1.1 trillion, compared with $43 billion of climate and green bond issuance, or 4% of the overall total.

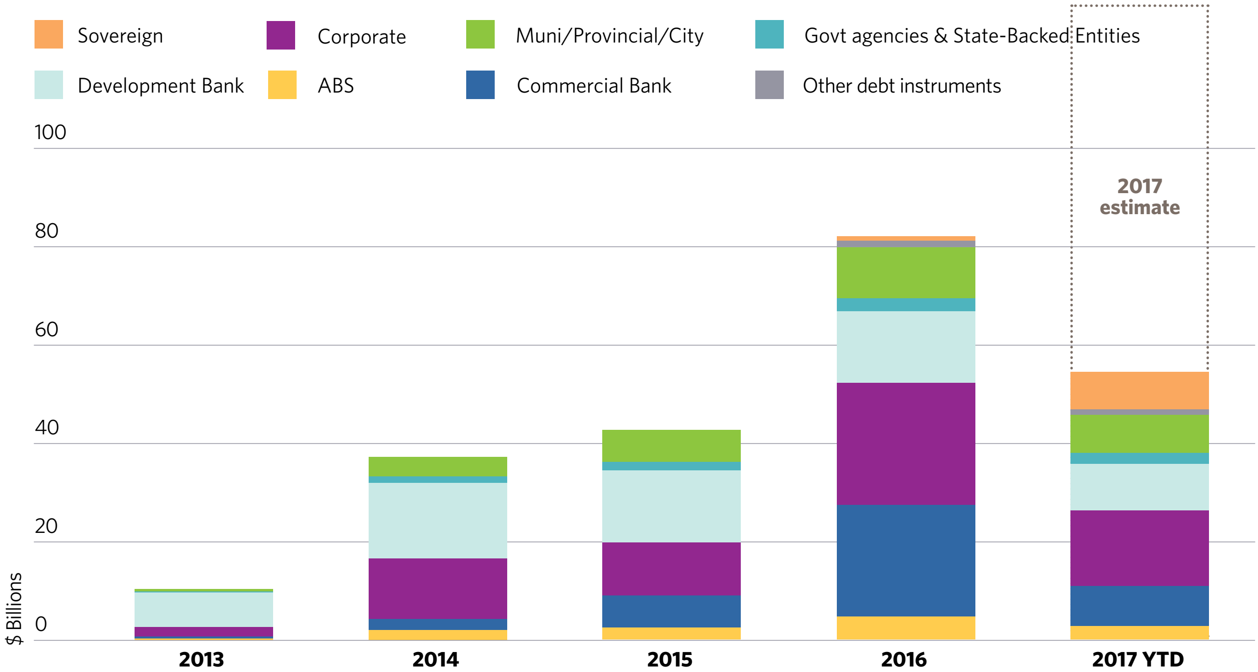


Figure 2.4: A breakdown of green bond issuance by type of issuer. Source: Climate Bonds Initiative (2017d).

In terms of labeled green bonds, in 2016 $81.4 billion in labeled green bonds was issued, double the amount of 2015 issuance, with the trend projected to continue. By the end of 2017, total green bond issuance was $155 billion, beating the projection in this report of $100 billion, and according to analysis by Moody's, 2018 is forecast to see issuance of over $250 billion (Sharma, 2018).

In their S&P report, Marin et al. (2018) discuss the application of their "Green Evaluation methodology to a sample of 45 self-labeled U.S. municipal green bonds" issued from 2012-2017 and found that "the U.S. green bonds scored on par with their international counterparts." This is based upon the Green Evaluation framework that S&P released in April 2017, which "scores how green a bond is, rather than providing an opinion whether or not it is green." This green evaluation tool establishes a score for the total environmental benefit or resilience impact "relative to a regional baseline and compared with that of similar projects and technologies globally" and also provides a second-party opinion consistent with the GBP. This method quantifies the "greenness" of a bond "based on three components with different weightings–Governance (25%), Transparency (15%), and Environmental or

Resiliency impact (60%)" with each transaction scored from 0 to 100 to reflect "the transaction's overall environmental contribution as well as its alignment with climate-change mitigation or adaptation goals." Then this score is expressed as a quartile from E1-E4, with E1 projects having the most benefit. They found that "the majority of global self-labeled green bonds evaluated under our Green Evaluation tool scored E2, with an average score of 70". This report concludes with a forecast, stating, "in the near-to-medium term, we expect growth in both labeled green bonds and unlabeled climate-aligned bonds as issuers seek to make investments that mitigate or adapt to the impacts of climate change, and as investors increasingly pursue yield associated with improving the environment."

2.3 Green Bonds in the Literature

One of the first papers to appear in the literature about green bonds was "Mobilizing private finance to drive an energy industrial revolution" (Mathews et al., 2010). This policy paper says, "if capitalist industrialism created the problem in the first place, then in our view a way has to be found for capitalist processes to solve the problem." It proposes the establishment of "Climate Bonds", stating that "privately financed instruments (that may tentatively be termed Climate Bonds) will have to play a significant role in the transformations that lie ahead." Furthermore, "when we look back at the history of financing of major infrastructure projects, we see that private debt finance instruments (bonds or debentures) have done the heavy lifting in getting the projects off the ground."

This was followed up by a paper called "Financing climate-friendly energy development through bonds" by Mathews and Kidney (2012). It states that "we see bonds as private and public sector financial instruments that are uniquely suited to facilitating major infrastructure investment projects" and focus on them as "critical component of any future financing system capable of scaling up energy investments." Their cited case studies include Clean Renewable Energy Bonds (CREBs) in the US muni market, Climate Awareness Bonds as issued by the European Investment Bank (EIB), Green bonds issued by the World Bank, Breeze Bonds in

Germany, and the then-proposed Green Investment Bank in the UK. This paper seeks to "explain what these financial instruments have in common and discuss how they can be generalised and scaled up so as to meet the challenges of building new energy systems around the world." They propose four essential characteristics for "climate bonds" to be successful. Firstly, the bonds needs to be backed by assets which can be aggregated, so that the climate bond acts as a bridge "and is designed to attract primarily institutional investors such as pension funds." Secondly, "the bonds are intended to be 'asset-backed'", or securitized on the basis of actual assets or cashflows. Third, these bonds need to have the longest possible tenors in order to "give the underlying renewable energy projects time to move from loss-making to making better profits than fossil fuel energy projects" in order to better match their profitability horizon. Finally, these bonds "need to be as closely modelled on existing 'vanilla' bonds as possible" so that they appeal to the widest range of investors as possible.

Specific examples given in this paper include: "1) single project bonds, which provide exposure to specified projects that are aligned with a transition to a low-carbon economy (such as wind farms); 2) bonds whose proceeds are invested directly in asset portfolios (such as onshore and offshore wind farms); and 3) secondary project finance loans that are bought from commercial banks and bundled by asset class into new bond issues." Overall, this asset class seeks to remedy the fact that "many renewable energy projects are rendered uncompetitive not because of technical inadequacies but because funding sources are limited to loans from very conservative banks."

In a report authored by Shishlov et al. (2016) under the auspices of the Institute for Climate Economics, titled "Beyond transparency: unlocking the full potential of green bonds", they state that "the green bond market unlocks a number of benefits by increasing the transparency of information available to investors on underlying assets and companies." Additionally, green bonds can "help bond issuers communicate their sustainability strategies, create internal synergies between financial and sustainability departments, and expand and improve relationships of borrowers with debt providers." One of the greatest benefits of green bonds is that they can broaden the pool of lenders and diversify the investor base. Nevertheless, this report does take the cautious viewpoints that "their tangible contribution to the low-carbon transition has so far been marginal", and "green bond market does not currently appear to directly stimulate the increase of green investments." This report seeks to explore the challenges facing green bonds and makes recommendations to overcome these challenges. The first challenge to be addressed is the risk of greenwashing. The second challenge is to enhance the financial benefits of green bonds. This report concludes by making a number of policy recommendations "aimed at informing systemic decision-making by policymakers and financial stakeholders to help them evaluate the options available".

In a report published by Ceres, "Investing in the Clean Trillion: Closing the Clean Energy Investment Gap", Fulton and Capalino (2014) provide 10 recommendations to increase global investment in clean energy "to at least $1 trillion by 2030". These recommendations include setting goals "such as 5% portfolio-wide clean energy investments", increased scrutiny on fossil fuel companies' exposure to stranded asset risks, and the standardisation of clean energy investment data. Furthermore, they focus on encouraging "green banking" to increase private capital investment in clean energy, and call for support for green bonds and "issuances of asset-backed securities to expand debt financing for clean energy projects".

In 2015, a report titled "Shifting Private Finance towards Climate-Friendly Investments" by Financing the Future Consortium (2015) was released with the aim of encouraging EU policymakers to foster the growth of climate finance. Their specific recommendations include increased green bond issuance from European public financial institutions, credit enhancement policies, policy risk insurance, fostering green securitisation, lengthening the time horizon of institutional investors, and the use of tax incentives (similar to those that are used in the muni bond market in the US).

In 2017, the OECD published a book entitled *Mobilising Bond Markets for a Low-Carbon Transition* (OECD, 2017a). This book "proposes a framework for understanding possible directions of bond market evolution and for analysing the potential contribution that the bond markets can make to a low-carbon transition." In their analysis, they study: "1) how much debt finance is needed to meet the IEA's 2C energy investment scenarios (2DS) between 2015 and 2035 in the four markets studied (the People's Republic of China, the European Union, Japan and the United States); 2) how the bond market might evolve in the same period to account for part of these debt finance needs; and 3) the implications for institutional investors that have driven the growth of the green bond market to date." They found that by 2035 in a 2DS regime, green bonds in these four markets have the potential to "scale to USD 4.7-5.6 trillion in outstanding securities globally and USD 620-720 billion in annual issuance," which is about 4% relative to the overall debt capital markets in these countries. In particular, this report states that "the share of municipal, sub-sovereign and sovereign bonds could grow over time but is seen as constrained by public finance limits and the fiscal capacities of governments", however, "efforts to expand the creditworthiness and ability of cities to issue bonds could positively impact these figures in emerging and developing economies."

In terms of assessing the size of the green bond market, the Climate Bonds Initiative issues an annual State of the Market report, which is sponsored by HSBC. This report is based upon green bond data that they aggregate by searching Bloomberg and Thomson Reuters issuer data and "reviewed over 1,700 issuers to identify those with over 95% of revenue derived from climate- aligned assets." They also added renewable energy project bonds and "domestic Chinese bonds from the ChinaBond China Climate Aligned Bond Index." The majority of the unlabelled issuers are pure-play green companies, and all of their bonds issued since the beginning of 2005 are included (Climate Bonds Initiative, 2017b). These reports also track developments in the size of the green municipal bond market, and the use of green bonds to foster investment in green infrastructure for cities.

2.4 Challenges to the Green Bond Market

One of the main criticisms levelled at green bonds is that there is the risk of labelling bonds as green when in fact the proceeds do not go to projects that are considered clean and/or sustainable. Given that the green bond market is currently unregulated and relies upon the good faith of issuers to ensure that the capital raised from a green bond issuance is invested according to the GBP, CBS, etc., there is no formal mechanism by which to enforce compliance. As the green bond market grows, there is a risk that some bond issuers may knowingly or unknowingly issue green bonds that actually finance projects or activities that do not fall into the "green" category, as declared by the Green Bond Principles or otherwise. As stated by Chiang (2017), "Greenwashing – issuance of bonds labeled as green that lack genuine environmental benefits – remains a concern for investors, while issuers worry about reputational and legal risks if green claims can't be substantiated."

Overall, "the lack of universal rules and standardisation of green definitions, reporting, and impact assessment is a shared and enduring source of concern" (OECD, 2017a). To try and remedy this situation, "some second opinion providers have developed their own assessment frameworks," which include CICERO, the Global Infrastructure Basel (GIB) Foundation, Sustainalytics, Trucost, the Climate Bonds Initiative, and UN Principles for Responsible Investment (PRI) (Shishlov et al., 2016). However, it remains that some bonds that are qualified as green by a number of second opinion providers may not be eligible for the CBS label and vice versa, so there is no canonical definition of what exactly is considered a green bond (OECD, 2017a; AfDB et al., 2015; World Wildlife Fund, 2016). As an attempt to address these problems, "a significant amount of effort has gone into shaping and cultivating a better-defined market with assurances for environmental integrity and impact of green bonds while keeping 'green transaction costs' low" (OECD, 2017a).

In 2016, the World Wildlife Fund issued a report entitled "Green bonds must keep the green promise! A call for collective action towards effective and credible standards for the green bond market". This report addresses some of the disadvantages of the current green bond system, namely that the GBP and CBS are voluntary standards with little to no oversight. The report raises the issue that these standards are more focussed on self-declared sustainability measures rather than post-facto demonstrable environmental benefits, such as tonnes of CO2 emissions reduced, or litres of water saved. They state that the "WWF believes that only a bond for which the issuer can actually demonstrate measurable environmental benefits according to widely-accepted, fully-developed standards should qualify as a 'green bond'", and particularly wish to see a focus on "developing criteria around adaptation and climate resilience assets and environmental challenges beyond climate change," including "ecosystem conservation, sustainable water use and pollution prevention." In large part, their argument rests on the lack of consideration for the preservation of natural capital by the existing green bond standards, however their key point is that "focussing on promised environmental impacts rather than actual performance raises the risk of greenwashing if bonds are issued and perceived as green, while only achieving minor or in fact no actual environmental benefits." This is crucial in light of the fact that there is relatively little impact reporting as of yet in the green bond marketplace, and there are few attempts to quantify actual carbon emissions reductions by the projects being financed by green bonds (Floods, 2017).

A related criticism is that green bonds do not actually lead to additionality, in that green bonds do not actually end up financing projects that wouldn't have come to market through conventional means. This assessment of green bonds is becoming more and more vociferous. In relation to green muni bonds in particular, a Forbes commentator (Amante, 2018) states that green bonds are nothing more than a marketing exercise, whereas "no investment is more fundamentally focused on improving people's lives than the municipal bonds. The explicit purpose of the $3.8 trillion municipal market is to function for the public good." They then assert that green bonds are "a marketing technique, used to generate interest in a new issuance and to attract interest from millennials or other investors searching for green and sustainable investments, according to market sources – an underwriter, portfolio manager and issuer – specializing in green bonds." Furthermore, "more demand should, in theory, drive the cost of borrowing down, resulting in cost savings for the issuer. However, significant cost benefits as a result of issuing green bonds have not materialized." This is in agreement with the WWF report, which questioned the posited benefits of additionality in the green bond market, citing the Natixis (2014) report that failed to find any bond over $200M that wouldn't have been funded through traditional means. The WWF stated that thus far "evidence of price premiums as well as 'additionality' remains anecdotal and controversial" (World Wildlife Fund, 2016).

In addition to exposure to greenwashing and policy risk, the process of issuing green bonds, even though they are fundamentally identical financial instruments to conventional bonds, still incurs extra transaction costs due to the level of disclosure and reporting required. Saha et al (2016) bring out the additional transactional costs and additional work that arise as part of issuing a green muni bond by saying, "extra work is needed to track the use of proceeds and report the information to investors, for example. The estimated cost of an independent review is $10,000-50,000, depending on who is doing the review and other factors." This is part of the reason why both issuers and investors are very interested to see if a greenium materialises in the green bond market: higher green bond prices at issue help translate to lower cost of capital, thereby offsetting some of these additional costs. Without effectively being reimbursed for the extra reporting and paperwork, it could be hard to convince more (particularly smaller, more cash-strapped) issuers to issue more green bonds. Furthermore, as stated by Preclaw and Bakshi (2015), "we have not yet encountered mandates that specify a price (in terms of foregone return) that investors are willing to pay for their environmental friendliness."

In order to help overcome these challenges to the green bond market, Shislov (2016) lays out some policy recommendations. First, the market players should "clearly lay out the objectives of different standards in order to define 'greenness'." Also, governments should "clarify investment areas compatible with long-term national sustainable development pathways, and publicly endorse standards that are aligned with long-term decarbonization strategies." Secondly, to deal with transparency risk in relation to reporting, market players should seek "convergence around the enhanced transparency frameworks", and "reinforce the global efforts around standardizing practices." On the government side, policies should be set in place to "support the issuance of green bonds by public institutions, and mandate similar disclosure requirements for all asset-linked bonds."

Furthermore, one of the key ways to try and overcome the risk of greenwashing in the market is through external reviews and certification of green bonds. In the external review process, second party reviews brought in to assess the green bond's use of proceeds and compliance with reporting requirements, and these external reviewers then report on the eligibility for the bond to be labelled "green". As an additional step, issuers can also seek formal third-party certification, in which an external auditor reviews the bond and certifies it as green if it complies with an appropriate standard. (OECD, 2017a; Climate Bonds Initiative, 2017a). To date, dozens green bonds have been certified green with a total of $31.2 billion in issuance as of Q4 2017 (Climate Bonds Initiative, 2017a). Looking specifically at US green muni bonds, as of mid-2018, 23 of of these have been certified, most of them issued by New York state agencies, namely Metropolitan Transport Authority (MTA), New York State Energy Research and Development Authority (NYSERDA), and New York State Housing Finance Authority (NYSHFA) (New York Governor's Press Office, 2016; Climate Bonds Initiative, 2017a; Metropolitan Transportation Authority of New York, 2017).

The next chapter will focus specifically on this green municipal bond sector of the green bond market.

Chapter 3

Green Municipal Bonds

So far, most issuance of green bonds has come in the form of corporate bonds, or bonds that are issued by companies in order to finance their private activities. In contrast, municipal bonds are bonds that are issued by public entities, such as towns, counties, public universities, public utilities, etc. This research focuses specifically on the sub-set of green bonds that are also municipal bonds, which are green bonds that are issued by public entities in the United States. This allows us to target the market dynamics of the sector of the bond market that most directly affects sustainable infrastructure development in American towns and cities. These green municipal bonds are a small but growing part of the overall bond universe, and represent an opportunity where investment in these bonds can directly impact the carbon footprint and climate resilience of infrastructure in the United States. Furthermore, this green municipal bond market has the potential to grow to other countries.

3.1 Municipal Bonds in the United States

This work will focus on municipal bonds because they enable direct investment into public infrastructure. Municipal bonds are sub-sovereign bonds that are issued by non-national public entities, such as cities, counties, universities, etc. In the United States, municipal bonds have been a means of raising capital for investment in infrastructure since New York City issued a bond to finance the building of a canal in 1812 (Fahim, 2012). As of 2017, over a million municipal bonds were outstanding in the U.S., with a total principle value of $3.8 trillion (MSRB, 2017; Lambert,

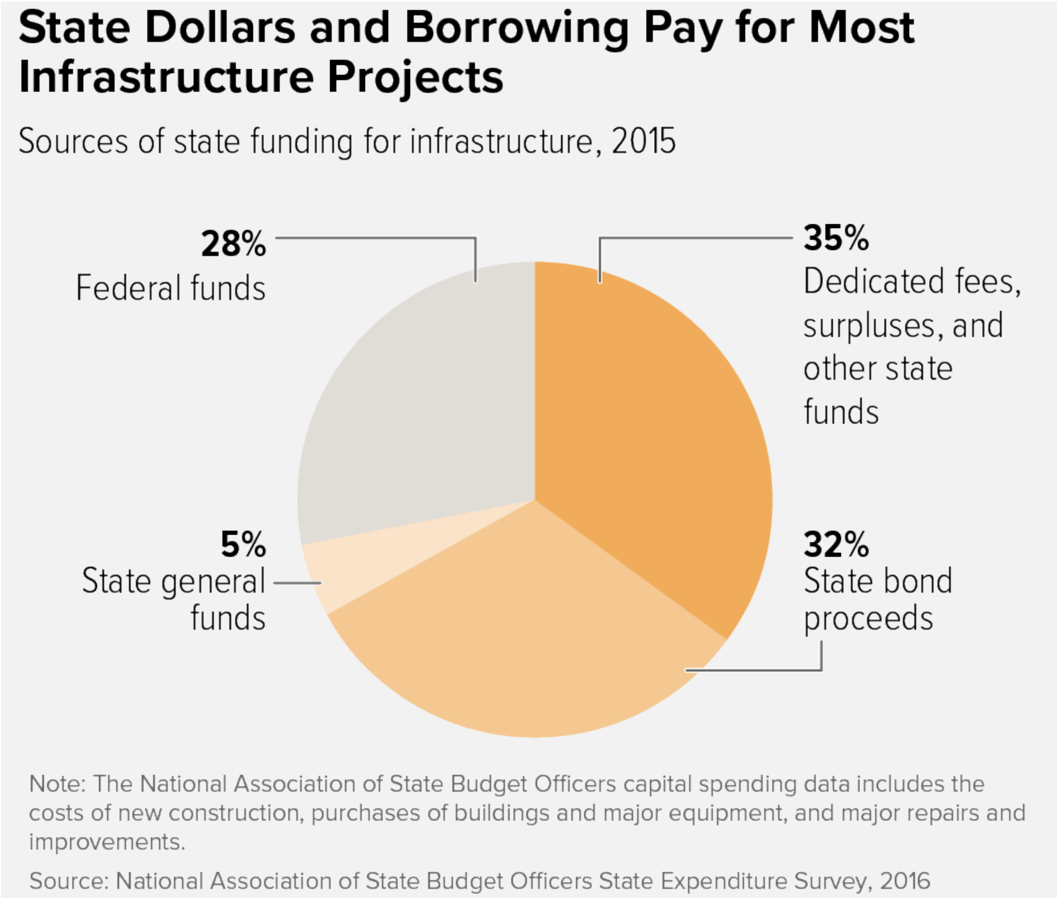


Figure 3.1: Sources of funding for state infrastructure. Source: McNichol (2017).

2014). As shown in Figure 3.1, 32% of state infrastructure is financed by bonds (McNichol, 2017). The US muni bond market has financed three-quarters of U.S. infrastructure, "including 4 million miles of roadways, 500,000 bridges, 1,000 mass transit systems, 16,000 airports, 25,000 miles of inter-coastal waterways, 70,000 dams, 900,000 miles of pipe in water systems, and 15,000 waste water treatment plants" (CDFA, 2011). A breakdown of the use of proceeds from US municipal bonds issued from 2010 to 2016 is shown in Figure 3.3.

The 90,000 local governments that have municipal bond issuing authority may be relatively small individually, but in aggregate, their spending can be substantial. As stated in *The Handbook of Municipal Bonds* (Feldstein and Fabozzi, 2008), "In 2003, federal spending was just 48% greater than state and local spending," as shown in Figure 3.2. In terms of infrastructure investment, according to the MSRB (2017), "Federal spending is generally directed at transportation projects; state and

Public Infrastructure	Federal	State and Local	Private
Schools	$0.40	$75.50	$23.80
Highways	30.2	36.5	n/a
Drinking Water	2.6	25.4	n/a
Mass Transit	7.6	8.0	0.0
Energy	1.7	7.7	69
Telecommunications	3.9	n/a	68.6
Other	16.1	17.2	12.1
Total	$62.50	$170.30	$173.50

Source: McNichol, Elizabeth. February 23, 2016. "It's Time for States to Invest in Infrastructure." Center on Budget and Policy Priorities. https://www.cbpp.org/research/state-budget-and-tax/its-time-for-states-to-invest-in-infrastructure.

MSRB

Figure 3.2: The amount of spending on public infrastructure in 2004. Source: McNichol (2017); MSRB (2017).

local government spending focuses on schools, highways and water systems; and private-sector investment is concentrated in electricity and telecommunications assets," and furthermore, "it is state and local governments that commit the bulk of the capital required to pay for U.S. infrastructure," which is why municipal bonds are crucial to infrastructure investment in the US.

As McNichol (2017) states, although the 2018 US budget included tax credits for private-sector infrastructure investors, it left out consideration for "maintenance of existing roads, bridges, and water lines, and construction of public schools and many public transit projects." Nevertheless, states are actually cutting funding to infrastructure in terms of real dollars: state and local spending on capital projects has decreased from "a high of 3 percent of the nation's gross domestic product (GDP) in the late 1960s to less than 2 percent in 2015. Falling federal spending on infrastructure is exacerbating the problem." Furthermore, the most recent American Society of Civil Engineers (2016) infrastructure rating report card gave US infrastructure a D+ or "poor" rating, and estimated that it would require $4.6 trillion in investment to bring it back to a state of good repair. Since state and local governments

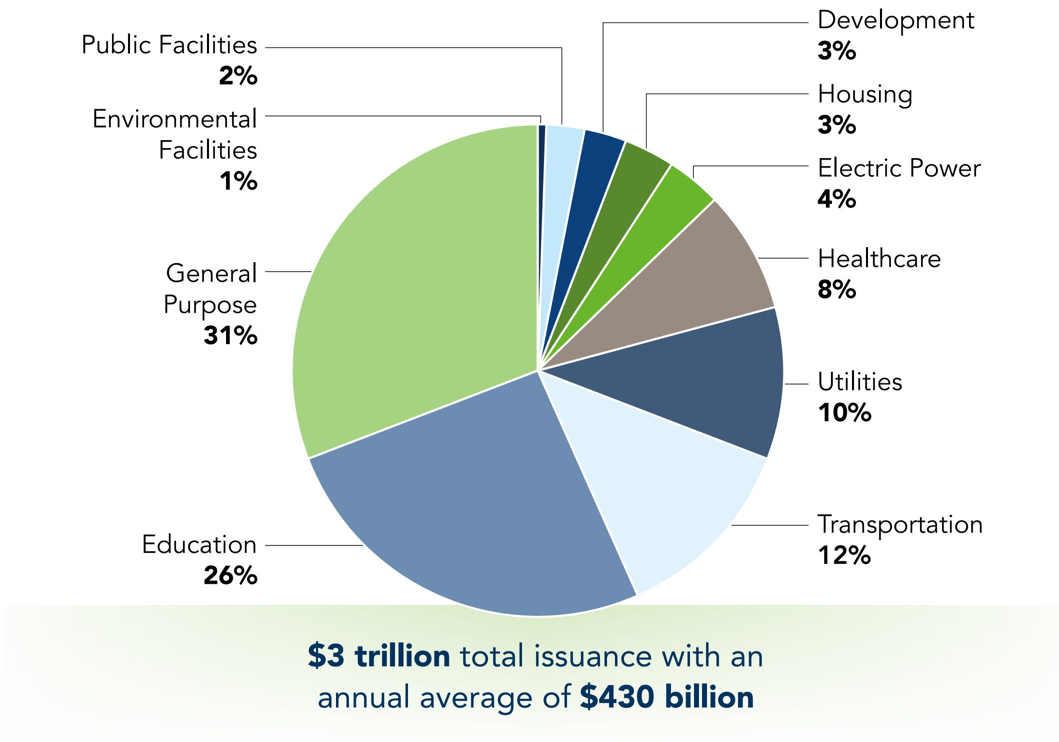


Figure 3.3: The use of proceeds for municipal bonds issued from 2010-2016. Source: MSRB (2017).

use municipal bonds to finance over 32% of their infrastructure investments (McNichol, 2017), it is crucial to focus on this market in order to leverage investment in sustainable infrastructure.

The US municipal bond market has unique characteristics in that it is one of the more mature bond markets with a high rate of issuance. Additionally, unlike the corporate bond market, the muni bond market is not dominated solely by large bonds issued for and purchased by large institutional investors. Instead, around 40% of muni bonds are bought by individuals in the retail market (SIFMA, 2018). As a group, household retail investors represent the single largest sector of buyers of municipal bonds in the U.S., as shown in Figure 3.4, and by 2012 they collectively held nearly $2 trillion of these securities (U.S. Securities and Exchange Commission, 2012). This makes muni bonds a way for individual Americans to directly invest in their local infrastructure, and muni bonds are issued by all sizes of municipalities and governmental agencies. Overall, “the municipal bond market plays a

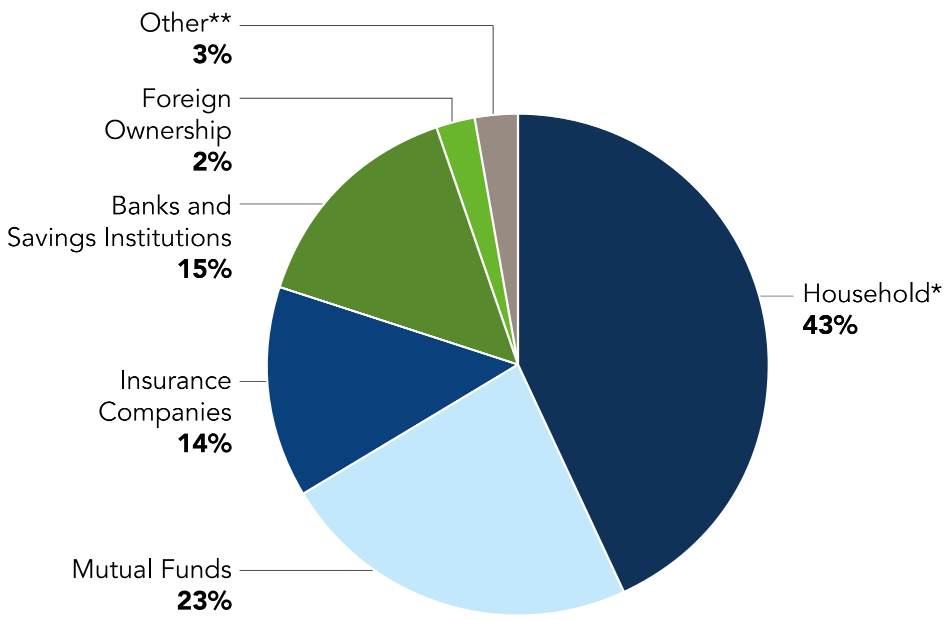


Figure 3.4: Breakdown of types of bond owners for US municipal bonds. Source: MSRB (2017).

vital role in lowering the cost of capital for state and local governments" (Chiang, 2017).

A key reason for the uptake by the retail market in the U.S. is that "interest paid on municipal securities is typically exempt from federal income taxation and may be exempt from state income and other taxes as well" (U.S. Securities and Exchange Commission, 2012). Therefore, the muni market is "supported primarily by individual investors seeking to shield income from taxes", and this tax exemption "allows issuers to offer lower yields than those carried by comparable taxable debt offerings" (Chiang, 2017). This tax efficiency, along with historically low default rates and a sense of local engagement, has made investing in muni bonds popular for retail investors in America.

Municipal bonds broadly have two types: general obligation bonds, or revenue bonds. General obligation bonds are guaranteed on the basis of local tax receipts, and revenue bonds are secured on the expected revenues generated from a public project. Revenue bonds are issued for specific projects, so that the proceeds raised from the bond sale earmarked so that they can be applied only to the to the purposes described in the "Use of Proceeds" section in the bond's Official Statement. The use of proceeds for general obligation bonds are not necessarily restricted to specific projects. In the case of default, general obligation bonds have full recourse to the issuer. The debt recourse for revenue bonds consists of revenue streams from the issuer, such as taxes, but not recourse to the issuer themselves.

There are two further muni bond category types that can come into play in the green bond universe: project bonds and asset-backed securities. The proceeds from project bonds are ring-fenced for use in a specific project, and accordingly debt recourse is restricted to solely the project's assets and revenues rather than the issuer's. Muni bonds that are issued as asset-backed securities raise funds that are either earmarked for various use of proceeds, or ring-fenced for a specific project. These types of bonds are guaranteed on the basis of a collection of assets that have been grouped together as collateral. These types of bonds can be a promising way to group together smaller projects and raise money at benchmark size for further development, which could be an efficient way of raising capital for the types of smaller, more fragmented projects that are common in urban areas. An example of which includes PACE bonds, which are described in detail in Section 3.9.4.

In recent times, a new type of muni bond has entered the U.S. market, the green muni bond, the proceeds of which are used to fund eco- and climate-friendly projects, such as renewable energy, building retrofitting for energy efficiency, LEED-certified building development, new sewers and storms drains, public transport projects, etc. The rest of this chapter will discuss these bonds in detail.

3.2 Climate Federalism

According to the Climate Bonds Initiative (2016), "the U.S. continues to be a leader in muni green bonds despite the political context." Notwithstanding the fact that the US national government has withdrawn their support for the Paris Agreement, 15 states have grouped together under the US Climate Alliance in order to honor their Paris Agreement commitments and to "address the existential threat of climate change by investing in clean energy, energy efficiency and clean transportation and making our communities and our economy more resilient to the climate impacts that are already occurring" (US Climate Alliance, 2017). This Alliance represents 36% of the US population and $7 trillion dollars in economic activity, "enough to be the world's third largest country." The primary objective of the Alliance is meeting their share of the emissions cuts agreed to previously by the US in the Paris agreement, "a 26-28% reduction in greenhouse gas emissions below 2005 levels by 2025." This movement is echoed by We Are Still in and the Council of Mayors, a group of over 2,600 signatories that have signed up with the intention of honouring their Paris Agreement obligations (We Are Still In, 2017; United States Conference of Mayors, 2017; Bloomberg and Pope, 2017).

The reason that individual American cities and states have the political will and fiscal capacity to essentially defy the national US government over their climate policies is because of the way that the country's government is federalised, so that states and cities can function as semi-autonomous regions (Rabe, 2018; Lutsey and Sperling, 2008; Marlowe, 2014). The US muni bond market thrives because of the federalised borrowing powers that are given to cities, counties, and states (Feldstein and Fabozzi, 2008; MSRB, 2017). The federalism of the American government was set in place intentionally very early on in the establishment of the country. This system of federalism has led to conflict between the national government and local governments many times, not least as one of the causes of the American Civil War from 1861-1865.

Even now, the political landscape of the US is highly fragmented, with each individual state or municipality representing a population with a range of different political viewpoints, as is apparent from the willingness of many state and city governments to break with national policy over climate action. While federalism can make it difficult to navigate policy on the national level, it does enable a pluracy of political regimes that may not be readily apparent on the international scale. This is one reason why this research into US green muni bonds is timely and relevant: the viewpoints and political will of a large segment of American society is not being reflected in national policy, however this does not necessarily stymie progress on the climate front as many observers may have feared.

3.3 Green Municipal Bonds: Background

A growing number of muni bonds are being issued in the US as green-labelled municipal bonds. A useful definition of a green municipal bond is given by Saha and D'Almeida (2017), who state that:

> a green municipal bond is a fixed-income financial instrument for raising capital through the debt capital market. As with any other bond, the bond issuer raises a fixed amount of capital from investors over an established period of time (the "maturity"), repays the capital (the "principal") when the bond matures, and pays an agreed-upon amount of interest ("coupons") during that time. The key difference between a green bond and a regular bond is that the former is explicitly labelled as "green" by the issuer, and a commitment is made to use the proceeds of the green bond to exclusively finance or re-finance projects with an environmental benefit.

Overall, 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." Just like green bonds in general, there is a segment of bonds that could qualify has green, but issuers have not, for whatever reason, chosen to label them as green. Projects that are eligible to be financed by 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). Their relationship to municipal bonds and green bonds in shown in Figure 2.1.

The advantages of green muni bonds are outlined in Saha and D'Almeida (2017) and are similar to those of the green bond market in general. To summarise, green muni bonds are helpful to issuers who wish to grow and diversify their investor base, especially those who want to appeal to the expanding ESG investor class. “By issuing a green bond, municipalities have attracted investors who do not typically buy municipal bonds, including environmental, social, and governance (ESG) investors and institutional investors.”

Green muni bonds also foster greater cross-agency collaboration, because the “process of structuring and issuing a green bond can also promote cross-agency cooperation within a city by bringing together departments responsible for finance, sustainability, infrastructure, and planning.” Green issuance sends a green signal to the market that the issuer is interested in sustainable development, and the investors of green bonds are interested in supporting that agenda.

One of the biggest challenges to the green bond market is the lack of bankable green projects or project pipelines. In order to be financed through the debt capital markets, the projects need to have proven cash flows and sufficient backing from their issuers in order to sufficiently de-risk the project enough to attract funding. One key problem with the green infrastructure pipeline is that, especially in terms of energy projects, these types of projects are generally smaller in scale than the bond markets typically like to see come to market. Aggregation and securitisation are keys to scaling up this market, because “without suitable aggregation mechanisms, the typical small-scale green projects can find it difficult to tap into the bond market” (Saha and D’Almeida, 2017).

Institutional investors such are generally only interested in benchmark size bonds of about $250 million and up, however the US municipal bond market is different from the overall bond market in that it has a large amount of smaller-sized yet successful issuance. This is largely due to the fact that most muni bonds are issued as series bonds, where a larger bond is broken down into a series of bonds with differing sizes, tenors, and coupons. So far, this has not noticeably been a barrier to entry for the muni bond market, although only the larger bonds are given prominence, such as in index listings, as will be seen in later sections.

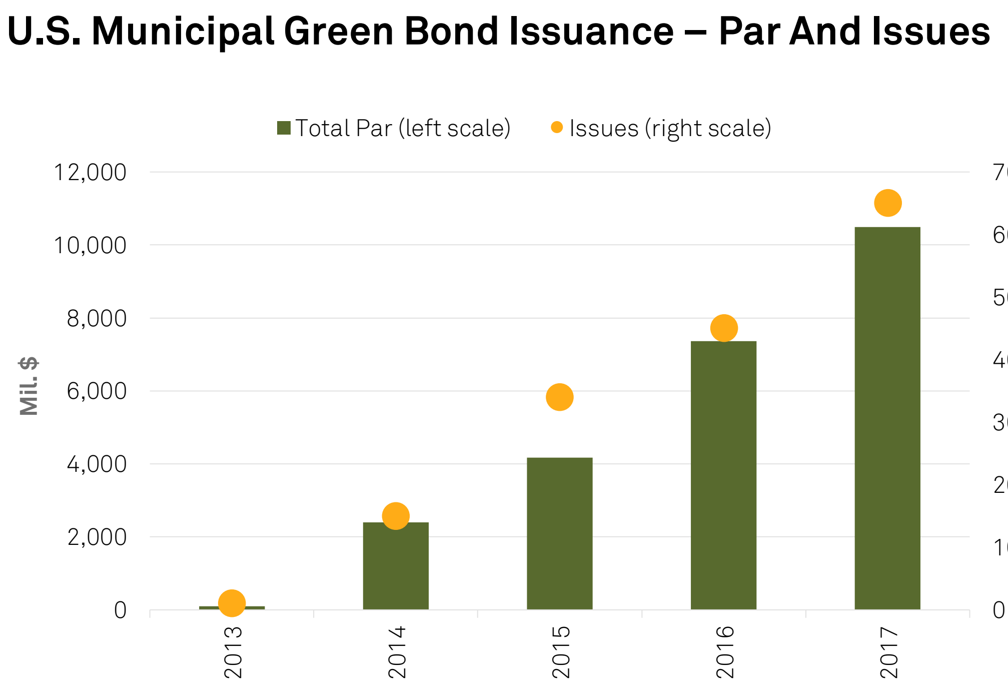


Figure 3.5: The size of the US green municipal bond market by year, both in terms of issuance and total amount outstanding. Marin et al. (2018).

3.4 History and State of the Market

The first green muni bond was issued by Massachusetts in 2013, and the market has grown rapidly since then. By 2017, green labelled muni bond issuance reached $12 billion, which was 27% of the total US green bond issuance for that year (Marin et al., 2018; Climate Bonds Initiative, 2018a), as shown in Figure 3.5. So far, 31 states have issued green muni bonds, although the top 3 states account for 64% of activity. As of mid-2018, "New York ranks first (USD7.2bn issued as of end Q2 2018), followed closely by California (USD6.9bn). The third largest is the pioneer: Commonwealth of Massachusetts (USD2.9bn)" (Climate Bonds Initiative, 2018a).

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 $4.7 billion in issuance, up by 47% over 2014", making a total of $9.7 billion outstanding and an additional $20.6 billion 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

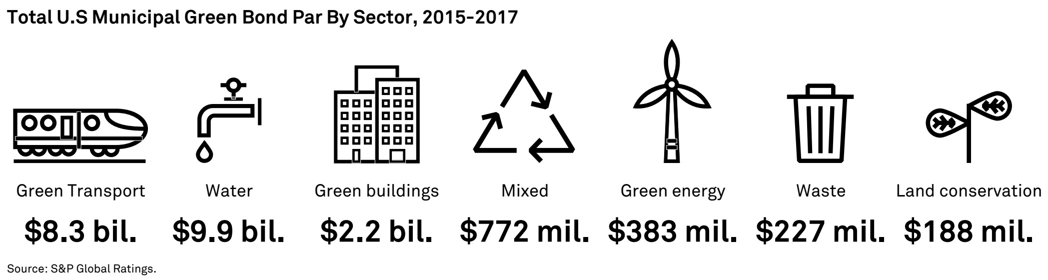


Figure 3.6: Amount outstanding for green municipal bonds by sector, 2015-2017. Marin et al. (2018).

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 billion in green municipal bonds in 2017, an increase over the $6.8 billion 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 $10 billion mark with New York retaking the lead from California and becoming the US state with the highest 2017 issuance of municipal green bonds and the highest cumulative issuance," and forecasts that 2018 issuance should grow to $20 billion.

According to the S&P Global report titled, "2018 U.S. Municipal Green Bond & Resiliency Outlook" (Marin et al., 2018), "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" (see Figure 3.6), and that "self-labeled municipal green bond issuance continues to rise, marching up steadily to 65 issues totalling $10.4 billion in 2017, representing about 25% of the $42.2 billion par total of U.S. green bond issuances that year" (shown in Figure 3.5.

They found that 64% of issuance from 2013-2017 was from New York, California, and Massachusetts, but 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. They also state that "we believe the market for financing projects with environmental benefits is significantly larger than the self-labeled universe of municipal green bonds," which is in alignment with the non-labelled but climate-aligned universe of bonds. As of 2017, 43% of green muni bond issuances have been reviewed externally, up from only 13% in 2013.

In a report issued recently specifically about US municipal green bond issuance by the Climate Bonds Initiative (2018a), they noted that "US Muni green bond issuance dropped in H1 2018" (see Figure 3.7). This is occurring as a result of changes in the tax code in the Tax Cuts and Jobs Act that was passed by Congress in 2017, and generally has curtailed the ability to issue refunding bonds in the municipal market in general. Overall muni bond issuance decreased by 22% in the first half of 2018 due to this effect: while new capital bond issuance increased almost 20%, refunding bond issuance decreased by 58%, depressing the entire market.

This report also identified US municipal issuers who were issuing climate-aligned but unlabeled bonds who could potentially help build the green labeled muni bond sector. They found nearly 1,500 issuers whose revenues come from climate solutions, who have a total of $254 billion in bonds outstanding. Only $14 billion of these bonds (from 23 issuers) are green labeled. This report targets specific pure play issuers that could easily label their bonds as green as an illustration of how much headroom this market has to grow. Agencies that they identified as issuing qualifying bonds include the New York City Municipal Water Finance Authority, Chicago Transit Authority, Ohio Air Quality Development Authority, the Florida Department of Environmental Protection, and The Tuolumne Wind Project Authority.

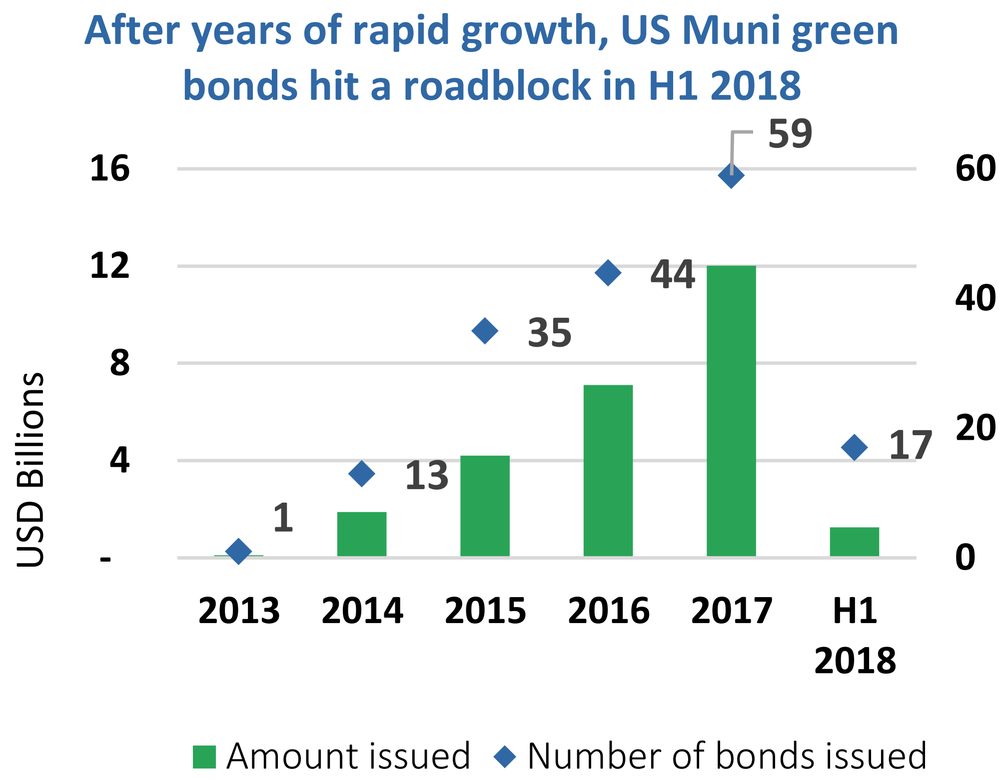


Figure 3.7: Amount outstanding for green municipal bonds by sector, 2015-2017. Climate Bonds Initiative (2018a).

3.5 Green Muni Bonds: Policy Review

The Clean Energy and Bond Finance Initiative (Milford et al., 2012) has discussed using the municipal bond market in the United States to scale up investment in green infrastructure, stating that municipal bonds are an "old, well-established conventional tool" in the US, and they could therefore be key to scale up clean energy. However, there needs to be one critical change: "Energy policy makers must figure out how to successfully transfer conventional credit enhancement tools to the clean energy sector." There is discussion about novel financial instruments for climate-friendly projects, but as pointed out by Richard Kauffman (Chairman of Energy and Finance for New York State) (2013), the key could lie in "applying financial techniques that have already been invented and are used widely in other parts of the economy, but have not yet been applied to this sector", such as green muni bonds.

A report, "How to Scale up Demand for U.S. Clean Energy and Green Bonds?"

(2014), also recommends that clean energy bonds could be fostered by issuing green muni bonds with longer tenors, larger issuances, more taxable bond offerings, and aggregation of multiple energy projects into a single offering. They also advocate "explicitly label[ling] all clean energy bonds as 'green bonds' in order to harmonize and integrate bond financing for renewables and energy efficiency into what is clearly consolidating into a distinctive category of the bond market." Milford et al. (2014) also state, "using bonds in new ways, states and regions can lead the way in a new era of clean energy finance that reduces the cost of capital and financial risk."

Within this context, green bonds can be seen to have an important role in the financing of green infrastructure for cities, especially against the background of "declining federal subsidy support and tighter bank lending, and a growing interest in bond financing" (Clean Energy Group and Croatan Institute, 2014). In their report titled, "What Investors Want: How to Scale up Demand for U.S. Clean Energy and Green Bonds", the Croatan Institute in collaboration with the Clean Energy Group (2014) examine investor demand for clean energy bonds in the US market. In particular, this work delves into the investment characteristics that institutional investors are particularly looking for, based on interviews with "over three dozen bond buyers", including corporations, investment banks, and public pensions. They discuss the distinctions between corporate green bonds and municipal green bonds, and outline "key investment criteria these investors use when evaluating green and clean energy bonds: liquidity, credit quality, size, terms, use of proceeds, and labeling."

Saha (2016) published a short policy paper that reiterates the point that the US muni bond market could be ideally situated to raise capital for sustainable infrastructure via green muni bonds, and that this is a nascent but growing sector. This paper uses the same figures from the Climate Bond Initiative that have been discussed previously, and claims that no pricing premium has been found as of yet despite higher issuance costs. Overall, the confluence of climate urgency and investor demand will "provide a unique opportunity for state and local governments to tap into the growing market to access financing for a multitude of infrastructure and climate projects." In 2017, Saha followed this up with a chapter on green municipal bonds in a book titled *Finance for City Leaders* (Saha and D'Almeida, 2017) . This chapter provides an overview of what green municipal bonds are and how to issue them, along with their advantages and the challenges they face. This is a high level introduction to the market, which is an appropriate resource aimed at city policy makers. This chapter is a useful reference and summary of the green municipal market to date, and also describes some specific green muni bond business cases and provides some policy recommendations to help spur growth. The information in this chapter is very similar to that presented in a preceding report authored by the Climate Bonds Initiative, titled "How to Issue a Green Muni Bond: The Green Muni Bonds Playbook" (Climate Bonds Initiative et al., 2015).

In 2014, 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), a point which informs the main objective of this research and our inquiry into the presence or absence of greenium.

Comptroller Stringer posits three benefits for NYC from green bond issuance: "expanding our investor base, creating a model program for other cities around the United States to follow, and encouraging a greener capital program." New York City is already one of the largest issuers of municipal debt, "with an anticipated $30 billion of borrowing over the next four fiscal years." Furthermore, the tracking of use of proceeds that is required to issue a green bond "could lead to greater focus on environmentally beneficial projects," so that "sustainability could be tracked and such capital needs prioritized."

A subsequent report by Stringer (2015) reports on market research that was conducted to gauge market demand for green muni bonds issued by NYC. Representatives from the city's Office of Management and Budget met with seven large institutional green bond buyers, including money managers, insurance companies, and investment firms with ESG mandates. These stakeholders were supportive of expansion of green muni bond issuance, stating that "the lack of supply in both the primary and secondary market remains a concern" in light of increasing demand. Furthermore, the investors felt that a high quality green bond program would reflect favourably on the city's reputation, and in turn, the size and credibility of NYC's bond issuance could add credibility to the green muni bond market. Overall, it would "re-confirm the City's strong management practices and improve the City's risk profile amongst investors." One of the main takeaway messages was that "the City may be able to realize a quantifiable pricing impact depending on the addition of new green investors, potentially saving taxpayers money over the long-term."

In 2017, California State Treasurer, John Chiang, spearheaded the release of a report entitled "Growing the U.S. Green Bond Market, Volume 1: The Barriers and Challenges" (Chiang, 2017), which outlines some of the findings that resulted from a listening tour of 57 participants from 27 institutional investors and underwriters active in the green muni bond market around the US between February and August of 2016. The findings of this report echo some of the points made in the previously-discussed sources: there is a lack of supply, not demand. The main issues that are flagged as reasons the market has been slow to grow are "a combination of sporadic deal flow, small offering size, index ineligibility, illiquidity, and lack of standardization," however, "the more fundamental explanation for green bonds' slow takeoff in the United States lies not in the bond market itself, but in the broader cultural, political, and legal environment that holds back action" due to the fact that there is no national political consensus or mandate on climate change. Nevertheless, other issues that may prevent an issuer from issuing a green bond includes the "widespread perception that green issuance adds cost and complexity without providing a demonstrable benefit in pricing," and participants in the listening tour had so far seen little to no evidence for a green bond premium, "particularly for new issues." However, some participants said that "it is possible – perhaps even likely – that persistent premiums will eventually emerge as the U.S. green bond market matures."

Furthermore, the listening tour participants “emphasized that improving liquidity is a major hurdle for green bonds from U.S. issuers” which would help to dispel the “myth that green bonds are expensive, exotic, and illiquid”. However, the participants ranked credit quality and yield as the most important factors influencing their green bond portfolio decisions, with liquidity coming in third. The main factor affecting liquidity is small offering size, with the report stating that “issues much reach a $250 million threshold to be eligible for index inclusion”, however this is only true for corporate bonds, not muni bonds, with the report itself stating that “liquidity is not as severe a problem in the municipal green bond market, which has always featured smaller offerings.” Nevertheless, there is still demand for state-level aggregators to bundle up smaller projects into larger bonds.

One of the very first reports to suggest that clean energy projects in the US could be financed through muni bonds was “Clean Energy and Bond Finance Initiative (CE+BFI): An Action Plan to Access Capital Markets”, released by the Clean Energy Group and the Council of Development Finance Agencies (Milford et al., 2012). This report opens with the statement: “The prospect for sustained and growing federal financial support for clean energy is, to put it bluntly, bleak, especially without additional congressional action. Other options must be pursued, especially state, regional and local financing tools.” As a result, “more clean energy experts are looking to the states, regions and localities–a return to federalism–as an investment strategy.” One of the mechanisms that could be leveraged are the over 50,000 development finance agencies, which are “state, county, and municipal agencies and authorities that provide or support economic development financing programs, including tax-exempt and taxable bonds”. At the time this report was written, the development agencies had not been very active in the clean energy sector. The proposals in this report, according to Milford et al, make sense against a background of increasing energy federalism. This paper also discusses the tax treatment of bonds, and raises Private Activity Bonds (PABs) as one possible instrument for clean energy financing. Overall, the main thrust of this policy paper is that the existing development agencies can use their tax-advantaged status to help with clean energy financing.

The previous paper was built upon by another report from the Clean Energy Group and Council of Development Finance Agencies, this one titled "Reduce Risk, Increase Clean Energy: How States and Cities are Using Old Finance Tools to Scale Up a New Industry" (Sanders et al., 2013). This paper explores many of the same concepts as the previous one, stating that "conventional tools such as bonds can meet much of the [clean energy] challenge to dramatically increase investment." However, this report expands on this idea to elaborate on mechanisms for credit enhancement as a way of stimulating the sector. In particular, "states and cities, for the first time, are beginning to use these credit enhancement tools to finance clean energy technology deployment." This report also discusses some of the more recent bond issuance models, such as the Morris Model from New Jersey, the Hawaii securitised bond issue, the Delaware Sustainable Energy Utility (DSEU), and the NYSERDA model, which are discussed further in Section 3.9. Credit enhancements that can be used to de-risk clean energy projects are discussed, including loan guarantees, debt service reserves, subordinated debt, interest rate buy-downs, bank letters of credit, and credit insurance. Rydin et al. (2015) also provides an overview of the Morris Model.

Milford et al. (2014) wrote a report for the Brookings Institution in entitled "Clean Energy Finance Through the Bond Market: A New Option for Progress", which follows on from the previous report. The main point from this work is that "state and local bond finance represents a powerful but underutilized tool for future clean energy investment." As this report states, "different types of financing are going to be required to scale up the clean energy industry", and "bond finance holds tremendous potential for future clean energy investment, perhaps at levels in the tens of billions of dollars in the next several years." This report also addresses some of the challenges facing this market sector, namely: "Weak cooperation between development finance agencies and clean energy offices", "lack of a large market for clean energy bonds", "spotty performance data and the lack of standardized documentation", and limited institutional investor demand. Despite these limitations, "states and regions have led clean energy policymaking in the United States," including the use of renewable portfolio laws and green banks, and "given this history, states and regions should once against lead from the front to scale up the use of existing development finance tools for clean energy." The policy recommendations that are made include fostering partnerships between finance experts and clean energy officials at the state and local levels, and the use of credit enhancement to mitigate risks for bond financed clean energy projects. Also, the availability of data should be improved, and documentation should be standardised in order to better manage investment and project risk. These policies can help create a pipeline of "rated and private placement deals" in order to "meet demand by institutional investors for fixed-income clean energy securities."

3.6 Issuing Green Muni Bonds

Green muni bonds are issued in largely the same way as conventional municipal bonds in the US, however there are some extra steps involved in order to label the bond issuance as green. The steps involved are described in detail by Saha and D'Almeida (2017) and in the Green Muni Bonds Playbook authored by the Climate Bonds Initiative (2015), but the general process is as follows:

- Identifying qualifying green projects and assets: The issuer goes through their portfolio of existing assets or projects they have in development and select those that qualify as green according to the GBP (or other green bond standard). As stated by the CBI, "The 'greenness' of the issuer is irrelevant – it's about the physical assets or projects" (Climate Bonds Initiative et al., 2015).

- Arranging independent review: A second-party external reviewer is brought in to look at "the green credibility of the proposed Green Muni Bond investments" along with "the processes established for tracking funds and for reporting." This step is key to verifying that any so-called green bonds are credibly green and thereby prevents greenwashing.

- Setting up tracking and reporting: "It is critically important that issuers of green municipal bonds always maintain full disclosure on the allocation of proceeds" (Saha and D'Almeida, 2017). This step also ensures that the total amount of financing raised by the bond issue is fully allocated to the green projects specified in the use of proceeds.

- Issuing the green bond: this step is generally the same as with a conventional bond. First, if approval for the bond issuance is required, that is obtained. Then, "working with an investment bank or advisor, they structure the bond." After that, a credit rating is assigned, and the bond is marketed and priced. "It should be noted that creditworthiness is judged the same as for other bonds. Issuers should expect to get credit rated in the usual manner" (Saha and D'Almeida, 2017).

- Monitor Use of Proceeds and Report Annually. It is a requirement of the GBP that in order to "maintain the status of a green municipal bond, the issuer would need to provide confirmation to investors at least once a year that the funds are being used for qualifying green projects."

While the additional steps can add some costs and workload to getting the bond to market, subsequent green bond issuance will be simpler, because "repeat green municipal bond issuers can use the same framework for identifying green projects and assets, the same independent reviewer, and the same processes for management of proceeds and reporting" (Saha and D'Almeida, 2017; Climate Bonds Initiative et al., 2015).

As stated by Saha and D'Almeida (2017); Climate Bonds Initiative et al. (2015), "the majority of green bonds issued are green general obligation bonds backed by the issuer's entire balance sheet. The other types are green revenue bonds, green project bonds, and green securitized bonds." However, there is a larger universe of bond types, and several of these are particularly relevant to green muni bonds. The different types of bonds are set apart not only by the guarantees upon which they are issued, but also by their different debt recourses in the case that things go wrong and the bond goes into default (Climate Bonds Initiative, 2015a).

3.7 Taxation

A feature of municipal bonds is that their interest is usually exempt from federal income tax, and is also frequently exempted from state taxation as well when the bond buyer lives within the state in which the bond was issued (Feldstein and Fabozzi, 2008). This has the result of raising the effective yields of tax exempt muni bonds relative to their taxable counterparts, which in turn affects both the price to the buyer, and the cost of capital for the issuer, because the tax exemption acts as a form of subsidy. As stated by Milford (2012), “A bond issuer’s objective is to raise capital at the lowest cost. Tax-exempt treatment of Governmental Bonds makes them the lowest cost option.”

In 2014, over $2 billion of tax-exempt green muni bonds were sold in the U.S. (Clean Energy Group and Croatan Institute, 2014). Individual investors are particularly active in the tax-exempt green muni bond market, especially since these types of local-issue bonds also provide a means of informing residents of the municipalities about capital investment decisions, and a way of earning tax-exempt income by investing in their local communities. Nevertheless, tax exempt muni bonds are still crucial to financing infrastructure in the US, because “between 2000 and 2014, the federal tax exemption saved state and local governments an estimated $714 billion in additional interest expenses” with savings of $8 billion in 2015 alone (United States Conference of Mayors, 2017a). Without tax exemption for muni bonds, issuers will be forced to pass on higher interest rates to investors in order to cover their increased cost of capital due to taxation.

Regardless of whether they are general obligation or revenue-backed bonds, this tax exemption is in place (for domestic investors in the US) as a form of a subsidy for infrastructure that is for the public good. Tax exemption benefits both the issuers and retail bond buyers, because “tax exemption effectively lowers the borrowing cost for state and local government bond issuers, as investors are willing to accept a lower yield comparable to other taxable securities of similar risk and maturity due to the tax benefit offered by municipal bonds” (Luby, 2012). However, there is also a segment of the muni market that are taxable, whether because they are for projects that seemingly do not provide major benefit to the public, or because they are targeting investors that can't take advantage of tax exemption in order to achieve the right yields, such as institutional investors or other corporate entities. According to the SIFMA Municipal Bond Issuance Survey for 2017, tax-exempt municipal issuance is expected to reach $375.0 billion in 2017, compared with a total taxable issuance of $42.5 billion (SIFMA, 2018). This tax exemption status has an important effect on the effective yield of municipal bonds, and this difference in yield can have a significant impact on the cashflows of returns from muni bonds (O'Hara and SIFMA, 2012). However, while taxable muni bonds may seem to be at a disadvantage for many domestic retail investors, they open up the market for international and institutional investors, which, in addition to stricter rules around qualifying for tax exemption, explains their growing use (Invesco, 2013; Barnett, 2017).

The initial impression is that it would be disadvantageous to issue taxable municipal bonds in a market where nearly half of the buyers are retail investors, who are individuals who stand to benefit from the beneficial tax treatments that tax-exempt munis provide. However, this particular characteristic of the US muni bond universe is changing rapidly, especially under the regime change resulting from the Trump presidency. There were fears in the market that Trump would remove the tax-exemption status from muni bonds as a whole, which is one explanatory factor around the decline in market returns in the aftermath of his election in 2016. While the most recent budget has not removed tax-exemption, it has made it impossible to issue refinancing bonds, which normally makes up almost 20% of the market. Many institutional investors such as public pensions and charitable foundations already have tax-exempt status, so there is no particular advantage to investing in tax-exempt bonds for them (Clean Energy Group and Croatan Institute, 2014).

However, in the California Treasurer's report (Chiang, 2017), many participants felt that "the unique tax treatment of muni bonds in the United States impedes green bond market growth" because it essentially excludes all foreign investment and sizeable amount of domestic investment from this asset class. They proposed state or national subsidies that would allow taxable green bonds to be issued with the same yields as tax-exempt green bonds, thus levelling the playing field for those that don't benefit from tax exemption. As stated in (Kalaitzidis, 2010), "Taxable municipal bonds possess several qualities that make them particularly attractive when compared to taxable corporate bonds and Treasuries," including favourable spreads, higher yields, and lower historical default rates along with higher average recovery rates. These works cited the model of the Build America Bonds (BABs) or other tax credit bonds as a potential existing mechanism to emulate or expand, as explained in the next section.

3.8 Tax-Credit Municipal Bonds

A class of muni bonds that could be leveraged to finance green infrastructure development in the US are the tax credit bonds, such as the Build America Bonds (BABs), Certified Renewable Energy Bonds (CREBs), and Qualified Energy Conservation Bonds (QECBs). These bonds were created as part of the American Recovery and Reinvestment Act (ARRA) of 2009 and were intended to encourage investment in recovery from the credit crisis of 2008 (Marlowe, 2014). It is unlikely that the Trump administration would bring them back in name or form, however the BABs could be slightly modified to fit with the prevailing mandate to increase investment in infrastructure.

3.8.1 Certified Renewable Energy Bonds (CREBs) and Qualified Energy Conservation Bonds (QECBs)

Two types that are particularly relevant to the energy sector are CREBs and QECBs, which were bonds that were created at the federal level explicitly to serve as a stimulus for investment in clean energy infrastructure. According to Milford et al. (2012), "ARRA has been the largest stimulus program for clean energy in American history, about $65.6 billion dollars from 2008-2012. This includes the $3.2 billion energy efficiency block grant funding for municipalities." CREBs, Clean Renewable Energy Bonds, are tax-credit muni bonds that were created specifically to provide a mechanism for raising money for energy technologies such as: geothermal, solar, wind, biomass, hydroelectric, waste to energy, and tidal. Eligible issuers included local and state governments and schools (DSIRE, 2015a). QECBs, or Qualified Energy Conservation Bonds, could finance the same types of energy projects as CREBs, however the funds were allocated from the federal government to each state in proportion to population. From there, each state could distribute its QECB funds to eligible energy project applications that came from municipal governments as a means of offering low cost financing. QECBs offered the bond holder tax credits rather then cash interest payouts, which was the mechanism of subsidy by the U.S. government (DSIRE, 2015b).

Some accused the QECB program of "chronic underutilization" (Milford et al., 2012), however, some municipalities, such as Los Angeles and Louisville, Kentucky, fully utilised their QECB allocation (Clean Energy Group and Croatan Institute, 2014). Nevertheless, there were many reasons behind this low uptake, including high transaction costs due to small issuances, and "a lack of awareness and capacity in bond issuance" (Kidney and Oliver, 2014). Nevertheless, the CREB and QECB bond mechanisms, amongst others, encouraged about $230 million annually in new bond issuances. This is in addition to the nearly $2 billion of tax-exempt green muni bonds that have been sold in the U.S. since September 2014 (Clean Energy Group and Croatan Institute, 2014).

3.8.2 Build America Bonds (BABs)

BABs (like CREBs and QECBs) were created as part of the ARRA plan to help the US recover from the Great Recession of 2008, which "led to a 68 percent drop in monthly municipal bond issuances and a doubling of borrowing costs" (Puentes et al., 2013). BAB bonds are taxable bonds that were issued specifically in 2009-2010 that either received a 35% federal subsidy to the issuers (Direct Payment BABs) or a federal tax credit worth 35% of owed interest to the bond buyers (Tax Credit BABs). One of the key motivations behind the creation of BABs was that they would provide "access to the much bigger $30 trillion conventional taxable bond market, which includes more long-term institutional investors." Overall, "by broadening the set of investors interested in holding municipal bonds, BABs helped

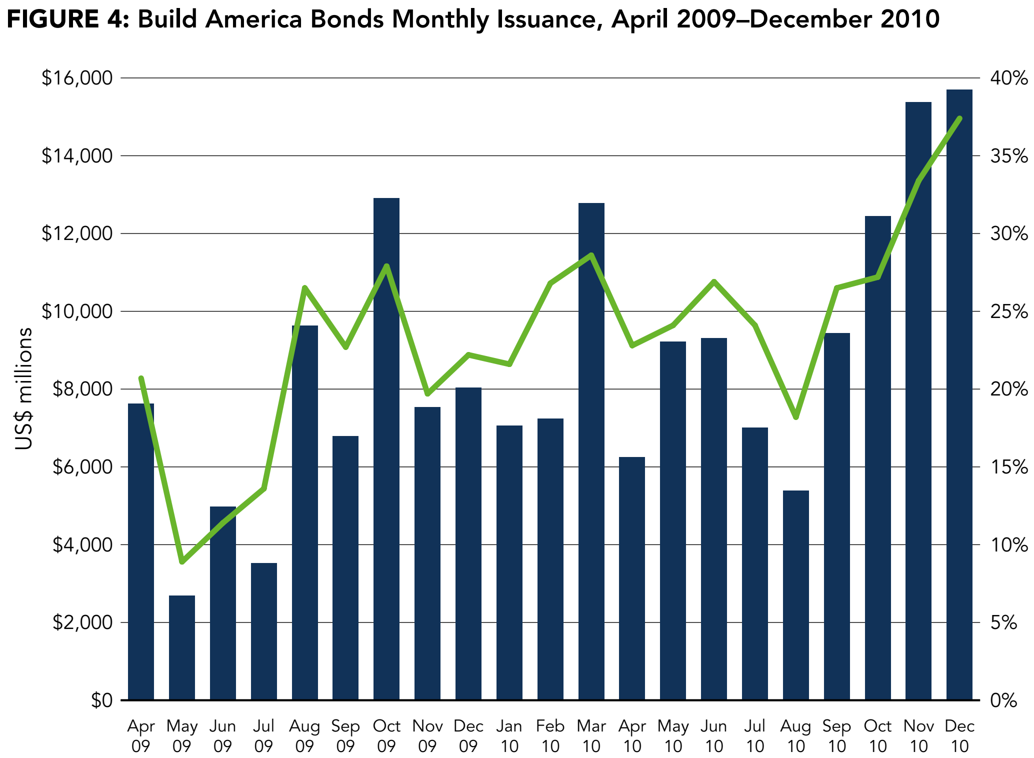


Figure 3.8: Monthly issuance of BABs in millions of dollars from April 2009-December 2010. Source: MSRB (2017).

to reduce issuer borrowing costs, especially on longer maturity issues." (U.S. Treasury Department, 2011)

There are several papers that specifically discuss the use of BABs to help finance infrastructure, although BABs are not climate-specific. The first paper to discuss the preliminary results of the BAB programme was issued by the US Treasury Department (US Treasury Department, 2010). In a "fixed-effects" regression model, they found that issuers of BABs saved 31 bp on yield on a 10 year bond, and 112 bp on 30 year bonds. They also did a comparison of underwriting fees, and found that while they were initially higher than normal muni bonds, they quickly came down to comparable levels. Overall, this report projects that BAB issuers would have saved "$12 billion in borrowing costs on bonds issued during the first year of the program."

In a follow up report also by the Treasury issued in the following year (U.S. Treasury Department, 2011), they assessed the BAB market from inception in April

2009 to expiry on December 31, 2010. This report states that issuers saved "84 basis points on interest costs for 30-year bonds and also received significant savings on shorter maturities", as compared to traditional tax-exempt bonds, using the same regression methodology as the previous report. Overall, this paper claims that "BABs issuers saved an estimated $20 billion in borrowing costs", and makes the recommendation that BABs be renewed in 2012 at a revenue neutral rate of 28%. This report claims that "BABs more efficiently deliver the federal subsidy for state and local government borrowing because each dollar of subsidy goes directly to the issuer," as opposed to tax-exempt bonds, where federal revenue costs in terms of lost taxes are greater than the benefits to local governments in terms of lower costs of capital.

In 2010, Ang et al released a paper assessing the market performance and take up of BABs, stressing that theirs was the only paper not issued by the US Treasury Department (Ang et al., 2010). They state that "by the end of December 2009, around $63.4 billion of BABs have been issued compared with $332.2 billion of regular municipal bonds. Thus, BABs represent 16% of all municipal finance raised during this period [since February 2009]", as shown in Figure 3.8. This paper specifically looks at whether "opening up the municipal bond market to a a larger clientele has lowered the cost of borrowing for state and local governments." They compare the price returns of BABs to "traditional municipal markets, Treasury bonds, and high credit quality corporate bonds" and determine if individuals benefit from holding BABs rather than regular muni bonds. Using a collection of 6,177 Direct Pay BABs issued between April and December 2009, they compare them with all 95,233 tax-exempt muni bonds issued over the same time period by comparing "the BAB issue yield with hypothetical yields computed using different discount rates." Overall, they found that "the BAB program has succeeded in lowering the cost of funding for state and local governments with BAB issuers obtaining finance 54 basis points lower, on average, compared to issuing regular municipal bonds." One of the key reasons they posit that BAB yields are lower is because "the BAB program has succeeded in opening up the municipal market to non-taxable and other non-traditional investors," and this increased liquidity compared with regular muni bonds makes the BABs seem "less risky", however they accept the caveat that measuring liquidity in the muni bond market is difficult.

In 2013, after the BAB program had ended, Puentes et al. (2013) released a position paper for the Brookings Institute stating that BABs "financed one-third of all new state and local long-term debt issuances", with "(47.6 percent) for projects in the 100 largest metropolitan areas" based on the US Treasure figures (U.S. Treasury Department, 2011). One interesting key point in the Puentes paper is that "the federal government forgoes nearly $26 billion in lost revenue from tax-exempt municipal bonds every year, which significantly exceeds the value of the interest rate deduction passed on to states and localities," and about 20% of this subsidy is passed on to bondholders, who are primarily high net worth individuals in the higher tax brackets. Overall, this paper also recommended reinstating the BAB program but with the subsidy set at 28% rather than 35% to make it revenue neutral to the US Treasury.

The end result of the BAB program was not all positive, however, as outlined by Luby (2017). BABs were successful at stimulating the muni bond market, "the program even propelled total bond issuance in 2010 to $433 billion, a record that still holds today" (Farmer, 2018). However, in 2013, due to failure to agree to federal budget cuts, the entire budget was subject to sequestration. Due to these mandatory sequestration cuts, "BAB subsidy payments were reduced by 8.7 percent" through the end of 2013, and have continued, so that there was a 6.9% reduction in 2017. The cutbacks affected the direct subsidy payments for BABs, leaving the local government issuers obliged to make up the shortfall. Luby (2017) found that in the case of Illinois alone, $70 million has had to be paid out by state and local governments. Overall, the annual subsidies for BABs decreased from 9 to 7 percent. Additionally, since BABs are generally not eligible for refinancing, the issuers were unable to find cheaper ways of financing. Assuming that the sequestration rate remains at 6.9% for the life of the bonds, "we can estimate that the full term to maturity BAB subsidy reduction would be $394 million" for the City of

Chicago alone. Overall, "nationwide, Luby figures the total subsidy losses are in the billions." As stated by Luby, "It's stressing out these governments one way or the other, and the expectation is, it's just going to continue" (Farmer, 2018).

Within the context of using green muni bonds to help finance green infrastructure for cities, it is of particular note that 47.6% of BABs were issued for funding projects in the 100 largest US metropolitan areas (Puentes et al., 2013). One interesting point in the Puentes paper is that "the federal government forgoes nearly $26 billion in lost revenue from tax-exempt municipal bonds every year, which significantly exceeds the value of the interest rate deduction passed on to states and localities," and about 20% of this subsidy is passed on to bondholders, who are primarily high net worth individuals in the higher tax brackets. This paper recommended reinstating the BAB program but with the subsidy set at 28% rather than 35% to make it revenue neutral to the US Treasury.

3.9 Green Muni Bonds Case Studies

This section will explain some of the implementations and business models that have proven to be innovative uses of green municipal bonds. As the market develops, these business models have also evolved to become more and more sophisticated uses of a relatively straightforward financial instrument, bonds, in an innovative way to help foster investment in green infrastructure. Given that many of these bonds are included in our analysis, it is worthwhile delving into the details of these deals to better understand how some of these securitizations are structured. These case studies serve as illustrations of how conventional finance in the form of the municipal bond market can be used in new and inventive ways, particularly in the clean energy sector.

3.9.1 The Morris Model

The Morris Model originated in Morris County, New Jersey (2016), and was an innovative way to using a public-private partnership to finance the installation of solar panels on public buildings . This was a bond/PPA (power purchase agreement) hybrid, where "a public entity issues a government bond at a low interest rate and transfers that low-cost capital to a developer in exchange for a lower PPA price" (Kreycik, 2011). In this model, the municipal administrator arranges a lease-purchase agreement with winning solar developer, who in turn constructs a PPA on behalf of the municipality to buy the electricity from the PV system. The solar developer, who is the owner of the installation for tax reasons, sells the power back to the municipality. Bonds are issued by the municipality in order to raise low cost development capital to initiate the project. In terms of cashflows, the municipality pays the developer the start up capital (resulting from the bond proceeds) and makes payments for the power received. The solar developer pays the municipality lease payments for roof access (Kreycik, 2011).

This model was used to finance solar installations on schools and county administrative buildings in several districts in New Jersey (Morris, Somerset, and Sussex counties), and the cost savings were meant to materialize as the solar PPA undercut the price of electricity on the overall net present value (Milford et al., 2012, 2014). The bonds that were issued to finance these project were issued on a taxable basis since "the proceeds are used to fund a project owned by a private entity", the solar developer (Kreycik, 2011). The bonds lowered the cost of capital through the good credit rating of the municipal agency that issued the bonds, so the solar lease payments were lower than could have otherwise been leveraged. The cheaper cost of capital enabled the solar developer to make a profit while still offering an attractive PPA tariff. In this model, the public entity secures the lower cost of capital, and also takes on the risk. By the end of 2012, $88 million in bonds for these solar projects had been raised (Sanders et al., 2013; Kreycik, 2011; Milford et al., 2012, 2014; Rydin et al., 2015).

What actually happened with the Morris Model was very different from the expectations set by the literature at the time of its instantiation. As stated by Stephen Pearlman, one of the key architects of this bond/PPA hybrid, in (Rydin et al., 2015), "the county guarantee will only get called on if the developer does not live up what they said they would do." Also, the value of the cash flows was "highly dependent on negotiation with reference back to market price-setting in investment and energy markets but with discounting to share out the financial benefits of the coordinated arrangement." In particular, the Morris Model had risk exposure to SREC (Solar Renewable Energy Certificates) prices, where in New Jersey, "each time a solar installation generates 1,000 kilowatt-hours (kWh) of electricity, an SREC is earned" (New Jersey's Clean Energy Program, 2018), which can then be sold in over the counter markets to entities that buy them in order to conform with renewable portfolio standards. New Jersey has the largest SREC market in the United States (New Jersey's Clean Energy Program, 2018).

The main reason that the projects ran into cashflow trouble was because the value of the SRECs potentially generated by the projects plummeted shortly after the deals were made, curtailing a main source of repayment money. In late October of 2012, NJ SREC prices unexpectedly bottomed out at around $60/SREC, compared with $230/SREC for April 2018 (Flett Exchange, 2018). One of the main problems that seem to have beset the Morris Model was the sharp decline in SREC prices in 2012 after the deals were brokered. Interestingly, the literature pre-dating the legal and money troubles make only passing mention of the SREC aspect of the deal (it is listed parenthetically as "other revenues" in (Kreycik, 2011)) . It seems that that was insufficient cashflow analysis done around the risks around the value of SRECs, which unfortunately led to cashflow problems, despite the known volatility of the SREC markets (Coulon et al., 2015).

Additionally, the developer and the contractor fell into dispute over late payments as these cashflows were curtailed (Horowitz and Augenstein, 2015). The project developer, SunLight General, kept having trouble with cost overruns and "failed to make scheduled lease payments, according to material events notices the Somerset authority filed on the Municipal Securities Rulemaking Board's EMMA systems. The Morris authority, which also issued bonds for Sussex County, reported 'events of default' by the lessee [contractor]." (Coen, 2015) As a result, several lawsuits were filed and the projects were halted. Even worse for the bond buyers and tax payers, the three counties that issued these bonds were on the hook for the full $88 million (Horowitz and Augenstein, 2015; Coen, 2015).

Despite the fact that "the structure of the model makes it very unlikely that the county's guarantee will be called upon because the debt was reduced 'to just an amount that can be covered from PPA and some minimum SREC value'" (Rydin et al., 2015), that is exactly what happened. In the end, the projects in Somerset County were completed, but as of 2015, only half were completed in the remaining two counties. Eventually, a settlement was made in court, leaving the counties liable for $22.2 million in order to complete the projects. However, the counties involved were never in danger of defaulting on the bonds, and in terms of credit rating, Morris and Somerset Counties are rated Aaa, and Sussex County rated Aa2 (Coen, 2015). Despite the pitfalls that has befallen these projects, Somerset County should still see a reduction in electricity costs by around 60% or $19 million. (Coen, 2015)

In the aftermath of these legal troubles, questions inevitably arise around the viability of the Morris Model. In an article in the *Bond Buyer* (Coen, 2015), there were some relevant quotes from interested parties. Stephen Pearlman, special energy counsel for the three counties, said, "The model is still sound, but any time the public and private sectors get together for a P3 there are risks." Nevertheless, he thinks that "the essence of the model holds and you can structure around these situations in the future." Similarly, Kim Magrini, an associate at Philadelphia-based law firm Ballard Spahr LLP, who represents municipalities in P3 and other public finance transaction, stated, "There is always an inherent risk in project finance due to many unforeseen factors, including cost overruns and contractual disputes. However, these types of risks are not necessarily more prevalent with 'green' bonds over other types of financings and should not be seen as a deterrent for other public green initiatives." Similarly, Moody's senior analyst Lisa Heller said that, "more municipalities are using the green bond approach to gain more interests for these projects."

Around 2013, much of the prevailing literature about energy and bond financing mentioned the Morris Model as a successful model that could be deployed to other states. While New Jersey has an SREC market, not all states do, thus potentially simplifying the model for deployment to other markets. However, there are other legal restrictions that may make PPP deals like the Morris Model legally unviable in many areas where regulations do not easily allow third-party PPA agreements, or may have rules against long term contracts such as PPAs. Kreycik (2011) does a comparison of the regulatory frameworks in states where the Morris Model could potentially be deployed: AZ, CA, CO, FL, HI, MA, NC, OR, PA, TX. The three categories that were compared were PPA legality and contracting, bond issuance laws, and laws governing procurement. Of these states, Florida did not allow PPAs at all, but the other states allowed them. Other than Florida, "significant legal barriers to the hybrid model do not appear in the states evaluated." However, the Morris Model could be replicated in other states, but it remains to be seen if any other bond/PPA type deals develop.

3.9.2 ESCOs with Muni Bonds

The Morris Model could be seen as an implementation of ESCO contracting combined with municipal bonds. ESCOs are energy service companies, which are businesses that specialise in energy efficiency solutions (Medda et al., 2015). They are usually privately held companies that create revenue through energy savings, which result from providing clients with more efficient equipment. These energy savings are used to pay for the new equipment and the services of the ESCO, usually though energy performance contracting (EPC), which overcomes the initial financial constraints of energy efficiency projects by paying off investment costs through the future energy savings that result from reduced energy consumption. ESCOs often perform energy efficiency services for municipal, governmental, educational, and hospital (MUSH) buildings, particularly for customers who spend at least $1 million per year on energy (Sclafani, 2008), since a sizeable economy of scale is required to generate enough energy savings with which to finance the project. ESCO services generally consist of three components: integration of a wide range of project services including design and implementation, facilitation of financing, and monitoring of project performance (Limaye and Derbyshire, 2014).

ESCOs can interface with municipal bonds in order to finance energy efficiency retrofitting on a municipal basis, as was done in New Jersey. This approach can be used for EE projects for MUSH buildings, with initial investment capital provided by the proceeds of a muni bond issuance, with the bond securitised on the cashflows arising from energy savings. Another example is the Delaware Sustainable Energy Utility (DESEU) (see Section 3.9.3). Energy efficiency measures for existing buildings has been a particularly tricky sector of energy infrastructure to address, and as noted by Helm (2008), "has not had a significant take-up." This is despite "claimed positive-NPV investments," as stated in the McKinsey report, "Unlocking Energy Efficiency in the US Economy" (McKinsey, 2009), which also states that "a $279 billion investment could yield $1 trillion in return in energy savings within the US building sector over a ten-year period." Furthermore, Limaye and Derbyshire (2014) state that "many municipalities have limited technical capacity to design, develop, and implement viable EE projects." In these contexts, "municipalities should give consideration to how energy service providers, such as ESCOs, operating under energy savings performance contracts (ESPCs) can help in project implementation and provide access to financing."

The ESCO business model operates on the basis that if the project does not save the customer money by saving energy, then the ESCO does not receive any revenue from that project. Working with ESCOs can help to overcome the upfront costs generally required for energy efficiency (EE) projects by financing the project against future cost savings that will result from reduced energy consumption. By sharing the risk in energy projects, ESCOs "offer an opportunity to curb increasing energy demand and control CO2 emissions while capturing market benefits by decreasing clients' energy costs and making profit for themselves" (Bertoldi et al., 2006). However, some municipalities remain skeptical about the ESCO approach, for reasons ranging from high transaction costs to concerns about transfer of risk, particularly with questions around the uncertainties that could arise if a municipality wishes to sell a building during the contract period (Taylor, 2014). In particular, "deep renovation of buildings with payback periods of 15-20 years is a trickier proposition for investors, but essential to achieve decarbonisation of the buildings sector" (Taylor, 2014).

Because of their underlying mechanism of promoting energy efficiency and reduction in power consumption, ESCOs are inherently green. More efficient energy production and management can help to reduce up to 58% of CO2 emissions reductions worldwide before 2030. This is particularly relevant to cities because EE technologies are "the fastest, highest impacting and most cost-effective way of reducing greenhouse gas emissions, particularly in densely populated areas" (BASE, 2006).

While the precise definition of the term ESCO varies throughout the world, they all tend to have similar business models that involve taking on the risk of EE projects while benefiting from energy savings. Directive 2006/32/EC of the European Parliament and of the Council of 5 April 2006 on Energy End-use Efficiency and Energy Service (European Parliament, 2006) defined an ESCO as "a natural or legal person that delivers energy services and/or other energy efficiency improvement measures in a user's facility or premises, and accepts some degree of financial risk in so doing. The payment for the services delivered is based (either wholly or in part) on the achievement of energy efficiency improvements and on the meeting of the other agreed performance criteria." Satchwell (2010) defines an ESCO as

> a company that provides energy-efficiency-related and other value-added services and for which performance contracting is a core part of its energy-efficiency services business. In a performance contract, the ESCO guarantees energy and/or dollar savings for the project and ESCO compensation is therefore linked in some fashion to the performance of the project.

In the US in 2014, ESCOs reported revenues of $5.3 bn, ESCOs reported 2014 industry revenue of approximately $5.3 billion (Stuart et al., 2016), while in Europe in 2012, the ESCO market had a volume of around EUR3 billion (Taylor, 2014). ESCos have been used extensively in Denmark, and in the UK, there was a national rollout of the Greater London Authority RE:FIT project that outsourced energy sources via standardised contracting and refined procurement procedures (Taylor, 2014).

Energy efficiency projects done by an ESCO can broadly be financed in one of three different ways, either through self-financing, by sharing the risk with the ESCO, or by the ESCO taking the risk entirely (Energy Charter Secretariat, 2003; Stuart et al., 2016). With all three methods of funding, the ESCO guarantees the project's energy savings and performance. Through Energy Performance Contracting (EPC), however, the attained energy savings will finance the project, and gives a financial basis for securing a loan to cover the capital. There are two ways of structuring an EPC: In the guaranteed savings model, the loan goes on the client's balance sheet, and in the shared savings model, the loan goes on the ESCO's balance sheet. In the guaranteed savings model, the ESCO takes the performance and design risk, but not the credit risk, which instead is carried by the client (Bertoldi et al., 2006). Usually the value of energy savings is guaranteed down to a certain base price sufficient to meet debt service obligations. In the shared savings model, the ESCO carries the full project risk, including credit risk. This model is often of particular interest for MUSH projects since the projects are kept off balance sheet. Typically the payments to the ESCO are linked to energy prices (Poole and Stoner, 2003).

According to Vine (2005), trends that are affecting the ESCO market include the removal of energy subsidies, institutional privatization, international competition. There has also been significant ESCO market consolidation through buyouts and mergers (Satchwell, 2010) which will have the affect of lessening the number of players in the EPC field. While most ESCOs are privately held companies, there are some examples of public ESCOs, particularly in Europe (Bertoldi et al., 2007). In these arrangements, typically the energy agency will act as an ESCO in order to facilitate EPC for municipal projects with high social importance. These public ESCOs tend to be more willing to accept higher risk or smaller profit than private ESCOs, which helps to fund EE projects in cities that might not otherwise find sufficient investment, and they are ideally situated to enable programmatic investment by leveraging the municipal bond market, as is described in the next section.

3.9.3 Delaware Sustainable Energy Utility

The Delaware Sustainable Energy Utility (DESEU) is a non-profit organization offering energy efficiency advice and financing to both businesses and homeowners. It was established in 2007 to help promote sustainable energy use in the state of Delaware, and is the first agency of its kind established in the US. This SEU "promotes energy economy restructuring along principles of sufficiency, dialling back energy use where possible and using onsite renewable energy where needed" (Taminiau and Byrne, 2016). It was particularly innovative in issuing $70.2 million in muni bonds where the use of proceeds financed energy efficiency retrofitting in state-owned buildings. In this example, the "credit enhancement takes the form of a general obligation guaranty of each state agency that is implementing efficiency measures, combined with the guaranty of each participating, pre-qualified ESCO" (Sanders et al., 2013).

One particularly unique aspect of the DESEU is that it was one of the first initiatives to combine ESCO with tax-exempt municipal revenue bonds through its performance contracting program aimed at MUSH and commercial buildings. This program addresses both energy consumption and water use by "providing contractual and financing mechanisms to execute the upgrades with minimal financial risk" (Delaware Sustainable Energy Utility, 2016). The performance contracting program uses energy and water savings to finance the improvements, which are implemented by a pool of pre-approved ESCOs. These ESCOs offer "guaranteed energy savings which cover annual payments for project costs, usually over a contract terms of 15 to 20 years." Institutions with utility bills in excess of $100,000 pa can be eligible.

Legislation was passed that enabled the DESEU to issue tax exempt bonds and to participate in performance contracting under Delaware state law in accordance with The Energy Performance Contract Act in Title 29, Subchapter V of the Delaware Code. It operates under the trade name "Energize Delaware", and financing for the program was intended to be raised primarily from the issuance of bonds. This means that participants are generally in the public MUSH sector due to the tax-exemption qualification, however projects for commercial projects could potentially receive low interest rate bridge loans from the proceeds of the bonds. They state that taxable bond financing may be used in the future for non-public participants. In line with the ESCO model (see Section 3.9.2), "debt service repayment is ensured through the guaranteed savings agreement with the ESCOs pledging contractual monetary savings to the public participant" (Taminiau and Byrne, 2016).

The process for financing follows the usual ESCO process: a public agency signals it intent to enter into performance contracting to Energize Delaware, who then help oversee the initial energy auditing and reporting. An investment grade audit is performed, and at least 10% energy savings must be planned for in order for the project to be eligible. Also, extensive consumption measurement is undertaken in order to establish a baseline. Assuming the 10% of savings can be guaranteed, the agency then executes the contract with the ESCO, and the project commences. Upon completion, annual reports must also be provided to the agency and to Energize Delaware.

The various projects that have been undertaken can then be aggregated for the purposes of bond issuance, much the same way that PACE bonds are securitized (Section 3.9.4). As DESEU states, "once sufficient project dollar volume has been aggregated, the bond issuance process will begin" (Delaware Sustainable Energy Utility, 2016). A series of muni bonds totaling $67,435,000 was issued by Energize Delaware in 2011, which was secured on the proceeds of projects undertaken by 6 different ESCOs at 3 state agencies, Delaware State University, and Delaware Technical and Community College (Delaware Sustainable Energy Utility, 2011), and invested in measures that stand to deliver $48 million in energy savings. A key aspect of this program that allowed for its success was the use of pre-approved ESCOs which enabled the use of standardized contracts, which are a crucial element to being able to aggregate deals and securitize bonds on their basis.

The SEU model has gone on to be implemented elsewhere, such as in Washington DC, Vermont, and New Jersey, so that "the mid-Atlantic region of the U.S. is emerging, alongside Vermont, as a hub for innovation in sustainable energy service delivery models" (Houck and Rickerson, 2009).

3.9.4 The PACE Model

One problem with the ESCO model is that while it is viable for use in larger buildings, and can be particularly effective for MUSH facilities, it is difficult to leverage ESCO financing for smaller scale retrofitting, such as on a residential scale. With this in mind, this is where Property-Assessed Clean Energy (PACE) bonds come into their own and help homeowners in the US to finance their domestic energy saving measures. Similar to commercial scale ESCO, energy efficiency measures can be rolled out on a residential basis, and these projects aggregated under one overarching bond issuance, again securitised on the either assessed property taxes, or from utility payments, as described by the Climate Bonds Initiative report, "Breaking Through the Energy Efficiency Logjam" (Climate Bonds Initiative, 2010).

The fundamental idea behind PACE is that it enables residential energy upgrades to be made via an energy services company, and then retrofitting repayments are made through property tax payments. Within the context of ARRA (mentioned passim), a report was published called "Recovery Through Retrofit" (Middle Class Task Force, 2009) which made several policy recommendations that paved the way for PACE programs. One of the key recommendations to reduce upfront costs and costs of borrowing for domestic energy retrofits was to use property tax or municipal energy financing which would allow "the costs of retrofits to be added to a homeowner's property tax bill, with monthly payments generally lower than utility bill savings. This arrangement attaches the costs of the energy retrofit to the property, not the individual, eliminating uncertainty about recovering the cost of the improvements if the property is sold."

The link to residential property taxation mechanism is crucial, because "Property Assessed Clean Energy (PACE) financing programs enable the costs for energy efficiency retrofits to be added to an owner's property tax bill as part of a municipal property tax assessment, which takes the same priority as traditional property tax liens and assessments" (Middle Class Task Force, 2009). This in effect acts as a governmental guarantee which de-risks the projects for investors and therefore brings down transaction costs, because it "provides strong debt collateral in the event of the homeowner – or business owner – defaults on the assessment", and because the lien is tied to the property, it can be transferred on sale. The time scale of the assessment repayments are generally 15 to 20 years, and as with mortgages in the US, the interest on the PACE assessment is tax-deductible (NREL, 2010).

Another important element of PACE financing is the establishment of special tax districts by municipalities, called "clean energy assessment districts". These districts serve two purposes: firstly to reduce the financial risk to the municipality and thereby protect their credit rating, and secondly to facilitate levying the PACE assessment only on properties who opt into the scheme. The establishment of clean energy assessment district then paves the way for the other crucial element of PACE programmes: if funds are not available in the municipal budget for the scheme, they can be raised by the issuing of municipal bonds. This keeps these energy efficiency projects off the balance sheets of the local governments (NREL, 2010).

PACE programmes have been shown to help unlock investment in energy efficiency. In an NREL report about the economic benefits of the PACE programme of 2009 in Boulder, CO (Goldberg et al., 2011), they found that the local PACE programme financed over $9 million in retrofits, and contributed to the creation of over 100 jobs and nearly $20 million in economic activity state wide. The first phase of the residential CSLP financed about $9.8 million in residential energy retrofits, most of which were completed in 2009. Overall, this programme, "saved participants a combined total of about $125,000 during the first year on their electric and gas utility bills."

Unfortunately, the PACE programme faced a challenge in 2010 when the Federal Housing Finance Agency issued a statement the Freddie Mae or Fannie Mac mortgages must have first-lien priority, and any properties with a PACE lien claiming superpriority would be disqualified for federal mortgage financing or support (Federal Housing Finance Agency, 2014). As a result of these measures, all PACE programmes were placed on hold for two years while these statements were tested in court (Saha, 2012), due to the fact that Fannie Mae and Freddie Mac finance about 90% of mortgages in the US. However, since then, PACE financing has carried on in some regions, with the states of California and Florida being particularly active (PACE Nation, 2016).

One interesting recent development that has arisen from PACE financing is that some third parties have aggregated PACE contracts across municipalities and used them as collateral on which to issue green asset-backed securities (ABS) bonds. The first such issuance was the HERO Funding 2014-1 bond which had an 11-year maturity and 4.75% coupon (Tempkin, 2014). This ABS was launched by Renovate America, a firm that has financed over 90% of PACE deals in California, the main market. In 2014 and 2015, Renovate America launched five ABS PACE bonds in total, the most recent issuance was $201.5 million in green bonds, representing nearly 9,000 home improvements (Hales, 2015).

Despite all of its promise, there are some disadvantages to the PACE model. Firstly, PACE is not a one size fits all scheme: in the American context, it must be tailored to each municipality's tax codes and debt rating. Additionally, in some programmes (e.g. Boulder, CO), the liens are placed on the properties at project inception, whereas in others (e.g. Berkeley, CA), the liens are placed after project completion, which has an effect on who holds the construction risk (NREL, 2010). Also, in order to truly take off and achieve scale, there is a need for debt aggregation and securitisation, such as what the recent PACE ABS green bonds have accomplished. While this could raise transaction fees, it could lower the costs of capital due to risk sharing and larger deal size. Finally, the major issue of the priority of the debt/lien on the property still remains to be settled in the US.

As of 2018, there are 34 states with PACE-enabling legislation, 20 of which have active markets (PACE Nation, 2016). Renovate America has issued 13 green bonds secured on the proceeds of residential PACE assessments through their HERO bond program, some of which are certified green (HERO Program, 2016). The HERO program is currently the largest issuer of green ABS bonds. The 13th series in particular were secured on assessments levied on "6,332 residential properties in 43 California counties and 12 Missouri counties." The PACE assessments have an average balance of $23,700 with "a weighted annual interest rate of 6.7 percent and a weighted-average original term of 17.8 years." The bonds that underlie this pool of assessment were issued between January and May, 2018.

PACE bond issuance has been increasing year on year, to the extent that in the past two years, a secondary market specializing in trading these bonds has emerged. According to Nicole Montecalvo, head of investor relations at Renovate America, "volumes are up by six times from an average of $5m a month in 2016 to $30m a month in 2017" (Padbidri and Kerr, 2018). This momentum is helped by increasing interest from foreign bond buyers, and the signing of two consumer protection bills for PACE in California just came into force in January 2018, which help to de-risk the business model. According to Greg Frost, the national communications director at Renovate America, "as of April 1, 2018, all PACE providers will be required to verify income and conduct an ability-to-repay analysis as part of their underwriting process" (Padbidri and Kerr, 2018).

PACE is not restricted to residential renovations, but also operates in the commercial sector. This segment of the PACE market has also seen considerable growth, with "origination levels more than doubling since December 2015 to reach $493M as of the third quarter of 2017" (Padbidri and Kerr, 2018; PACE Nation, 2016). As a result of this growth, the first commercial PACE $75M securitization was completed in September 2017. This model is also expanding into the international markets, with a PACE-like program due to launch in Spain imminently (EuroPACE, 2018).

3.9.5 Green Banks

The OECD (2016) defines a green bank as "a publicly capitalised entity established specifically to facilitate private investment into domestic LCR (Low Carbon, Climate Resilient) infrastructure and other green sectors such as water and waste management." Rather than giving out grants to eligible projects, green banks instead act more like revolving funds, and "seek to recycle public capital and focus on mobilising private investment using public capital." Green banks are active in working with ESCOs and help facilitate PACE financing. They can receive their initial capitalization when they are established through various means, including government capitalization, emissions trading schemes, utility bill surcharges, loans, etc. However, the means with the greatest potential is through the issuance of green bonds.

Green banks are important because "federal financial support for clean energy projects will likely decline" (Berlin et al., 2012), a fact that is especially pressing as many programs that were funded by ARRA, which was "the largest federal investment in clean energy in American history", have ended. Additionally, state budgets continue to be highly restrictive in the aftermath of the financial crisis, particularly for state investment in clean energy. As a result, there is a gap in the market that green banks could play a vital role in, especially when studies show that "that lowering the cost of clean energy loans by 225 basis points and providing long-term loans to all developers would lower the cost for a clean energy project by 15 to 20 percent", which would make many projects cost-competitive with conventional generation. As stated by OECD (2016), "by issuing bonds, GIBs can draw large amounts of private institutional capital to LCR infrastructure investment, and depending on the legal authority, a GIB may be able to issue government-backed bonds. This facilitates lower interest rates, enabling the GIB to lend the funds at a lower cost of capital."

So far, the several US states have established green banks, including California, Connecticut, New York, New Jersey, Rhode Island, and Hawaii. US Department of Energy (2015) provides an overview of all the green bank type programs that were extant in the US as of 2015. This section will focus on the specific cases where green banks have issued bonds in order to help finance clean energy projects: Connecticut and New York.

Connecticut Green Bank

We focus on Connecticut Green Bank because it has a history of issuing municipal bonds, and was the first green bank to be established in the US in 2011 with the objective of achieving "cleaner, less expensive, and more reliable sources of energy" with the intention of "working with private-sector investors to create low-cost, long-term sustainable financing to maximize the use of public funds" (Connecticut Green Bank, 2004b,a). This green bank is active on many different customer levels, from residential to the commercial and infrastructure sectors. Since inception, the

Connecticut Green Bank has deployed over $1 billion in capital for clean energy projects, and they have leveraged $6 in private investment for every $1 of public funds committed by the state. The support of the green bank has created "over 936 direct and 312 indirect and induced job-years in the state from installing nearly 60 MW of Residential Solar PV" (Connecticut Green Bank, 2004b,a), and overall it has created nearly 12,000 clean energy jobs in the state (Coalition for Green Capital, 2014).

The Connecticut Green Bank has also implemented C-PACE, one of the most successful PACE programs in the US. It was launched in early 2013, and in under two years financed retrofitting for 89 buildings totalling $54 million in costs. While Connecticut is not the only state to have a PACE market, "it is the only one to have created a state-wide program with centralised administration through a GIB" (OECD, 2016). This happened as a result of the reluctance of private lenders to get involved with PACE "despite pre-approving multiple banks to participate", "they were still hesitant to be the first investors in a new and unfamiliar structure." In response, the Connecticut Green Bank decided to finance PACE loans off its own balance sheet through the creation of an internal $40 million fund. Later, the bank issued a series of bonds totalling $30 million to recapitalise, demonstrating that green banks can effectively interface with the debt capital markets to bring innovative financing to the clean energy sector.

Overall, the state of Connecticut has been the issuer of no less than five series of labelled green muni bonds, all of which are trading at a premium (Municipal Securities Rulemaking Board, 2018).

New York Green Bank

The New York Green Bank was established in 2013 because "it wanted public funding that had previously been used almost exclusively for grant programmes to go further and attract greater private investment" (OECD, 2016). This green bank is a division of NYSERDA, the New York State Energy Research and Development Authority, which is notable for creating a bond deal to finance its Green Jobs/Green New York (GJGNY) program. The GJGNY Act of 2009 allocated $112 million in proceeds from selling carbon credits towards the "support of sustainable community development; create opportunities for green jobs; and establish a revolving loan fund to finance energy audits and energy efficiency retrofits or improvements for the owners or occupants of residential, multifamily, small business, and not-for-profit structures" (NYSERDA, 2018).

In order to raise the capital for GJGNY, NYSERDA issued nearly $25 million in AAA-rated QECB bonds in August of 2013. When they first proposed the deal, they received a much lower credit rating due to the novel structure of securing the bonds on their GJGNY residential energy portfolio. In order to raise the rating and lower the cost of capital, the New York State Environmental Facilities Corporation established an $8.5 million collateral reserve account out of their Clean Water State Revolving Fund under federal EPA approval on the basis that these energy efficiency measures contributed to clean air and water by lowering emissions. With this collateral in place, the credit rating was raised to the highest possible rating, AAA by S&P and Aaa by Moody's, and the deal was brought to market (CE+BFI, 2013; US Department of Energy, 2015). Trading data shows that these bonds have traded at a premium in the secondary market (Municipal Securities Rulemaking Board, 2018).

Hawaii Green Infrastructure Authority

Hawaii established its Green Infrastructure Authority in 2014 in order to help the state meet its renewable energy portfolio standard (RPS) goals, after declaring that it intended to adopt a 100% RPS in the electricity sector by 2045, after historically being the most oil-dependent state in the US. The first program it brought to market was the Green Energy Market Securitization program (GEMS), which was designed to 'make clean energy investments accessible and affordable to a broader cross-section of Hawaii's utility ratepayers, with a portion of its funds to benefit underserved communities, low- and moderate-income households, renters and nonprofits" (Hawaii Green Infrastructure Authority, 2018; OECD, 2016). It helps provide low-cost capital to finance solar PV and other clean energy systems for those who otherwise have difficulty qualifying for financing. Overall, "GEMS has the ability to finance the installation of over 44 MWs of energy, assisting as many as

30,000 Hawaii consumers, greatly reducing their energy expenses and advancing Hawaii's aggressive clean energy mandates" (Hawaii Green Infrastructure Authority, 2018).

So far, Hawaii has issued two series of taxable green bonds in 2014 (Municipal Securities Rulemaking Board, 2018), raising $150 million in capital. These bonds were issued as revenue bonds securitized on the basis of a green infrastructure surcharge that has been imposed on electric utility customers since December 2014. According to the state, the majority of utility customers will see no change in their bills, as the $1.29 per month surcharge is offset by "a reduction in a separate public benefits fund surcharge already paid by utility customers to support energy efficiency programs."

However, despite raising the initial capital needed, this program has been beset by problems, and as of 2016, only 17 residential loans totalling $14 million had been given out, and no commercial loans (Shimogawa, 2016). In 2017, they made adjustment to their loan approval process to make it more approachable to a wider market, and as of May 2018, the state also approved an on-bill financing program, so that the utility bears the burden of the up-front capital costs, which the consumer then repays through their energy bill payments (Mai, 2018).

3.10 Conclusion

This chapter has provided an overview of what green municipal bonds are, how they work, and the scale and growth of the market. We also discussed some of the supporting policy mechanisms that help build capacity in this sector. While policy support is crucial to helping to build the sustainable infrastructure pipeline that can be financed with these bonds, another very important factor in the uptake of green muni bonds is their market performance, which we consider in the next chapters.

Chapter 4

Green Bond Pricing

This chapter will discuss the pricing performance of green bonds, and includes a review of the existing literature on the subject. We will also introduce the techniques that are used to evaluate comparative pricing performance of bonds.

4.1 Greenium

When there is considerable demand for green bonds, this can enable issuers to adjust the terms of their bond issuance to lower the coupon rates, which leads to a better deal for them because it lowers the cost of capital. In order for this to happen, investors must be willing to accept a lower repayment rate in order to become bond holders. This market dynamic is a crucial focus to this research, since evidence of demand for green bonds can manifest as a pricing premium, where issuers are willing to pay more for less yield, and in subsequent issuances, bond issuers will adjust their terms to leverage this demand.

A recent example of this occurring in the corporate green bond market is the first green bond issued by SSE, one of the Big 6 energy utilities in the UK. Their EUR600 million bond was issued in September 2017, and at the time it was was the largest green bond ever issued in the UK. SSE stated that due to "significant demand" for the issuance, it was able to set its lowest ever coupon rate at 0.875% for an 8-year bond (John, 2018). Because the issuance was so successful, another EUR650 million green bond was issued by SSE in September 2018.

Because demand for green municipal bonds also currently outstrips supply, these green bond issuances are usually oversubscribed. As a result, “the issuer can try to leverage this demand to seek more favorable terms,” and that “some issuers have achieved a better price (cheaper debt) through green bonds” (Saha and D’Almeida, 2017), which also states 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).”

This green bond pricing dynamic is the primary focus of our research because it helps to overcome some of the perceived or actual expense incurred as part of issuing a green bond (Chiang, 2017). Investors and issuers are keen to discover the presence of a green premium, or “greenium”, in the green bond markets, however evidence so far has been mixed. This is because, as the Climate Bonds Initiative (2018b) pricing report explains, “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.” However, 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. Therefore, greenium is fundamental for making or breaking the green bond market.

The distinction between the primary and secondary markets in relation to bonds and fixed income securities is fundamental to the understanding of the dynamics of this market. Unlike equities, bonds have one market at issue, the primary market, and then another market for subsequent after issue trades, the secondary market. The reason the primary market is considered separately is because the prices that the bonds are issued at determine the amount and cost of capital that the issuers actually receive once a bond reaches the market. Once these numbers are fixed at bond issue, the issuers’ terms do not change as the resulting cashflows are then fixed. However, the prices and yields of the bonds will still fluctuate according to supply and demand in secondary market trading. In this case, it is the bond buyer and sellers that are exposed to the investment risk, not the issuer. The secondary market prices do not directly affect the issue terms already set in place by the primary market for the issuers, however, they can serve as an indicator about what the market considers to be a fair price, and will therefore inform the initial offering prices of subsequent bonds by that issuer.

The presence of a greenium in the primary market would help to lower capital costs for green infrastructure, and a pricing differential in the secondary market could lend pressure to primary market prices, since secondary market prices are an indicator of what the market will bear. As stated in the latest CBI pricing report (Climate Bonds Initiative, 2018b), "when green bond curves have a handful of maturity points, they could be used as a reference for pricing new green bonds. If green bonds were trading tighter than vanilla bonds, we would reasonably expect to see a consistent greenium emerging," however, "a secondary green curve does not guarantee a greenium." Zerbib (2016) also states, "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".

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. At the same time, "green bond price differential will vary depending on a range of factors such as the given market, ratings, sectors, and issue sizes," so that even if a consistent greenium is found in the US muni market, this does not mean that it is as easily realized in other green bond sectors.

However, while there is a growing body of support for the need for and implementation of green bonds and green municipal bonds, 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 one has published any assessment of greenium in the primary muni market, nor has anyone published any work relevant to the construction or benchmarking of a green municipal bond index as a tool for assessing secondary market prices above and beyond extrapolated yield curves.

To explore the market dynamics of green muni bonds and to benchmark their performance against conventional muni bonds, we used two approaches: bond index creation and benchmarking, and yield curve analysis, which are described below.

4.2 Market Performance Review

This particular area of research is very new, so 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 evidence of a greenium signal in the secondary green bond markets. One of the earliest was Preclaw and Bakshi, from Barclays (2015). Their research consisted of a regression run on green bond credit spreads that "decomposes OAS (option-adjusted spreads) into common risk factors and an indicator variable for green bonds." They conducted their analysis on seven cross-sections of data, on a quarterly basis since 2014. They 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." This report posits some reasons for the difference in green bond prices, with the first being potentially a "growing interest in the product and a resulting mismatch between the supply of and demand for green issues." Some have suggested that "green bonds should trade at tighter spreads to reflect their externalities", however these are difficult to price in on a cash flow basis. Furthermore, "tighter spreads could reflect a simple preference on the part of investors, which could be the case if investors accrue enough other benefits to offset the lower cash flow", again raising the question of how much greenium the market is willing to bear before reverting. Finally, they suggest that "it is possible that green bonds are actually less risky or volatile than otherwise similar conventional bonds, making the tighter spreads appropriate to their risk-adjusted return."

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.

Zerbib (2016) published a paper about the green bond premium, which is possibly the "first academic study focusing on the specific cost of green bonds." 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 essence, what the author is describing is a potential flight to yield away from green bonds if conventional bonds are perceived to be significantly cheaper, thus undermining growth in the green bond market. This paper is considered in more detail below.

In January 2018, Bos from NN Investment Partners issued a report titled "Unravelling the Green Bond Premium" (Bos et al., 2018). This research used the Bloomberg MSCI Global Green Bond Index as the source of their identified green bonds. They collected monthly bond data from December 2014 to November 2017, and their sample includes "133 unique labelled green bonds issued by 59 entities from 16 countries and 7 supranational organizations." The non-green bond group was comprised of "the bonds from green bond issuers in the Bloomberg Global Aggregate, Bloomberg Euro Aggregate, Bloomberg Canadian Aggregate and Bloomberg Australian Aggregate indices" in order to identify non-green bonds that have been issued by green issuers around the same time. They then use this data to construct yield curves, where the yield curve was interpolated on a monthly basis per issuer. The interpolated yields and the yield of the corresponding green bonds are then compared monthly, where “a negative difference means the interpolated yield is higher than the yield of the green bond with the same maturity and seniority.” For each month, a straight average was taken to calculate the average yield difference.

Overall, “on average every green issue is matched with 14 non-green bonds of the same issuer with similar seniority. Our full sample includes 2,417 data points of green bonds (36 months, 133 unique green bonds).” They found that green bond yields were on average lower than the interpolated yield of the non-green bonds, and “the difference between the observed and interpolated yields for the entire sample was -0.011% [11 bps],”, although 37% of the green issues “had a yield above the interpolated curve.” They attempt to explain the presence of greenium as one of two factors: “One is a possible mismatch between supply and demand,” and another is that green bonds may be less volatile. As they state, “in periods of risk aversion, green bonds tend to be more stable, due to more buy-and-hold investors holding the bonds in their portfolios. The bond’s lower volatility compensates the investor for its lower yield.”

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 2018b and covers green bonds that were issued Q3 2017. For dollar denominated bonds, they found that green bonds were issued with prices 12 bps lower than initial price talk, “compared to vanilla average of -10.2 bps”, with a similar difference of 2 bps for Euro denominated bonds. Overall, green bonds were oversubscribed by about 2.5 times, compared with 1.5 times for their vanilla counterparts. 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. As explained in this report, “the new issue premium is the extra yield that a buyer gets, and a seller pays, for a new bond, when compared to where seasoned bonds from the same issuer are trading in the secondary market.” Because new issue premiums are standard features of new bond issuance, any absence of this is notable. This follows on from their previous report for Q2 2017 and Q1 2017 (Climate Bonds Initiative, 2017c), which had similar findings.

There are only a few papers that have been published so far that deal with green premiums in the green municipal bond market, and all of these were released as this work was being written up. One of 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. Their data set included 1,880 municipal bonds that were labelled green by Bloomberg, along with 36,000 conventional bonds by the same set of issuers from 2010-2016. The Bloomberg green bonds are a superset of labelled green bonds, which encompasses both labelled green bonds and some unlabelled climate bonds that Bloomberg analysts deem worthy of the green label. Their pricing data came from the same source that we used in our analysis: the EMMA MSRB database. They used the technique of constructing yield curves to determine whether the green bonds in their data generally fell inside or outside of the issuer's yield curves. By using a regression analysis on the yields, they found that "the overall mean spread in returns between conventional and green bonds is 0.23%; that is, 23 basis points." They failed to find a clear greenium signal until 2016.

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 separately, because they have relied on the Bloomberg "green" label to identify bonds for study rather than a manual data mining and screening process, as we have done. They also do not break the bonds down by sector or state, and while yield curve analysis can uncover a premium via yield spreads at a particular point in time, it is difficult to draw out historical trends. For example, they analyze the yield spreads on an annual average basis, but this loses much of the intraday pricing movements and trends, rendering any nominally annualized yield trends as meaningless because the timeframe of the analysis is not specific enough. For example, they show a comparison of green and conventional yield curves in their Figure 1, stating "the green bond yield curve is systematically below the conventional bond one. This means that investors require, on average, a lower interest rate to invest in green bonds." However, they do not state which time instance this yield curve depicts. An inspection of their code indicates it is relevant to 23 January 2017, but it is tenuous to extrapolate market trends out from the yield curves of one given day, just as it is equally tenuous to investigate the spreads of annualized yield analyses as yields could change dramatically through the year (especially in a year like 2016 which was affected by the presidential election). This is the reason why our approach here has used an index to examine historical trends: it is easier to see relative price movements for an aggregate of assets over time via an index, and an index is also necessary for benchmarking a market sector against existing indices.

Baker et al. (2018) performs an analysis of 2,083 municipal bonds defined as "green" by Bloomberg, which could include climate-aligned but not labelled green bonds. Their comparison was based on 643,299 conventional municipal bonds, with the data spanning the years 2010 through 2016. Their focus was solely on the yields at issue, or the primary market. Through a linear OLS regression with fixed effects, they found an average greenium of 6 bp. Because their sample included taxable and tax credit muni bonds, they adjusted the yields of these bonds to an effective after tax yield before performing the regression. This crucial step is in contrast to the previous paper, and is in fact why Baker et al assert that Karpf and Mandel (2018) failed to find a greenium in the early years of the sample, since "early [Bloomberg-classified] green bonds were disproportionately taxable," and state that "our results suggest that this conclusion is incorrect."

A drawback of both of these papers is that both of them ran their regressions on the yields to call or maturity without subtracting out the underlying general municipal bond yield curve. These studies benefit from artificially high statistical significance scores due to the fact that the yield curves exhibit a strongly functional form, albeit not linear. It is the spreads between the green bond yields and their conventional counterparts that is measurement being investigated, which is actually highly non-linear. Performing a linear regression over a non-linear set of data can lead to spurious findings.

Two papers that regress the spreads rather than the raw yields are Febi et al. (2018) and Zerbib (2016), which also take any potential in differences in liquidity into account. In Zerbib (2016), 115 green (mostly corporate) bonds were analyzed over the years 2012-2016, and their secondary market yields were found to be lower than their corresponding synthetic conventional bonds, indicating a greenium. The greenium signal was particularly pronounced for bonds rated below AAA (-6.70%) and Euro-denominated bonds (-8.47%). According to this paper, "the rating is the major driver of the green bond premium: the riskier the bond is, the greater the negative premium will be," with currency found to be a secondary driver. The methodology used in this paper involved the creation of an "equivalent synthetic conventional bond for each green bond issued on March 15, 2016" in order to evaluate any green premium by a fixed effect panel regression. This paper quantifies the green premium as "the unobserved specific effect of the regression of the difference in yields between the two bonds on the difference in liquidity." In this paper, the proxy used for the liquidity measure was Zero Trading Days (ZTDs).

This work refined in a later paper by Zerbib (2018), where he explains that he is explicitly using a matching method to directly compare the yields of green bonds with synthetic conventional counterparts. These synthetic bonds were extrapolated from the bond data for the closest relevant bonds issued by that issuer, and the matched pairs are constructed to be identical except for their liquidity. The drawback of this approach is that because the proxies for the conventional bonds are synthetic, they are not based on the trading data from actual bonds out in the market, but rather are extrapolated from two conventional bonds from that issuer having the closest tenors. As stated by Zerbib, "the difference between the green bond yield and the equivalent synthetic conventional bond yield is therefore precisely the cumulative effect of the liquidity differential and the green bond premium." The green bonds in this sample are the 1,065 bonds labelled as "green" by Bloomberg as of the end of 2017, so this sample will include both corporate and municipal bonds. In this paper, a green premium of -2 bp is found across the sample.

Febi et al. (2018) compared 64 green labelled corporate bonds with 56 conventional corporate bonds over 2013 to 2016, looking at both primary and secondary prices. They use a LOT liquidity metric to account for liquidity premium in the green bonds. Using a pooled OLS and fixed effects regressions, they found a greenium of 70 bp in 2016. They used the spread between government bonds and their sample bonds in order to correct for the term structure curve. They only find a significant LOT liquidity difference in their bonds in 2016, and they found that generally green bonds are more liquid than the conventional bonds in their sample. The liquidity was positively related to the yield spread, however this effect has diminished over time.

Other papers that have looked at liquidity for muni bonds are Harris and Piwowar (2006), which investigated secondary trading costs in the municipal bond market and found that “transaction costs decrease with trade size and do not depend significantly on trade frequency.” They also found that muni bond trades are more expensive than similarly-sized equity trades, and attribute these results to “lack of bond market price transparency.’” They observe, “Not surprisingly, the municipal bond market is not noted for its great liquidity.” However, this paper was published in 2006 before the opening up of real time price data via the MSRB’s EMMA website, which has considerably improved muni bond price transparency. A more recent report on muni market liquidity was published by Markit researchers (Fenske and Chen, 2016). They analyzed 570,000 trades spanning January 2015 through March 2016 and found that liquidity was “stable during that period” and that the market was “relatively efficient”. Their methodology involved comparing the number of muni bond trades with the number of quotes generated. They posit that in a very liquid market, “price transparency and dealer inventories would both be higher than usual, so the breadth and volume of quoted bonds should also increase,” whereas in an illiquid market, “quotes would not be as broadly disseminated.” They found a very linear relationship between the number of trades and quotes, and across the types of muni bonds, found that in general, the daily trade count is 75% of the daily quote count, and remained stable across the time frame considered. They comment on this stability, stating that it is “likely due to brokers adeptly adjusting the breadth and quantity of bonds they are quoting to match the overall demand on a given day."

4.3 Bond Indices

All of these reports and studies mentioned in Section 4.2 relied on the analysis of yield spreads to detect any difference in green bond pricing as compared with comparable conventional bonds. While yield spread analysis is important for assessing bond pricing relative to the surrounding market conditions at a moment in time, it cannot sufficiently capture pricing trends as the markets evolve. Because of this, bond indices are a better tool for doing overall performance analysis for an asset class, especially with regards to the dynamics of pricing behavior over time.

An index is defined by European Union Law (2013) as "a statistical measure, typically of a price or quantity, calculated from a representative set of underlying data." Indices are most commonly used as market benchmarks, and are used as "the standard against which the performance of a financial instrument can be measured" (IBoxx, 2016). When used as a benchmark, an index "provides a way to measure the performance of a specific segment of a financial market" and is used to "measure the value of a section of the bond market." Indices are commonly used by investors and regulators to measure performance and monitor market developments.

The primary motivation behind creating a bond index is to facilitate the ability to assess and compare the performance of a bond market. As stated by Brown (1994), the main purpose for bond indices are: "to act as a benchmark for portfolio management; to act as an indicator of market performance and development [...]; [to act] as a comparator for different markets". Most of all, "one should try to compare instruments like with like," which is why we chose to re-implement the S&P methodology on a subset of bonds with characteristics that are as close as possible to the S&P index constituents. An index allows the market performance of a great many assets to be reduced down to a single time-series, which can be used as an indicator of the overall performance of the assets included in that index. Indices allow one to take a broader view on the performance of a market sector over time, 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). The creation of indices can also help to "promote investment in certain markets" (Bacon, 2008).

Indexes are important for encapsulating historical market data and price trends (Goltz and Campani, 2011). They enable an investor to view the overall performance of a market sector in aggregate and how that performance has evolved over time. Indices are usually constructed so that yesterday's market values inform today's index returns. In particular, "today's index value is defined to be the previous calculation times the aggregate percentage change in the value of the current constituents since the previous calculation" (Brown, 1994).

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 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.

While there is no existing academic paper discussing green bond indices, Coeslier et al. (2016) discusses low-carbon stock indices in relation to fighting climate change. This paper brings to light two interesting points about attempting to create low carbon indices in order to encourage emissions reduction and to hedge against climate risks. First, they found that the ability to avoid carbon risk is questionable at best once global carbon intensity of the constituent firms is considered. Secondly, they state that "current optimization methods do not improve the contribution of portfolios to the financing of the energy transition; the quantity of avoided emissions does not rise and the investment exposure to solutions for the energy transition (renewable energy, energy efficiency) remains steady or decreases." This potentially also diminishes access to capital for firms where they have positive climate impacts, but only in their extended boundaries, as compared with highly polluting firms. Overall, they show that low-carbon equities indices insufficiently hedge against carbon risk, and furthermore they are ineffective tools for financing the energy transition. It is important to note that equities indices will be comprised of fundamentally different assets to bond indices. Particularly in the case of our work, we can capture green infrastructure investment through green municipal bonds in a much more direct manner than an equities index is able to.

In 2016, Barclays Research published a report detailing their research into the effects of ESG impact investing on bond portfolio performance. This work focused on the corporate bond sector, and broadly diversified portfolios were constructed to track the Bloomberg Barclays US Investment-Grade Corporate Bond Index. These portfolios matched "the index's key characteristics (sector, quality, duration) but imposed either a positive or negative tilt to different ESG factors." They found that the positive ESG tilt correlated with a "small but steady performance advantage". Additionally, they found that "ESG attributes did not significantly affect the price of corporate bonds."

This report was followed up by another report by Barclays Research (2018), where they used a larger data set to build on these results. They confirmed their 2016 findings, and also found that "tilting a credit portfolio in favour of high-ESG bonds, while keeping all other risk characteristics unchanged, tends to lead to higher performance in all three markets considered." This survey used data from Bloomberg Barclays Bond Indices for bond characteristics and returns, and MSCI ESG Research and Sustainalytics for the ESG scores. Additionally, this report states that "one might have expected increased interest in sustainable investing to have driven up the prices (thus, reducing the spreads) of high-ESG bonds. This is not, however, borne out by the data, and we do not see a downward trend in ESG-related spreads

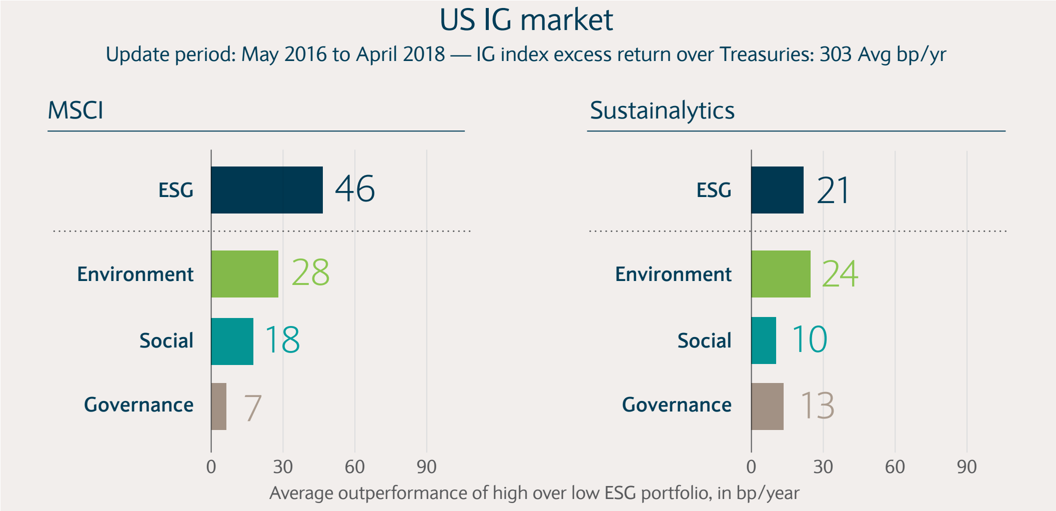


Figure 4.1: The returns of the US Investment Grade High ESG corporate bond portfolio relative to the low ESG portfolio in basis points for the time frame spanning 2016-2018. Source: (Barclays Research, 2018).

in IG markets; if anything, they seem to have increased," however this does not explain why the high ESG portfolios would then see better performance. One reason for the higher returns attributed to the high-ESG portfolio in the report is the lower rate of downgrades in the high-ESG bonds.

Our index construction and benchmarking methodology is discussed in detail in Chapter 6.

4.4 Yield Curves

Yield curves are commonly used to analyze the behavior of a bond or set of bonds by showing the relationship between yield and maturity graphically. Yield curves are constructed by plotting the yields to maturity (YTM) of bonds along with their time remaining to maturity. As stated by Bodie et al. (2011), "the yield curve is one of the key concerns of fixed-income investors," because they are "central to bond valuation and, as well, allow investors to gauge their expectations for future interest rates against those of the market."

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). 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.

Yield curves usually exhibit a curved trend rather than a linear one due to the term structure of interest rates, which is the relationship between bond yields and different maturities, and how bond investors have different expectations for bonds of different durations (Malkiel, 1989). Generally put, investors expect higher yields for longer term bonds, due to more exposure to uncertainty over changes in interest rates, etc. Furthermore, investors prefer more liquid assets, and will pay a liquidity premium for them (Bodie et al., 2011). Yield curves encompass these market dynamics, so they can be used to assess the expectations for short term interest rates, which bonds have liquidity premiums, and possible trends. In this work, we compare vanilla bonds that were issued at the same time as green bonds in order to explore how the green bonds perform compared with their counterpart vanilla bonds by looking at differences in their yield curves.

A report that is relevant to our yield curve analysis is by Luby (2012), which "analyzes two representative BAB transactions issued by the State of Ohio highway capital improvement program in 2010 subsequent to the creation of the BAB program." This analysis uses a matched pair analysis, because "we do not need econometric models to control for the differences between the compared groups since they are effectively the same except for bond type (matched on issuer, credit, maturity, coupon, repayment source, etc.)." This is similar to the green-vanilla matched pair analysis approach that we use to compare yields for green muni bonds vs vanilla. Furthermore, this BAB matched pair comparison is also relevant to our green bonds because there are additional paperwork and transactional requirements for BABs, similar to the reporting requirements for labelled green bonds. In both of the transactions, Luby found that yields were lower for the BABs compared with their tax-exempt counterparts.

An additional report about BAB performance that the US Treasury 2011 issued is relevant to our analysis in that their regression analysis is based on a similar premise and technique for data selection that we have used for our green bond yield curve analysis. In these reports, their estimation method "relied on comparing BAB yields with tax-exempt yields for a selected sample of issuers who issued both BABs and tax-exempt bonds on the same day." Their motivation for this technique is similar to ours:

> This estimation method allows for a comparison that nets out any differences between BABs and tax-exempt bonds that are due to issuer-specific characteristics or to trends in bond yields over time. This approach eliminates many potential sources of the difference between BABs and tax-exempt yields that are unrelated to the direct effect of the BABs program. For example, BABs issuers may have consistently different risk profiles than non-BABs issuers. Also, interest rates vary from day to day, and changed considerably throughout the two years that BABs were available. Failure to account for such differences, including differences in risk profiles or in time of issuance, could affect the accuracy of the comparison of BABs and tax-exempt yields and confound the estimates of the direct effect of the program. The estimation method in this analysis also controls for several observed characteristics of the bonds themselves, including their maturity and call features.

The specifics of our yield curve analysis are detailed in Chapter 7.

4.5 Conclusion

This chapter outlined the existing research that looks at pricing dynamics for the green bond market, and also introduces the main techniques for market analysis that can be used to assess the performance of these bonds. The next chapter will outline how we collected our green municipal bond data, and will assess any differences in liquidity amongst this data.

Chapter 5

Data and Liquidity

This chapter describes how we aggregated our bond data, and the constituents and characteristics of this data. The liquidity of the green-labelled bonds in our data set was also checked against the non-green-labelled bonds in order to determine if there was any significant difference.

5.1 Overview

The first major undertaking in this research was the creation of the data sets used in our analysis. Because the green bond market is very new, especially within the US municipal bond market, it was necessary for us to manually aggregate the relevant bond data because there were no relevant pre-existing data sets.

The first data set that was created was the green-labelled and climate-aligned muni bond data set, as described in detail below in Section 5.2. At time of writing, this was currently the only extant muni bond data set that includes climate-aligned but non-green-labelled bonds, which enabled us to draw out deeper insights into the market, due to the fact that there are still far more climate bonds being issued than green-labelled.

The second data set was constructed in order to facilitate deeper like-for-like analysis between labelled green bonds and their closest non-green or "vanilla" counterparts. This was also a unique dataset in that it was the only one extant at time of writing that brought together green and vanilla bonds that were issued by the same issuer at the same time under the same offering statement. As described in Section

5.3, this collection of bonds was further refined down into pairs of green and vanilla bonds that are as close to identical as possible in order to unpack any yield and pricing differences.

Both data sets took a great deal of screening and filtering in order to obtain a reasonably large and consistent sample of representative climate and green muni bonds that have been issued in the past few years, and these datasets are unique to this analysis.

5.2 Index 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 climate-aligned and green-labelled US muni bonds issued in 2014, 2015, and the first half of 2016. This data set of climate-aligned and green-labelled municipal bonds is unique, because until now no one has captured a view of both the labelled and unlabelled US green muni bond market. 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 5.1), 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), 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 scrutinized 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

Year	Amount Issued ($M)	Number	Labelled
2016 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 5.1: Green and Climate issuance by year, including the number of green labelled bonds.

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 5.2.

This manually collected data was combined with an existing non-comprehensive collection of unlabelled but climate-aligned bonds that spanned the years 2009-2013. We included every CREB (Certified Renewable Energy Bond) and QECB (Qualified Energy Conversation Bond) issued, particularly for the years 2010-2012 when that segment of the market was most active under the ARRA (American Reconstruction and Recovery Act) stimulus plan. All green-labelled muni bonds were included from 2013 (when the first one was issued) through the first half of 2016. We were restricted by earlier lack of issuance in the climate sector of the muni bond market in addition to the labor involved in manually checking each bond's use of proceeds for eligibility, therefore we were unable to comprehensively cover unlabelled issuances for the years pre-dating 2014.

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 5.1, the number and amount of issuance has grown consistently year on year, however it is also evident from this table which years (2009-

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

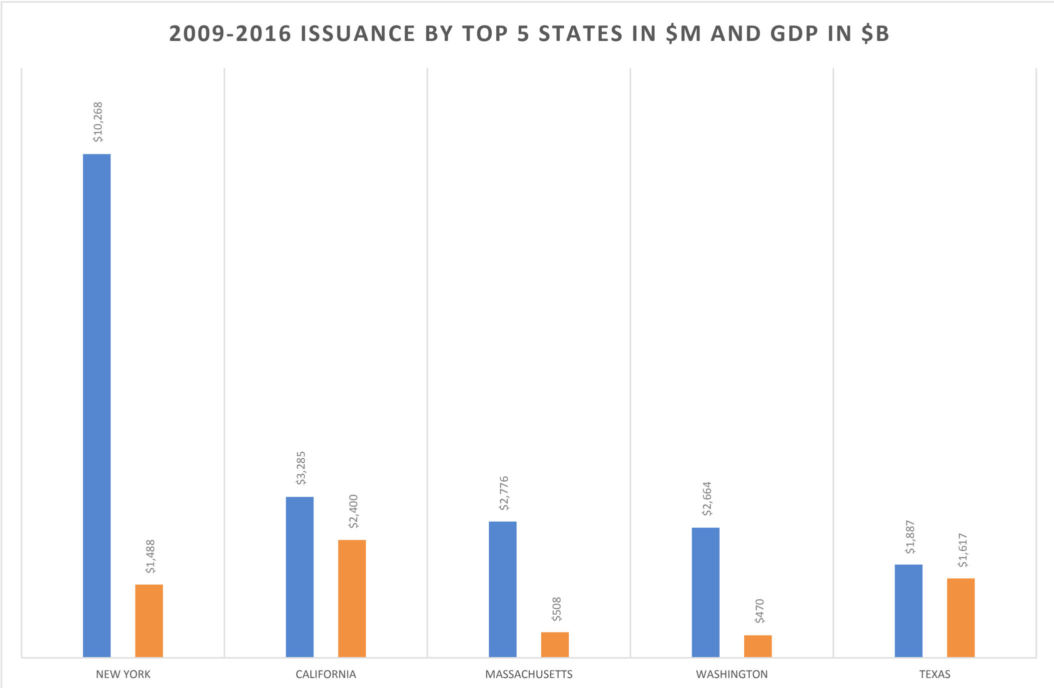


Figure 5.1: Amount of climate-aligned and labelled green municipal bonds issued by the top five most active states in $M.

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 and QECBs being easily identified as qualifying clean energy-related bonds (see Section 3.8). Additionally, the green muni bond database allows us to show which states have been most active in the green infrastructure bond market over the considered time period, as shown in Figure 5.1, along with their corresponding GDPs. We also broke down the green and climate-

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

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

aligned bonds in the database by their S&P or Moody's ratings, when available, as shown in Table 5.4.

In terms of the time to maturity of the green and climate aligned bonds, Figure 5.2 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 5.5. Despite collecting a sizeable database of green infrastructure related municipal bonds, the number of index-qualifying constituents is significantly smaller in the green (680) and climate aligned (1,200) indices compared with the S&P muni index (180,000), with a corresponding disparity in overall index market value. Because the index methodology normalized the indices by market cap, the trends of the smaller 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

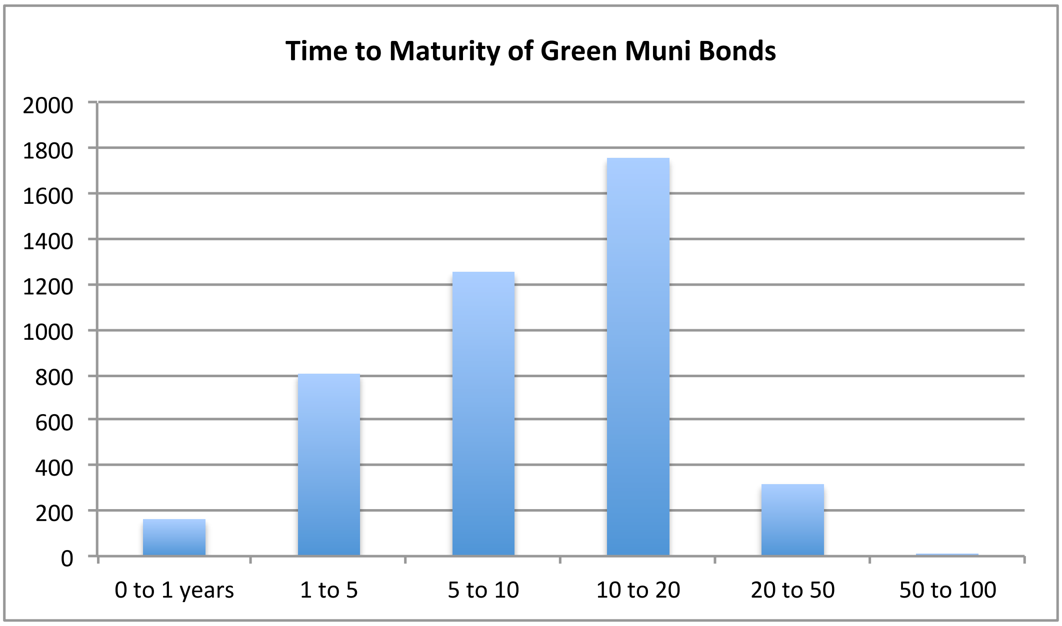


Figure 5.2: The tenor breakdown of green and climate muni bonds.

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

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. We took a particular focus on energy for the following reasons. First, it is straightforward to distinguish bonds for green energy infrastructure from conventional fossil fuel based infrastructure. In other sectors, like transport or water, the boundaries between traditional projects that are able to qualify for the green bond label are more blurred. Additionally, there is a clear and more robust set of data for bonds related to clean energy and energy efficiency.

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.

5.3 Yield Curve Data

Once the green indices were constructed, we then wanted to take a closer look at the yield differential between green muni bonds and conventional "vanilla" muni bonds, since the preliminary results of the index indicated a difference in performance. In order to better explore the difference, we constructed a second data set that was comprised of all the green municipal bonds that have ever been issued in the US in conjunction with vanilla bonds. Our primary motivation in using this approach is summed up by Michaelsen (2018), who 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." While that is true for the larger global corporate 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 muni market gave us a 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 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 enabled us to compare like for like in that the bonds are grouped into green/vanilla series with the same issuer, same credit rating, and

Bond Data Set	Number	Issue Amt $M
Green Series Bonds	548	5,279
Vanilla Series Bonds	667	8,255
Green Bonds from Pairs	472	2,692
Vanilla Bonds from Pairs	472	2,333

Table 5.6: The number of bonds and their volumes in the data sets spanning January 2015 to October 2017.

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 1,215 bonds, 548 of which were green (see Table 5.6). Similar to the index data, the green/vanilla series are all investment grade, as shown in Table 5.7. The tenors of these bonds are shown in Table 5.8, and the amount of issuance by sector is shown in Table 5.9.

This data set was further restricted down to 472 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 (shown in Table 5.6), 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 once these discounts

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

Table 5.7: 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.

	Tenor					
	Green		Vanilla		Overall	
Year	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
2014	14.1	6.50	9.89	6.28	11.4	6.65
2015	13.3	7.19	12.6	7.89	13.0	7.49
2016	14.3	7.32	12.2	6.89	13.0	7.12
2017	11.9	7.44	12.8	7.94	12.3	7.70

Table 5.8: The means and standard deviations of the tenors for the green and vanilla municipal series bonds in our set.

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.

5.4 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-

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 5.9: Issuance broken down by sector.

aligned and vanilla bonds serving as proxies for the non-green bonds). This was done in order to see if the an index based on the green market would be relevant in comparison to the overall muni market, since, in order to gain any insights from the green and climate indices and yield curves, they must be representative of a set of bonds with market characteristics similar to the prevailing muni bond market. If there is a difference in the liquidity of the green muni bond market, then this could have a distorting effect on the prices of those bonds through a liquidity premium.

Liquidity is a form of market price elasticity, and is defined as the ability for an an asset to be sold onto a market without causing significant change in the asset's price, and is often measured from the differences in bid and ask prices, which would be the most rigorous way of checking market liquidity. Schestag et al. (2016) also outlines alternative approaches to measuring liquidity, some of which also rely on intraday trading data, quotes, or transaction costs, which we also did not have access to. Instead, the metrics that we used for analysis were based on price, volume, and trade frequency.

Since 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 (Gabrielsen et al., 2011) 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:

$$\text{IoM}(i,t) = \sum_{i=1}^{N} \frac{(P_{it} - P_{it-1})^2}{V_{it}} \tag{5.1}$$

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 smaller the change in prices with respect to traded volume, the lower the ratio, and the higher the liquidity of the market.

(Grossman and Miller, 1988). This metric is actually a component of Amihud's illiquidity measure as described in (Schestag et al., 2016).

We also found the number of Zero Trading Days (ZTDs) for the bonds in our data sets as another proxy for liquidity. Both Febi et al. (2018) and Zerbib (2016, 2018) also look at differences in liquidity in the green bond sector via bid-ask spreads, however Febi also uses the LOT liquidity measure, whereas Zerbib uses ZTDs. Because Zerbib uses synthetic bonds for benchmarking, that paper does not perform a direct comparison of liquidity for green bonds against conventional bonds. We use the ratio of ZTDs to the total number of days traded for each bond in our sample in order to determine if there is a difference between the green-labelled and non-labelled bonds, where the lower the ratio, the more liquid. This is also discussed in Schestag et al. (2016), where they state that because this "does not measure transaction costs directly, we classify it in the group of 'other liquidity measures.'"

The converse measure, or the number of days where trading actually occurred, is another component of Amihud's illiquidity measure (AI) (Schestag et al., 2016):

$$\text{AI} = \sum_{i=1}^{N} \frac{1}{TD_i} * IoM_i \tag{5.2}$$

where TD_i is the number of days where each asset was traded, and the IoM corresponds to Eq. 5.1. This expression weights the Index of Martin for each asset by the number of the bond's "active" days in the market, before summing over all assets.

5.5 Liquidity Results

To attempt to determine the liquidity of the green muni bond market relative to non-green-labelled muni bonds, we calculated the Index of Martin using Equation 5.1. We performed this calculation on the two disparate bond data sets that we have aggregated, along with the strict green/vanilla bond pairings in order to take the broadest view possible.

As can be seen from Table 5.10, the normalized Index of Martin value is higher for both of the larger green datasets: the green index bonds and the green

Bond Data Set	Issue Amt $M	IoM	Ratio	AI	Ratio
Green Index Bonds	9,716	1.92		1.86	
Climate Aligned Index Bonds	22,186	1.72	1.11	1.70	1.09
Green Series Bonds	5,279	1.28		1.16	
Vanilla Series Bonds	8,255	1.21	1.06	1.07	1.08
Green Bonds from Pairs	2,692	1.48		1.38	
Vanilla Bonds from Pairs	2,333	1.54	0.96	1.42	0.97

Table 5.10: The normalized Index of Martin calculated from the traded prices and volumes of the bonds in the aggregated data sets (the green and climate-aligned index bonds spanning January 2015 to October 2017, and the green and vanilla series bonds spanning January 2015 through December 2017). The Index of Martin and Amihud metric have both been normalized by the total issue amount of assets in each basket, and the ratio of these values for each green/vanilla dataset is shown.

series bonds that we used to calculate the yield curves. The green index bonds ($n = 944$) had an Index of Martin of 1.92 compared with the Climate-Aligned Bonds ($n = 2,486$), which had an Index of Martin of 1.72. The ratio of these values (green/climate) for the overall index data set is 1.11 for the Index of Martin, and 1.09 for the Amihud ratio.

For the green and vanilla series bonds that were used to calculate the yield curves, the number of bonds are more evenly divided between green ($n = 712$) and vanilla ($n = 779$). In this set of bonds, the green bonds still had a higher Index of Martin of 1.28 compared with 1.21 for the vanilla bonds. After normalizing by total issue amount, the green/vanilla ratio is 1.06, and 1.08 for the Amihud metric. When we focus only on the strict green/vanilla pairs of bonds within this dataset, the green bonds have a slightly lower Index of Martin value of 1.48, whereas the vanilla bonds have 1.54. When normalized by issue amount, the green/vanilla ratio is 0.96 for the index of Martin, and 0.97 for the Amihud ratio. 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.

The Amihud illiquidity ratios appear to be consistent with the Index of Martin values within 2%. These findings are also consistent with the Index of Martin findings in that the climate index bonds were found to be about 10% more liquid than the green bonds. In the green and vanilla combination pairs data set, the green

	Mean ZTD	SD	IoM	AI	t-test	p-value
Green Index	0.971	0.043	1.92	1.86	-6.671	3.603e-11***
Climate Index	0.982	0.035	1.72	1.70		
Green Series	0.904	0.120	1.28	1.16	2.8351	0.0046**
Vanilla Series	0.882	0.151	1.21	1.07		
Green Pairs	0.930	0.092	1.48	1.38	0.90553	0.3654
Vanilla Pairs	0.924	0.104	1.54	1.42		

Table 5.11: The mean ratios of Zero Trading Days (ZTDs) to trading days for the green bonds and the vanilla bonds in our sample, along with t-test values to assess their statistical significance. The normalized IoM and AI are also shown for reference.

Year	# GTDs	# VTDs	Green/Vanilla Amihud	Green/Vanilla Martin
2015	216	184	0.445	0.751
2016	238	225	1.669	1.1813
2017	251	247	1.165	1.050
2018	250	248	0.798	0.701

Table 5.12: The Amihud and Martin illiquidity ratios along with the number of active aggregated trading days calculated for the strictly paired green (GTDs) and vanilla (VTDs) bonds in our data set, broken down by year.

bonds are actually found to be slightly more liquid than their vanilla counterparts.

For each bond, we also found the number of zero trading days (ZTDs), and divided this by the total number of potential trading days. This ZTD ratio was compared for the green-labelled bonds against the non-labelled bonds, and the average of these ratios is shown in Table 5.11. The green bonds in our sample showed only slightly less activity than the vanilla bonds. Using ZTDs as a proxy for liquidity, for the pairs of bonds, there is no statistically significant difference, and only marginal significance for the series bonds, which is consistent with our Index of Martin findings. There is a statistically significant difference for the index bonds, however the difference in means implies that by this measure the green bonds are only 1% more liquid than the climate bonds. Overall, the ZTDs agree with the IoM and AI ratios in terms of relative liquidities: the green and vanilla series bonds seem to be the most liquid by both measures.

To look closer at any potential differences between the strictly paired green and vanilla bonds, we looked at the development of the Amihud illiquidity metric

5.2 on an annual basis from 2014 to 2017, as shown in Table 5.12. We show this analysis for the pair data because this helps to isolate any differences in liquidity that would arise from investor demand rather than differences in the bonds making up the sample. We also show the aggregated number of trading days for each of the green and vanilla sets of bonds. These aggregated trading days differ from the ZTDs in that the ZTDs are calculated for each asset before being averaged, and the active trading days are the total number of days in sample where any of the assets have traded. This is shown for reference: traded days per asset are used for the Amihud calculation. This table shows that there is wide variance in the liquidity ratios for 2015 and 2016.

5.6 Conclusions

This chapter provided an overview of the data sets that were used as the basis for our analysis of the green municipal bond market. We also assess the liquidity of these green bonds and compare them against non-green-labelled bonds, in order to determine whether or not any significant differences in liquidity could lead to a liquidity premium effect. Trading volume has limitations for representing market liquidity, however we were limited by access to market data in performing more comprehensive analysis. In our analysis, we found that the results from the Index of Martin metric were consistent with those from the zero traded days approach and the Amihud Illiquidity ratio.

The index bonds did show a slightly higher liquidity for the climate bonds relative to the green bonds in the index bond sample, however given that this set of bonds is comprised of a wider variety of issuers, it would be surprising to find identical results between the two classes of bonds. It was not possible to calculate similar liquidity metrics for the benchmark S&P indices for the sake of direct comparison. Nevertheless, using the climate bonds as a proxy, we did not observe a difference in liquidity greater than 10% between the green index bonds and the climate bonds by any of these metrics. In particular, the strictly paired green and vanilla bonds exhibited both Index of Martin and Amihud metrics that indicated that the green bonds in this sample were slightly more liquid than the vanilla over the broader timeframe being considered, and this is also consistent with their . We nevertheless observe a wide variance in results of these ratios over time as show in the evolution of the Amihud ratios in the past few years, as shown in Table 5.12.

In aggregate, these liquidity ratios indicate that it is still too early in the development of this market to indicate any clear trends in differences in liquidity between the green bonds and their non-labelled counterparts. Overall, the metrics indicate that the green bonds have comparable liquidity with the muni market, and therefore support the relevance of the green and climate aligned indices to serve as a valid benchmarks.

The next chapter will describe the methodology that was used to construct the bond indices, along with with fixed income mathematics that was used to calculate the descriptive characteristics of the bond indices and benchmark their performance.

Chapter 6

Green Municipal Bonds Index Benchmarking

This chapter describes how we used the data that we collected as described in Chapter 5 to construct indices for the green-labelled and climate-aligned bonds. These indices were benchmarked against existing municipal bond indices in order to evaluate their performance compared with the overall municipal bond market.

6.1 Green Muni Bond Index Construction

We created bond indices specific to the green-labelled and climate-aligned municipal bond market in order to test the competitiveness of the green sector of the muni bond market against the overall muni bond market. We used the S&P bond index construction methodology in order to optimize the consistency between our generated climate indices and the S&P market benchmark indices. These indices are market-value-weighted indices, where the total return "is calculated by aggregating the interest return, reflecting the return due to paid and accrued interest, and price return, reflecting the gains or losses due to changes in [price]" (S&P Dow Jones Indices, 2016). The market values, interest returns, and price returns were calculated according to this methodology, and an attempt was to keep the construction rules as consistent as possible between the climate indices and the S&P benchmarks. According to Brown (1994), these indices are tracker bond indices weighted by market value, rather than issue amount, since "it is a better measure than the amount in the issue, since it allows one to compare issues with different coupons and lives". Summary statistics and benchmarking statistics, such as modified duration, volatility, returns, and correlation, were calculated from the daily returns of the indices using the standard approach outlined in *Investments*, chapter 8 (Bodie et al., 2011).

To establish their performance relative to the overall market, the green muni indices were compared with their respective S&P muni indices. S&P muni indices were chosen as the benchmarks because of three reasons: 1) the size of the S&P indices allow them to stand in as a proxy for the overall muni market, 2) 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, and 3) 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.

Once the green muni bond data was aggregated and the liquidity was checked as described in Section 5.4, 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 was comprised of the tax credit bonds, particularly the CREBs and QECBs, that were issued as part of the 2008 economic stimulus package (as described in Section 3.8). This sub-index had two of the selection criteria lifted: the constituent bonds 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, 2017b).

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 outdated due to lack of activity, and similar approaches of filtering index inclusion by trading activity have been taken by other bond indices (FTSE, 2017). Some concern could arise that these frequent price movements could also induce asynchronous trading effects, which is an issue that we address in greater detail in Section 6.5.

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, and this has an affect of dampening volatility. The primary reason for this is because the S&P indices are based on a 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 6.1, which shows the number of bonds 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

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 6.1: 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.

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).

6.2 Index Methodology

In order to construct our market value weighted indices, we followed the S&P methodology (S&P Dow Jones Indices, 2016) as follows. The bond issue and trading price data was loaded into the database, then we calculated the daily market value for each asset based upon their closing prices for each day. The market value at close on day t was calculated as:

$$MV_t = PAR_t * \frac{(P_t + AI_t)}{100} \tag{6.1}$$

where PAR_t is the par amount of the index security as of the last monthly rebalancing, P_t is the clean price (that is, the price excluding accrued interest) of the asset on day t, and AI_t is the interest accrued on that asset up to and including day t.

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. The interest return is calculated as

$$IR_t = \frac{(AI_t - AI_{t-1} + Cpn_t)}{MV_{t-1}} \tag{6.2}$$

and the price return is calculated as

$$PR_t = \frac{(P_t - P_{t-1})}{MV_{t-1}} \tag{6.3}$$

where AI_t is the interest accrued on day t (or $t-1$ for the day before), Cpn_t is any coupon payment made on that day, MV_{t-1} is the market value for the previous day, and P_t is the clean price for the bond on day t ($t-1$ for the previous day). The total return is the combination of the interest return and the price return, $TR_t = IR_t + PR_t$.

Then, these values were used to create an overall index return for the aggregated assets in the index. The index returns are calculated each day for the price returns, interest returns, and total returns for the overall index such that:

$$\begin{aligned} IndexTR_t &= \sum_i TR_{i,t} \\ IndexPR_t &= \sum_i PR_{i,t} \\ IndexIR_t &= \sum_i IR_{i,t} \end{aligned} \tag{6.4}$$

which is a sum over all the respective returns for each asset per day. The index returns can then be used to create the index values, which are:

$$\begin{aligned} TRIV_t &= TRIV_{t-1} * (1 + IndexTR_t) \\ PRIV_t &= PRIV_{t-1} * (1 + IndexPR_t) \\ IRIV_t &= IRIV_{t-1} * (1 + IndexIR_t) \end{aligned} \tag{6.5}$$

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 a collection of assets, in this case 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 (Eq. 6.1). These market values, along with any coupon payments that day, were used to calculate the index return (Eq. 6.2), price return (Eq. 6.3), and total returns on each day. These values were summed across all active assets on each day to calculate the overall index returns (Eq. 6.4) and these returns were used to find the overall index values, IRIV, PRIV, and TRIV (Eq. 6.5). 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 6.1.

6.3 Fixed Income Mathematics and Descriptive Characteristics

In order to ensure that our indices were comparable to the S&P indices, we first compared 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.

The performance of an individual bond can be assessed by the overall cash-flows that occur as a result of buying a bond. The price paid for a bond influences the yield, or overall returns, of the bond. The relationship between the purchase price and the cashflows of the coupon payments and final redemption of the bond is given by the yield to maturity, which encapsulates all the of the cashflows over the lifetime of the bond. As described by Bodie et al. (2011), "The yield to maturity (YTM) is defined as the interest rate that makes the present value of a bond's payments equal to its price. This interest rate is often interpreted as a measure of the average rate of return that will be earned on a bond if it is bought now and held until maturity." It is important to note that many municipal bonds have early redemption provisions in the form of early call dates, which is also reflected in the market prices of the bonds. Callable muni bonds are popular with issuers because historically it has enabled them to exercise the option to call in the bonds and then refinance them at lower rates. Therefore, for callable bonds, the yield to maturity actually needs to be calculated as yield to call, which we did using the call dates, where applicable.

In order to calculate the Yield to Maturity 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:

$$\text{Price} = \sum_{t=1}^{N} \frac{Payment}{(1+r)^t} + \frac{Par}{(1+r)_{end}^{N}} \tag{6.6}$$

where N is the total number of coupon payments outstanding, with N_{end} being the number corresponding to the last payment, and t is the time period between payments (in the case of muni bonds which pay out twice a year, this is a six month interval). *Payment* is the amount of the coupon payment, *Par* is the par value of the bond, \$100 in this case, and r is the coupon interest rate that the bond pays to the holder (Bodie et al., 2011). In order to solve for yield to maturity, an optimization using Newton's technique is performed (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:

$$\text{WeightedAvgYTM} = \frac{\sum_N y_N s_N}{\sum_N s_N} \tag{6.7}$$

where y_N is the traded yield of the Nth asset, and s_N is the size of that trade.

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.

Bodie et al. (2011) gives an effective outline of bond pricing relationship based on the term structure of interest rates as described by Malkiel (1989). The relationship between bond prices and yields are inversely proportional, such that an increase in yield to maturity (Eq. 6.6) creates a smaller change in price than a decrease of equal size. The longer the tenor of a bond, the more sensitive it is to changes in interest rate environment, because there are outstanding cashflows that are more discounted, with more distant cashflows being most impacted. Bond prices become less sensitive to changes in yield as their maturity approaches. Finally, interest rate risk is inversely proportional to bond coupon rates, and the sensitivity of bond prices to changes in yield is also inversely proportional to the current yields to maturity.

Taken together, these principles explain why it is important to ensure that we are comparing like with like as much as possible when benchmarking bond indices or comparing yield curves. These principles can all be tied in together in the concept of duration, which is important because it helps to describe the effective maturity of bonds. Bonds with higher coupons making more coupon payments have a shorter overall effective duration, since more of their cashflows are transacted in a shorter time frame. As interest rate risk is higher for longer term bonds, duration is a way of measuring this risk through price sensitivity to interest rate changes.

The first effective maturity formulation was the Macaulay duration, which is the weighted average of the times to each coupon payment or principle repayment:

$$D = \sum_{t=1}^{T} t \times w_t \tag{6.8}$$

where

$$w_t = \frac{CF_t/(1+y)^t}{Price} \tag{6.9}$$

and CF_t is the cash flow at time t, y is the bond's yield to maturity, and T is the time of maturity. Modified duration takes this concept a step further, and encapsulates the idea that longer tenor bonds are more sensitive to changes in interest rate environment, such that:

$$\frac{\Delta P}{P} = -D \times (\frac{\Delta(1+y)}{1+y}) = -D\Delta y \tag{6.10}$$

where the proportional price change is equal to the proportional change in yield times duration (Eq. 6.8).

As related to Maikel's bond pricing principles, there are also some principles for duration. First, the duration of a zero-coupon bond is equal to its time remaining until maturity, and if maturity is held stable, the duration of a bond is lower when its coupon is higher. Furthermore, if coupon is held constant, duration increases with respect to time to maturity, and duration is higher when yield to maturity is lower, all else being equal.

As stated in the Handbook of Municipal bonds Feldstein and Fabozzi (2008), "Simply put, duration is a measure of the approximate sensitivity of a bond's value to rate changes. More specifically, duration is the approximate percentage change in value for a 100 basis point change in rates." Because of the many factors that come into calculations of duration, durations can vary widely among a basket of traded bonds, and this is why we compare durations across our indices.

Overall, the importance of this calculation is summarised by Zipf (2003): "We use duration as a measure of bond risk. Its importance is linked to bond volatility. Modified duration is a better measure of bond volatility, or bond risk." In particular, we used modified duration for use in index comparison, which 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), who uses the following definition:

$$\text{Modified duration} \cong \frac{P^- - P^+}{2(P_0)(dY)} \tag{6.11}$$

where dY is the change in yield, P^+ is the price of the bond in response to a increase in yield by amount dY, P^- is the price of the bond after the yield is decreased, and P^0 is the initial price. This approach has the caveat that dY must be a small change, because the yield curve is usually not linear. With this approach, 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.

6.4 Index Benchmarking

Once these values were 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. 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.

The returns calculations were based 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 raw index TRIV values (Eq. 6.5) for our indices and the S&P indices in order to perform a benchmark analysis of the returns (the S&P TRIV values were available to download from their website). The Climate and Green indices were specifically 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 5.4 and 5.5).

The daily index values for the climate, green, and S&P indices formed a time series that could then be benchmarked. These time series each consisted of a TRIV value calculated for each day, according to the methodology given above. The first step was to establish the daily logarithmic returns, which are defined as

$$\text{Log Return} = R_{daily} = ln\left(\frac{TRIV_t}{TRIV_{t-1}}\right) \tag{6.12}$$

where TRIV is the index total return value for day t, and $TRIV_{t-1}$ is the total return for the day before. These calculations were based on log returns rather than geometric returns because our subsequent calculations were made easier (such as Sharpe ratio and annualization of returns) by starting with logarithmic returns (Bacon, 2008; Bodie et al., 2011).

The first thing to compare was the annual returns for each of the indices. First, the Compound Annual Growth Rate (CAGR) was calculated over the time period spanning 1 October 2014 to 1 October 2017 for each of the indices. This was done with the formula:

$$\text{CAGR}(t_0, t_n) = \left(\frac{V(t_n)}{V(t_0)}\right)^{\frac{1}{t_n - t_0}} - 1 \tag{6.13}$$

where t_0 and t_n are the start and end times, and $V(t_0)$ and $V(t_n)$ are the TRIV values corresponding to these times. Since we have kept our analysis to a timeframe of exactly three years, the exponential term simplifies to $1/3$. We also calculated the annual rates of return for each of these years on a rolling basis from October to October.

Next, the TRIV values were used to calculate the excess returns and the relative returns. Excess returns are defined as returns achieved above those given by the risk-free rate, r_f. The risk-free rate is a proxy for a low-risk "safe" investment used as a form of minimum guaranteed returns, which the index in question should outperform to be successful. 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 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 (Eq. 6.15), and the relative returns were used to calculate the Information Ratio (Eq. 6.16). The risk free rate, r_f, is also used in the alpha calculations (Eq. 6.17).

In the context of finance, volatility (σ) is the variation in the trading prices over an interval of time, and is measured from the standard deviation in the logarithmic returns. From the index data, we specifically measured the historical realised volatility, rather than the implied or forecast volatility, as:

$$\sigma_{annual} = \text{Standard Deviation}(R_{daily}) * \sqrt{360} = \sqrt{\frac{\sum_{i=1} n(R_i - R_{avg})^2}{n-1}} * \sqrt{360} \tag{6.14}$$

in accordance with Bodie et al. (2011), where R_{daily} are the daily log returns specified in Eq. 6.12, i is the daily return on day i, and we use $\sqrt{360}$ as the annualization factor because used the 30/360 trading day standard in order to be consistent with ISDA (2006) trading rules.

Two common values that are used to benchmark the performance of an asset or a collection of assets and to calculate the risk-adjusted returns are the Sharpe Ratio and the Information Ratio. The Sharpe Ratio is considered "the industry standard for measuring risk-adjusted returns," (Kidd, 2011) and is defined as:

$$SR = \frac{R_{avg} - r_f}{\sigma_{avg}} \tag{6.15}$$

where R_{avg} is the average returns on the assets, σ_{avg} is the average standard deviation of R_{avg}, and r_f is the average risk free rate. The Sharpe Ratio "measures a portfolio's added value relative to its total risk" in the form of excess returns above the risk free rate (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.

We also benchmark the returns of the indices directly using the Information Ratio, which is defined as:

$$IR = \frac{R_{index} - R_{benchmark}}{\sigma_{(index-benchmark)}} \tag{6.16}$$

where in this case, R_{index} is the average daily returns of the (climate) index over the time period under consideration, $R_{benchmark}$ is the average daily returns of the benchmark (S&P) index, and $\sigma_{(index-benchmark)}$ is the standard deviation of the difference in those daily returns. Like the Sharpe Ratio, higher values for the Information Ratio indicate stronger performance.

Two more important values to consider when benchmarking the performance of an index are alpha (α) and beta (β), which are values that are derived from the Capital Asset Pricing Model (CAPM) (Bodie et al., 2011). Overall, β is a measure of an asset's volatility relative to a benchmark, and α is a measure of the active returns of the asset compared with the benchmark. The CAPM makes use of the security characteristic line (SCL), which is a linear regression performed on the returns of the index, and the excess returns of the benchmark relative to the risk free rate, known as the Single-Index Model (Bodie et al., 2011).

When a regression is performed on the excess returns of the climate index with the excess returns of the benchmark index, the SCL linear equation that results is of the form:

$$R_i = \alpha_i + \beta I R_B(t) + e_i(t) \tag{6.17}$$

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. Stated even more generally, this corresponds to a linear equation of the form:

$$Y = \alpha + \beta x \tag{6.18}$$

such that the slope of the line corresponds to the index's beta, and the intercept, α is the expected excess return when the benchmark excess return is zero, however β can also be calculated directly from the returns as:

$$\beta = \frac{\text{Cov}(r_i, r_b)}{\text{Var}(r_b)}. \tag{6.19}$$

The daily TRIV values were used to create daily log normal returns for each index. These returns were used to perform a regression for each pair of indices in order to find the alpha and beta from the SCL Eq. 6.17. The volatility (Eq. 6.14), Sharpe (Eq. 6.15), and Information Ratios (Eq. 6.16) 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.

6.5 Results of Index Benchmarking

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

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

labelled index against the broader climate-aligned index, with the pairings as shown in Table 6.2.

The performance chart showing returns relative to the first day of the benchmarking period is depicted in Figure 6.1. A summary of annual returns in the form of CAGR (see Eq. 6.13) for the different indices is shown in Table 6.3. The overall climate-related indices (across all sectors) plus the climate-aligned sector indices for water, energy, and transport are shown in Figure 6.2, and the returns for the state indices for California (CA), New York (NY), Massachusetts (MA), Washington (WA), and Texas (TX) in Figure 6.3.

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 6.5 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 (in order to have three round years of data). These values were annualised on a 360-day basis, in accordance with the 30/360 day count

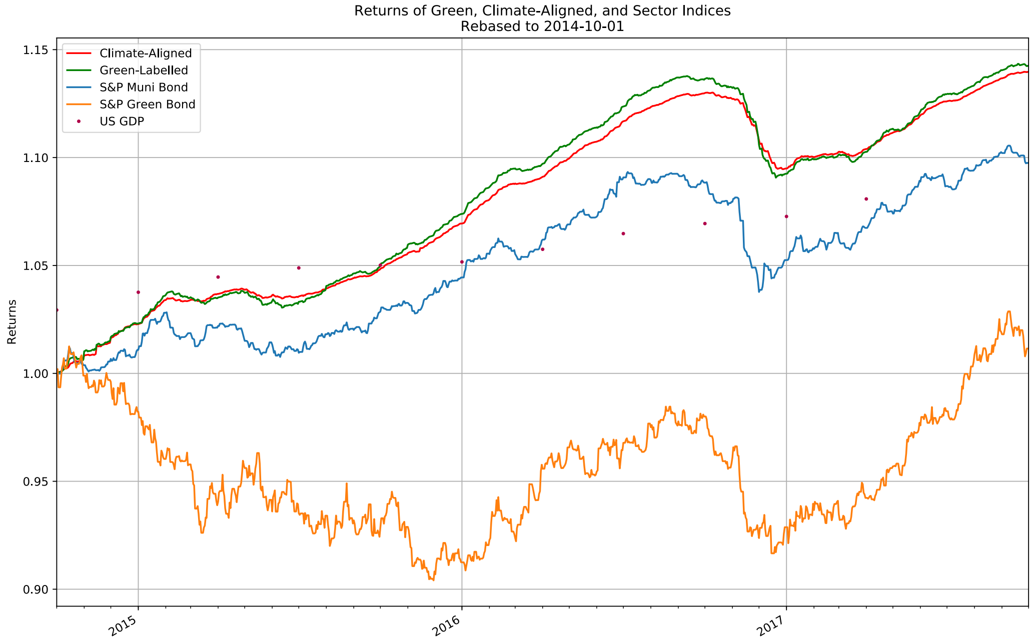


Figure 6.1: The returns of the climate-aligned and green-labelled municipal bond indices for 2014-2017 in relation to the S&P Muni Index. Rebased so that 2014-10-01 = 100; GDP for reference.

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 6.3: 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 6.4: Tracking errors in the returns of the climate indices compared with their respective benchmarks over October 2014 to October 2017.

standard explained in Section 6.3.

As shown in Table 6.5, 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 6.4, with the energy index showing the greatest difference from its S&P Public Power benchmark.

These alpha and beta values were confirmed by performing linear regressions on the logarithmic excess returns of the Climate and Green indices against the S&P Investment Grade Muni index. This was done in order to determine the coefficients for the Security Characteristic Line (SCL) as shown in Eq. 6.18. The results of these regressions is shown in Table 6.6. The alpha for the green index from this regression is 3.84%, and the alpha for the climate index was estimated to be 4.04%. Not only are these values for α and β consistent with those calculated from the correla-

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 6.5: 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.

Regression of Climate/Green index returns against S&P returns.				
	Coefficient	Std Error	t-value	p-value
Green α	0.0384	0.0047	8.585	<2e-16 ***
Green β	0.1426	0.0013	10.855	<2e-16 ***
Climate α	0.0404	0.0040	10.04	<2e-16***
Climate β	0.1120	0.0011	10.04	<2e-16***

Table 6.6: The results of the linear regressions performed on the excess returns of the climate and green indices against the excess returns of the S&P Investment Grade benchmark index, along with their statistical significance.

tions and covariances (shown in Table 6.5), but the t-values and p-values for these regressions indicate a high level of statistical significance for these coefficients.

Table 6.7 shows the three-year annualised returns for the Climate and Green Labelled indices along with the S&P Muni. The Green Labelled 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.

Figure 6.4 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 occur during the only period of time in which these indices experienced significant losses within the timeframe being considered. Inspection of the index returns plots (Fig-

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

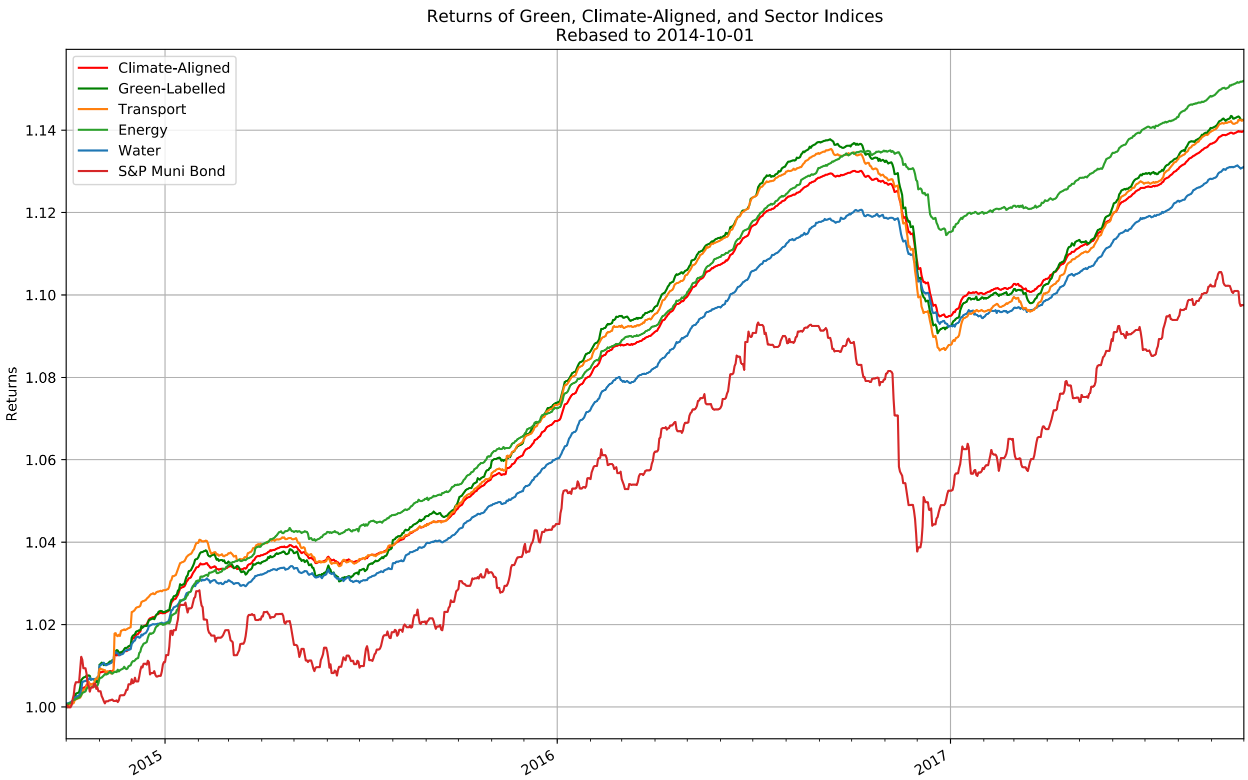


Figure 6.2: Green municipal indices by sector for Energy, Transport, and Water, along with the overall climate-aligned and green-labelled muni indices, and the S&P municipal index.

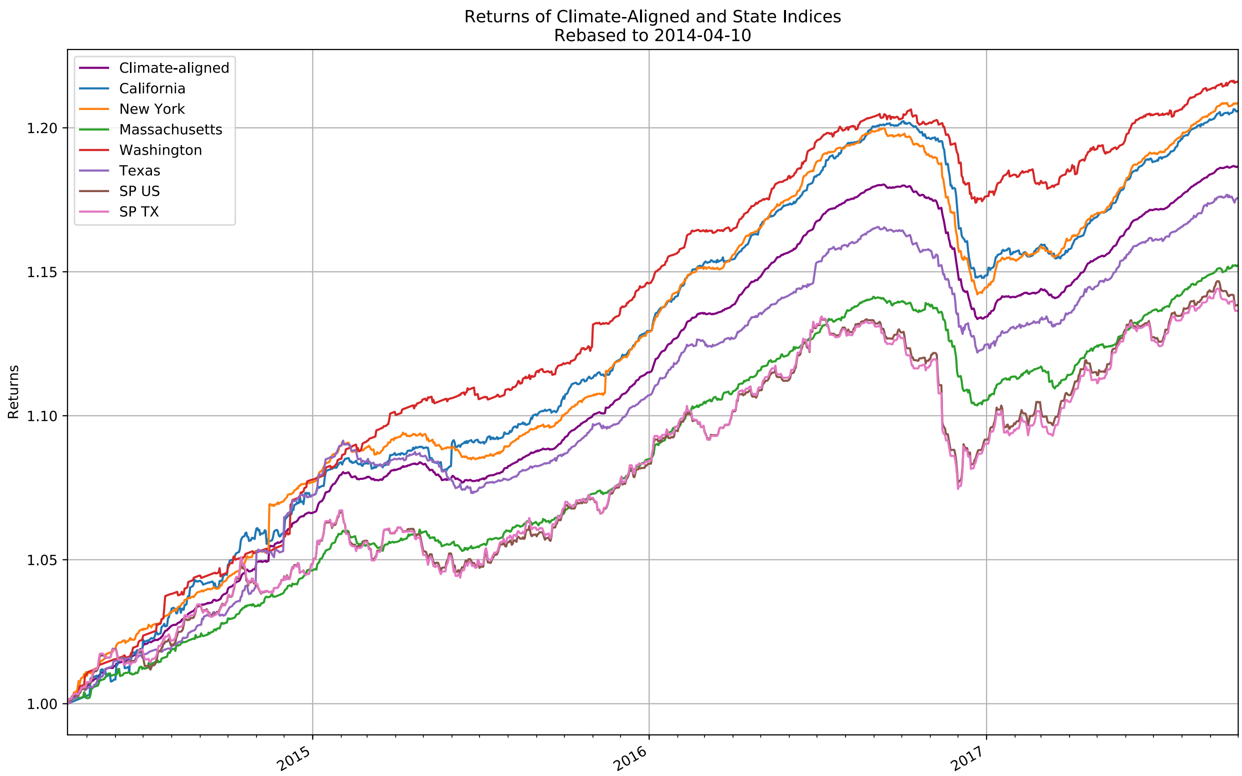


Figure 6.3: Green municipal indices by state, and their corresponding state S&P municipal index.

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

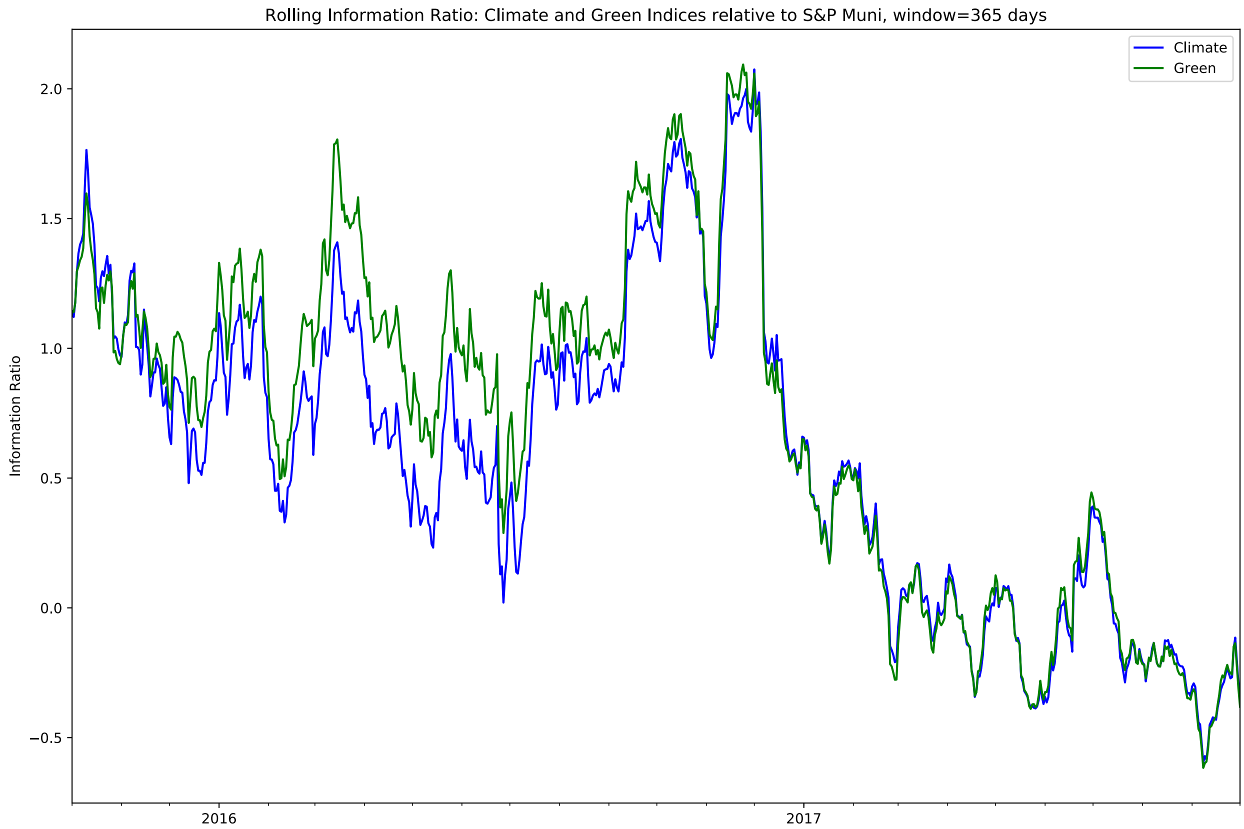


Figure 6.4: Rolling information ratio for the Climate-aligned (blue) and Green-labelled (green) indices benchmarked against the S&P Muni index with a window size of 365 days.

ures 6.1, 6.2, and 6.3) 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.

Table 6.9 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. The differences in these relative losses could indicate that the climate and green indices were more resilient against losses in

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%

Table 6.9: Drawdowns experienced in the aftermath of the Presidential election in the last quarter of 2016. The overall climate and green indices experienced a smaller downturn after the election than their S&P Muni index.

the overall market, however some of the individual climate sector indices experienced larger drawdowns than their S&P counterparts, such as the the transport index (8.01% compared with 7.11%) and especially the energy index (10.93% compared with 5.50%). It is understandable that the climate-aligned and green energy sub-index would have the largest exposure to policy risk at the time of the election, given that part of the Trump election platform was support for the coal mining and fracking industries.

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 like Bloomberg or Thomson Reuters, 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 actually 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.

Another factor to be considered in this approach is the potential for asynchronous trading effects (Campbell et al., 1996). Because our index data uses end of close daily traded prices, and because sometimes the bonds in our sample don't trade for periods of time, this could cause asynchronous effects to arise. The use of matrix prices by the commercial indices also potentially masks this issue, giving the illusion of price movement on days where an asset wasn't actually traded.

Nonsynchronous trading effects could potentially have an impact on the returns generated by that asset, including the mean, variance, and cross-correlation coefficients. The price of an asset that has less liquidity, and is therefore traded less frequently would exhibit price movements that appear to jump further and less often than a more liquid asset which would show a continuous movement of prices, and therefore returns. Measuring the asset returns using a fixed period timeframe (such as daily), the disparity between this and the actual, less frequent, trades generates a behaviour where the price reverts infrequently to the fair value of that asset.

Various models have been introduced in literature to estimate the effect of this non-trading behavior, including Lo and MacKinlay (1990). However, where non-zero expected returns are measured, negative serial correlation in individual assets can be demonstrated, but when comparing the non-observed return errors between two different portfolios or indexes, they are found to be negligible when assuming markets that are not substantially volatile and the two portfolios have reasonably similar non-trading probabilities (Campbell et al., 1996). Also, when considering the first order serial correlation effects, it was noted by Perry (1985) that non-stationary trading effects were significantly less than the overall serial correlation. Furthermore, it was shown by Atchison et al. (1987) that the level of autocorrelation empirically observed in indexes greatly exceeds the amount predicted by the effects of nonsynchronous trading, implying that other price-adjustment delay factors play a more significant role in this.

According to their disclosed methodologies (S&P Dow Jones Indices, 2016; S&P Dow Jones Indices, 2017a), the S&P do not include non-stationary effect adjustment in the calculation of their indexes. Consequently, this effect was determined to be of insufficient magnitude to be included, and doing so would have led to unequal comparison with third party indexes such as the S&P.

6.6 Conclusions

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.

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 5.4). We ran an unfiltered prototype version of the index that includes all available bonds above the threshold size, and it made very little difference on the returns. However, this is a less rigorous approach, especially as the bonds in the sample reach maturity over the years and the last traded prices potentially drift from their actual market values.

The disadvantage of our use of end of day traded prices 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. This caveat more directly applies to any of the risk-adjusted returns in terms of the Sharpe and Information Ratios, alpha, the beta, etc.

For example, because the mathematical definition of the Sharpe Ratio requires the excess returns to be divided by the volatility (see Eq. 6.15), and the volatility of the climate indices is lower than the S&P indices due to the fact that we use actual trading prices rather than matrix prices, this gives the impression that our climate indices are performing unusually well compared with the S&P. While the values in Table 6.5 indicate that the climate sector indices showed strong market performance, these values are skewed by the very low beta coefficients. In every comparison, the betas are all positive indicating that the climate index follows the same movements of the S&P benchmark, however the average beta was only 0.07, indicating that the price movements of the climate indices are considerably damped compared with their benchmarks. Furthermore, we do not include non stationary effect adjustment in the calculation of our indices because doing so would have led to unequal comparison with third party indexes such as the S&P, and it is unlikely to have much effect on the returns according to the analysis in Section 6.5.

Nevertheless, the climate indices exhibit the same directional movements and trends as the S&P benchmarks. Because the returns and trends are robust across the indices, and since these are calculated solely upon price movements rather than any volatility measures, they are directly comparable. On a returns and trends basis, the climate indices have consistently outperformed their S&P counterparts, as shown in Figs 6.2 and 6.3, and Table 6.3. As shown in the tracking errors (Table 6.4), 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%.

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 6.8). The ARRA index is anomalous in that it is quite a small index, and it contains CREBs and QECBs. These types of muni bonds are nominally taxable, although they benefit from tax credits (see Section 3.8). As such, they are considered ineligible for the usual S&P muni indices, however their inclusion in the climate indices was crucial in order to build a comprehensive index that accurately reflected the state of the market, particularly for the clean energy sector. These bonds are an important source of sector-specific pricing data, however, their tax status could potentially affect their effective yields for domestic retail investors. Therefore we have created a separate ARRA index comprised of solely CREBs and QECBs, which was benchmarked against the S&P Build America Bond (BAB) muni index, which has similar tax credit treatment. These subindices are of particular interest because they have the longest running lifetime of any of the green muni indices given that they are able to be generated since 2010. In particular, the green energy subindex experienced CAGR of 6.16% compared with 2.96% from the S&P municipal public power index over the benchmark timeframe. The ARRA-specific index, which is comprised of tax credit muni bonds (see Section 3.8) similar to the S&P BAB index, posted a CAGR of 5.60% compared with 5.26% from the S&P BAB index.

In terms of drawdowns (see Table 6.9), 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 6.9) 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.

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 optimization in order to get a broad and unbiased view of market activity. If the index portfolios were actively managed or optimized, they would be likely to produce higher returns.

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." 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 (Karpf and Mandel, 2018; 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), which is why the next chapter will look closer into this subject.

Our findings that the green muni indices are competitive with the standard market indices should lend reassurance to investors and policy makers. Of particular note is the fact that the green-labelled muni bond index outperformed the climate-aligned (unlabelled) muni bond index, indicating that there is some value to labelling eligible muni bonds as green. A key motivation behind green labelling is that it aids discovery and could encourage a more diverse investor base, along with encouraging more direct financial engagement with the citizens that stand to benefit from the infrastructure that the bond finances. This is key because "states and municipalities can incur extra cost and additional work – getting a second opinion, reporting on the use of proceeds, impact reporting, among other things – to issue explicitly labelled green bonds" (Saha, 2016).

In this chapter we described our methodology behind the construction of bond indices based on green and climate-aligned municipal bonds, along with the benchmarking of these indices against the standard S&P municipal indices in order to ascertain their relative market performance. The objective of this analysis was to compare the market dynamics of the green and climate muni bond sector against that of the prevailing muni bond markets, and to see the evolution of their relative performance over time.

We observed that the climate municipal indices generally outperformed the S&P municipal indices, both in terms of annual growth rates and in terms of risk-adjusted returns, however the latter may be skewed by the lower volatilities of the climate indices. When broken down by sector and state, all three green sector subindices perform at or above their corresponding S&P benchmarks. Furthermore, These results demonstrate that, at least over the relevant time frame, green labelled and climate aligned US municipal bonds are competitive with their conventional counterparts. However, while index benchmarking can compare the performance of an asset class, in the next chapter we will discuss the use of yield curves and analyze the spreads between the green yield curves and their conventional counterparts to take a closer look at potential greenium in the green municipal bond sector, especially in the primary market.

Chapter 7

Green Municipal Bonds Yield Analysis

In this chapter, we will outline our methodology and findings from the analysis of the yields of a set of green municipal bonds and their “vanilla” (non-green-labelled) counterparts. The main approach to this analysis will use yield curves, which can show if there is any difference, or spread, between the yields (and therefore prices) of the green bonds and the vanilla bonds. We will also perform linear regression analysis to help reveal if there if is a green premium present in the primary or secondary markets.

7.1 Yield Curve Analysis

We used the dataset that was created as described in Section 5.3, which was comprised of contemporaneous series of green and vanilla bonds. These bonds were used to construct yield curves in order to investigate whether the green muni bonds in this data set exhibited a green premium (“greenium”) or not. The dataset consisted of series of municipal bond issuances where green bonds were issued simultaneously with vanilla bonds, and this data was also refined to create a subset of matched pairs of green and vanilla bonds, which are (mostly) identical except for the green label.

If a green bond has a greenium, it has lower yields and correspondingly higher prices than similar vanilla bonds, indicating that investors are possibly 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. This consistency in the data makes it easier to directly compare the green bonds with the vanilla bonds and pull out any pricing differences.

First, as in the index analysis, we checked the relative liquidity of the green and conventional muni bonds as described in Section 5.4, and found that the liquidity for these green bonds was similar to the vanilla bonds, therefore any difference in yields is due to other factors rather than any difference in liquidity. Once that check was complete, we constructed yield curves for both green and vanilla bonds. This was done with the initial yields at issue for the primary market, and by using traded market prices to investigate performance after issuance in the secondary market. The yield curves were constructed using the Svensson technique, which is an extension of the Nelson-Siegel method of construction (Svensson, 1994; Nelson and Siegel, 1987), and is described in more detail as follows.

The Nelson-Siegel technique is a way of fitting a curve to known yield to maturity and time remaining until maturity bond data, which is done in order to interpolate and extrapolate the behaviour of a more complete yield curve from a limited set of bond data. It uses a more responsive equation for curve fitting rather than a standard polynomial fit, and is a more robust way of modelling than linear regression, since yield curves are generally non-linear.

The Nelson-Siegel model (Nelson and Siegel, 1987) uses the following equation to fit the curve:

$$y(m) = \beta_0 + \beta_1 \frac{[1 - \exp(-m/\tau)]}{m/\tau} + \beta_2 \left(\frac{[1 - \exp(-m/\tau)]}{m/\tau} - \exp(-m/\tau) \right) \quad (7.1)$$

where $y(m)$ and m are the yield to maturity and time remaining until maturity, respectively. The parameters β_0, β_1, β_2 and τ, are fitted, in this implementation, a non-linear least-squares curve fitting technique via the SciPy *optimize* library (SciPy.org, 2018) is used. β_0 is interpreted as the long-term levels of interest rates; β_1 is the short-term; β_2 is the medium-term; and τ is the decay factor. The Svensson model

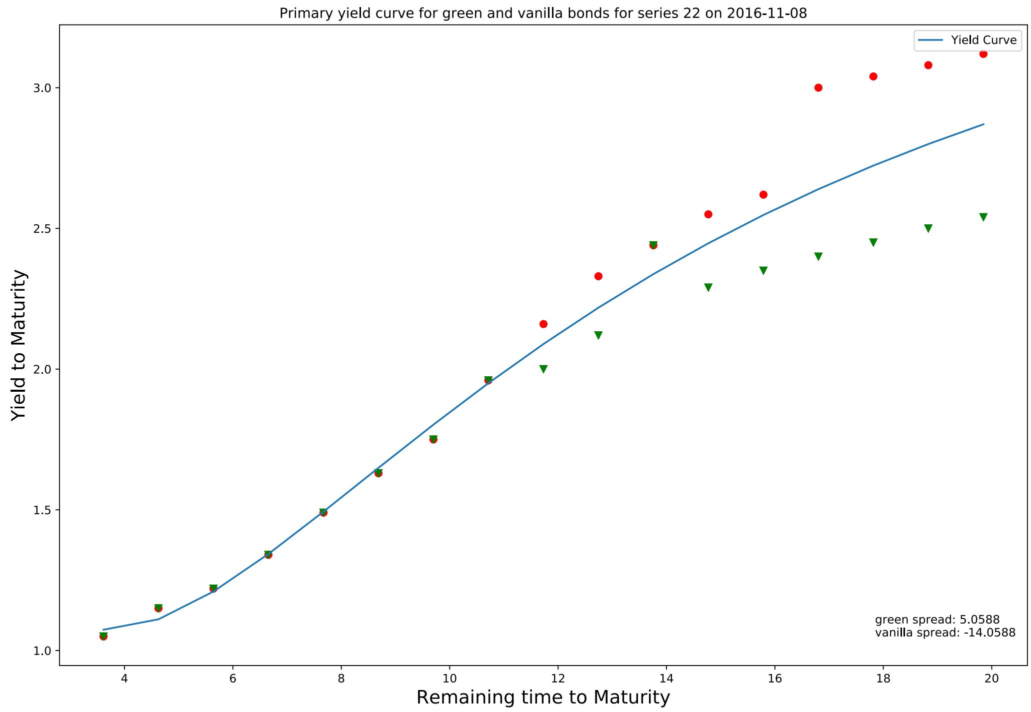


Figure 7.1: The yield curve for Arizona Board of Regents University of Arizona series of bonds issued in November 2016.

(Svensson, 1994) is an extension of the Nelson-Siegel model which adds an additional "hump" term, and is referred to as the Nelson-Siegel-Svensson (NSS) model. The additional term specified by the NSS model, in addition to Eq. 7.1, is:

$$+\beta_3\left(\frac{[1-\exp(-m/\tau_2)]}{m/\tau_2}-\exp(-m/\tau_2)\right). \tag{7.2}$$

The data that was used for the NSS yield curve modelling consisted of the market traded yields for the set of green and vanilla simultaneous bond issuances, along with the remaining lifetime of the bond at the time of each trade. For the primary market, the time remaining is the tenor. All of the bonds issued in each month had their issuance data and market trading prices used to calculate their respective yields to maturity, or in the cases where there the bond has an early redemption option, yield to call. In order to calculate the yield to maturity/call and modified duration (see Table 7.1), we used the same method as we did for the yield to maturity for the index data (see Eqs. 6.6 and 6.10). We first used the strict green-vanilla pairs so that we were comparing like with like to the greatest extent possible in or-

	Number	Modified Duration	Maturity	Tenor
Climate Index	1,200	9.7	14.0	15.8
Green Index	330	10.4	15.0	17.3
Green + Vanilla Series	1,215	7.9	15.0	15.9
Green + Vanilla Pairs	944	8.0	16.3	17.5
Green-only Partners	472	7.9	16.3	17.5

Table 7.1: Weighted average characteristics for the green municipal bond data sets. The index values are for the end of the index (1 October 2017) and the green+vanilla values are averaged over December 2017.

der to perform a preliminary matched pair analysis. Yield curve analysis was first performed on the total green and vanilla series data, and then, where possible, on the matched green and vanilla pairs only.

There were a total of 50 green and vanilla combination 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 fit. While some of the series yield curves did indicate that some green muni bonds were issued with prices inside their yield curves (for example, see Figure 7.1), these were not sufficient to give an overall view of the market. Despite the fact that this technique is commonly used (as described in Section 4.2), there was no clear trend for greenium on a series by series basis.

In order to incorporate a broader view across the full dataset, we 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 across all series outstanding 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 yield curves that were relevant to the market's prevailing conditions at the time.

Each bond was considered in turn and had its remaining lifetime (until maturity or call) 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 according

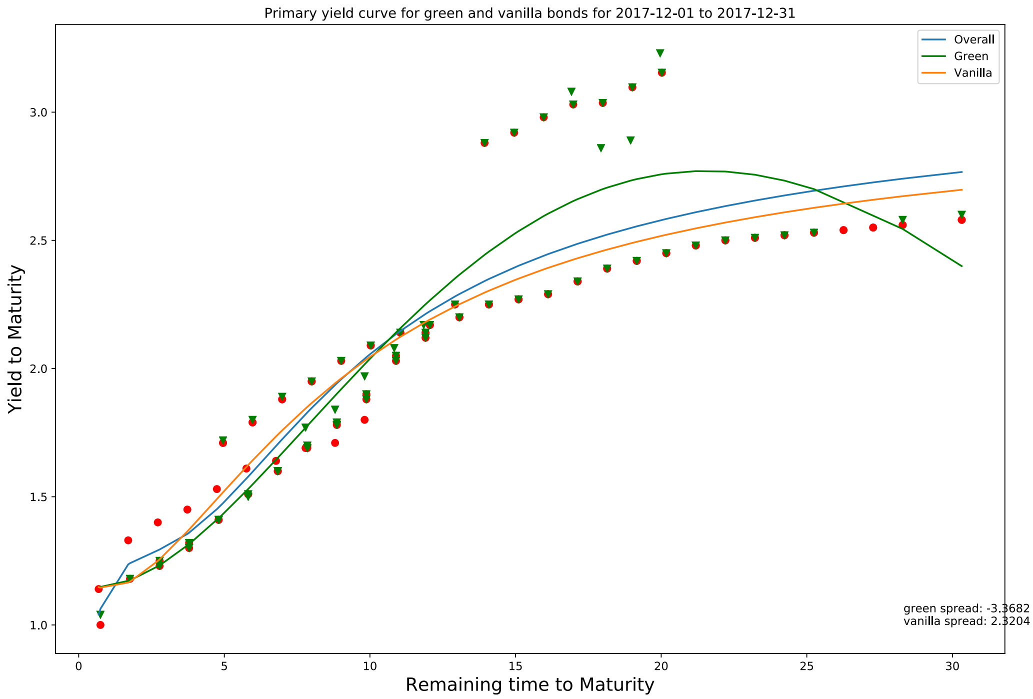


Figure 7.2: The aggregate primary market yield curve for December 2017.

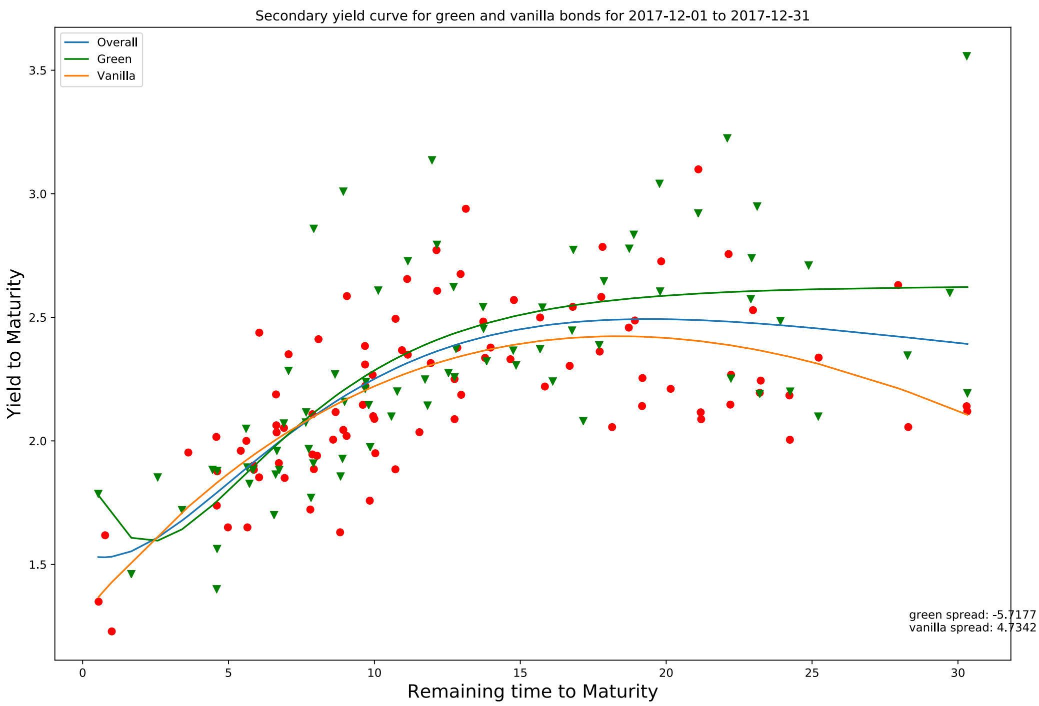


Figure 7.3: The aggregated monthly yield curve for the secondary market for December 2017.

to the method described above in Eq. 7.2 for each month between June 2013 and January 2018. The weighted average of those bonds' time remaining to maturity (or call, where applicable) was calculated, as were the weighted averages of the initial offering yields and coupons. For the primary market, the amount of each bond's issuance was used to weight these averages. A monthly yield curve (as shown in Figure 7.2) was constructed from the entire aggregate bond data set for that month, and then for the green bonds and vanilla bonds only, respectively. 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 at the time of the trade. 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 trading data (as shown in Figure 7.3), and then green and vanilla curves were overlaid separately where sufficient data was available. Similar to the primary yield curves, there was not enough green bond data available to reliably generate monthly yield curves until the beginning of 2015.

For both the primary and secondary yield curves, an average monthly spread was found between the green yield curve, the vanilla yield curve, and their differences with respect to the overall aggregate yield curve. Measuring the green and vanilla spreads separately enables us to decompose their trends individually. The spreads were calculated by iterating over each time to maturity and checking the yields that correspond to that time for the overall curve, the green curve, and the vanilla curve, and taking the differences. These differences were averaged for the month for each type to create an overall monthly average yield spread between the green bonds and the overall yield curve, and the overall monthly average yield spread between the vanilla bonds and the overall yield curve. The difference between the green and vanilla spreads reveals any pricing differential, or premium.

For the strict green-vanilla pairs, a more direct approach was used in addition to finding the spreads between NSS yield curves. The actual yields were compared at the same times across the set of bond pairings. This approach was taken because, in this case, we could use actual traded prices rather than yields extrapolated from a best fit Svensson curve, since each bond pairing had the same time to maturity and coupon. 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 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. 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. This technique enabled us to still be able

	Initial Yield				
	Green		Vanilla		Difference
Year	Mean (%)	Std Dev	Mean (%)	Std Dev	Spread (bp)
Series Bonds					
2014	2.63	0.775	2.11	0.874	52
2015	2.49	0.871	2.33	0.993	16
2016	2.27	0.724	2.11	0.741	16
2017	2.23	0.726	2.34	0.761	**-11**
Paired Bonds					
2014	2.24	0.815	2.20	0.755	6
2015	2.30	0.903	2.30	0.928	0
2016	2.24	0.715	2.22	0.689	2
2017	2.30	0.707	2.29	0.695	1

Table 7.2: The means and standard deviations of the initial offering yields for the green and vanilla municipal series bonds in our set. Note the presence of greenium in 2017.

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.

7.2 Results of Yield Curve Analysis

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. For example, the Arizona University Board of Regents bond issue for November 2016 (shown in the yield curve in Fig. 7.1) was comprised of 43 bonds, 22 of which were labelled green. Overall, there were 548 green bonds, and 667 vanilla. The overall characteristics of this data set is shown in Table 7.1, along with the index descriptive characteristics for reference. These values are largely consistent across both the index data and the series data.

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 vanillium bonds it was 117.63 ± 4.30. There is not a clear signal for greenium

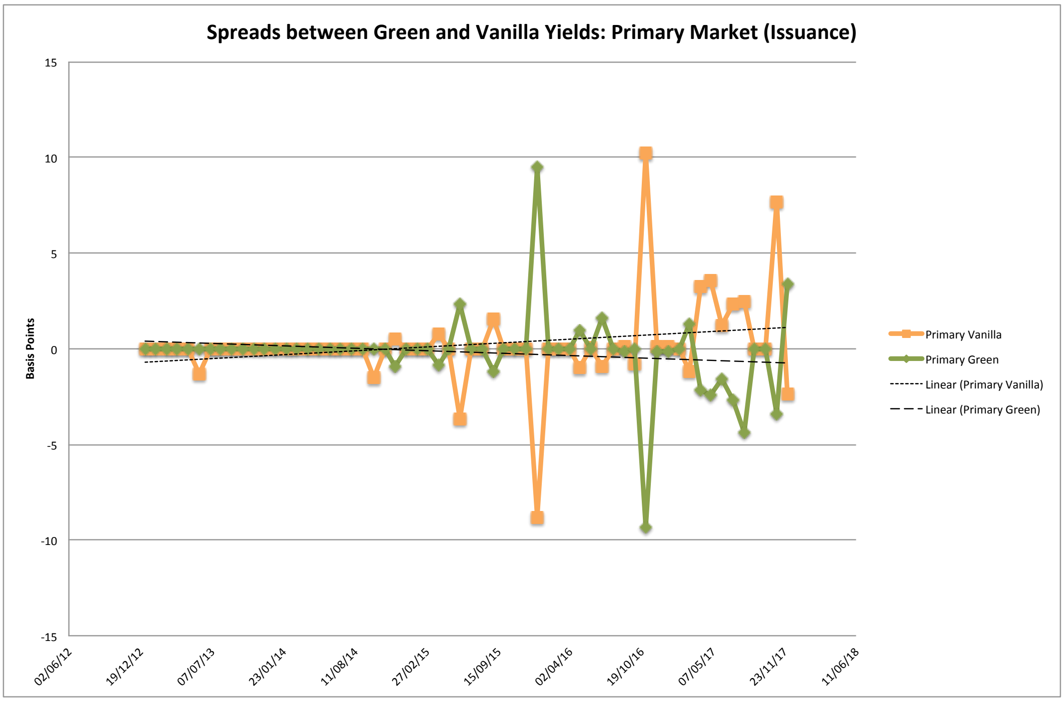


Figure 7.4: Spreads between the green and vanilla aggregate yield curves in the primary market.

in the municipal bond market by comparing these average values, however there were twice as many green bonds issued with a premium compared with the vanilla bonds. The average lifetime of the premium bonds, both green and vanilla, was about 16.0 ± 6.2 years. Looking only at the bonds issued in 2017, 744 bonds were issued in this data set, 375 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.

The average initial yields from 2013-2017 for the full green and vanilla data set is shown in Table 7.2. For the complete set of bonds, the only year with a clear greenium was 2017, with initial average yields of 2.23% for the green, and 2.34% for the vanilla, a potential 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 2.30% for the green, and 2.29% for the vanilla, a difference of only 1bp.

The average green spreads and the vanilla spreads in the primary and the secondary markets are shown for each year in Table 7.3. The annual average spreads in

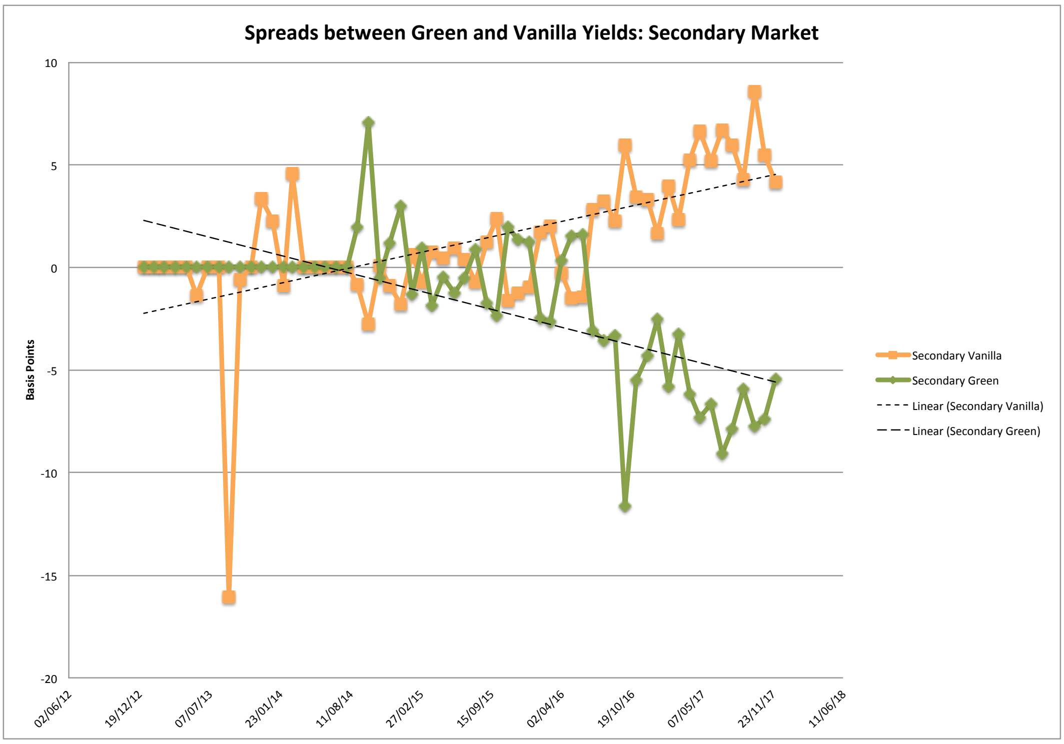


Figure 7.5: Spreads between the green and vanilla aggregate yield curves in the secondary market.

Year	Primary	Std Dev	Secondary	Std Dev
2014	0.002	0.628	0.667	3.431
2015	0.136	2.033	-0.176	2.393
2016	0.330	0.781	-4.183	5.835
2017	-2.114	5.256	-10.841	3.814

Table 7.3: The weighted average spread between the green and vanilla series bonds in basis points, along with the standard deviations for these means.

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 2bp. The annual average results from the secondary market also show a trend of increasing greenium from 2015 onwards, with a difference of over 10bp in 2017. However, the standard deviations on these monthly means are relatively large, which implies that some of these values will not have high statistical significance.

These findings are supported by plotting the monthly average spreads over time for the primary and the secondary markets. The plot of the monthly spread in

Year	Primary	Std Dev	Secondary	Std Dev
2014	0.325	1.125	0.551	1.910
2015	0.078	0.833	-0.092	0.585
2016	-0.014	0.783	-0.528	0.576
2017	-2.223	2.256	-2.691	2.882

Table 7.4: The weighted average spread between the green and vanilla strict pairings in basis points, along with the standard deviations for these means.

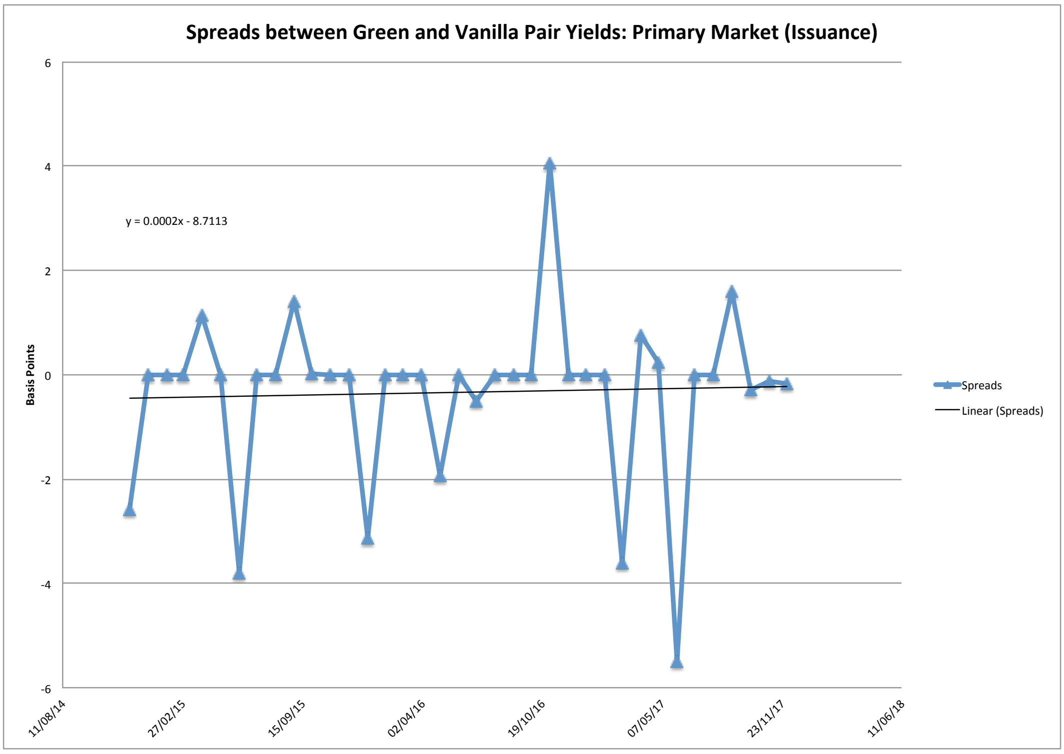


Figure 7.6: Spreads between the green and vanilla pairs in the primary market.

primary yields (Fig. 7.4) shows that there is an increasing greenium price signal at issuance, especially since late 2016. Overall, however, 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. For the secondary markets, the plot of the monthly average yields (Fig. 7.5) shows that there is a clearer trend towards widening spreads, and deepening greenium, which supports the findings in Table 7.3.

When a linear regression is run on the green and vanilla primary and secondary spreads, the resulting slope coefficients indicate that there is a trend of widening spreads, with the green yields decreasing, and the vanilla yields increasing,

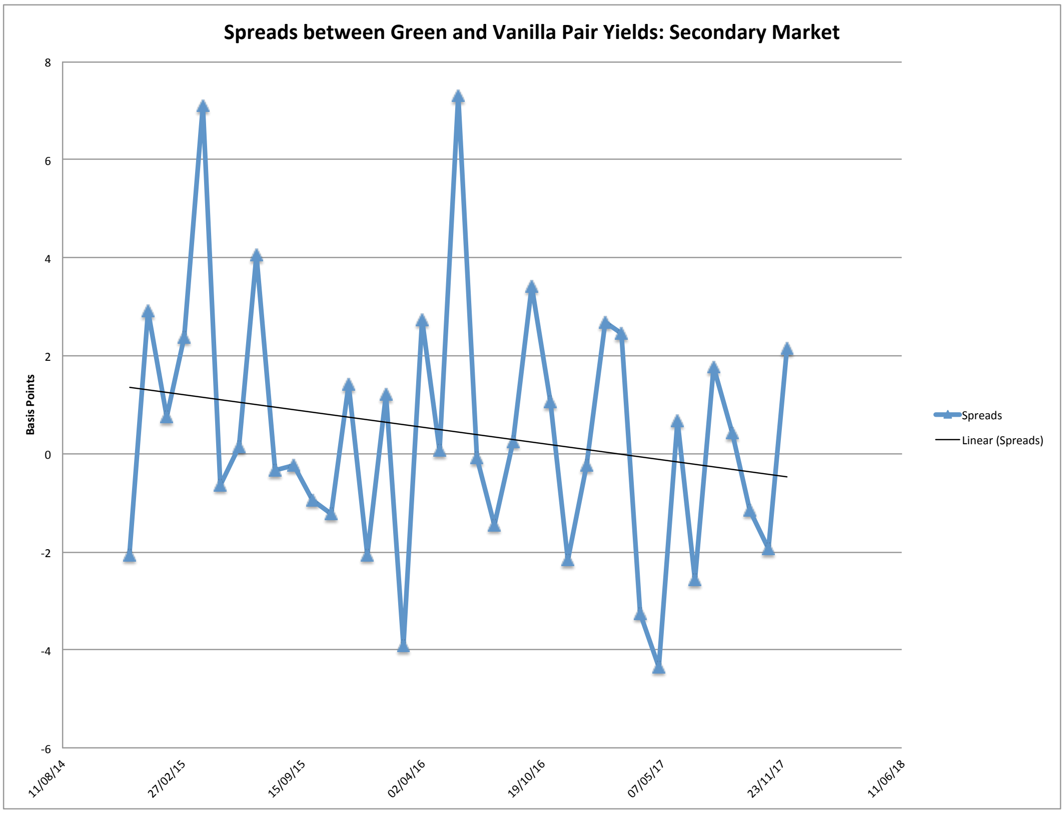


Figure 7.7: Spreads between the green and vanilla pairs in the secondary market.

Series	Coefficient	Error	t-value	p-value	r^2
Green Primary	-1.240	1.086	-1.142	0.258	0.02
Vanilla Primary	1.665	0.990	1.683	0.098	0.05
Green Secondary	-3.649	0.513	-7.117	1.87e-09***	0.47
Vanilla Secondary	3.00	0.556	5.394	1.32e-06***	0.33

Table 7.5: The results of linear regressions in the spreads over time for the green primary series bonds, the vanilla primary series bonds, the green secondary series bonds, and the vanilla secondary series bonds.

as shown in Table 7.5. These results are not statistically significant in the case of the primary market, however there is high statistical significance for the secondary market, which is consistent with Figs. 7.4 and 7.5.

For the strict green and vanilla pairs, as shown in Table 7.2, the primary green bonds have exhibited a slight average greenium since data was available (2015 onwards). Table 7.4 shows that the spreads are increasing in both the primary and secondary markets. Nevertheless, as can be seen in Fig. 7.6, the trend for this greenium for the pairs is relatively flat across time. When looking at the spreads in the secondary market, there is a downward trend in the spreads present from the beginning of 2015, shown in Figure 7.7, indicating a trend towards increasing greenium. The standard deviations shown in Table 7.4 for the monthly averages are quite large, therefore in the context pair analysis, this technique does not provide clear evidence for greenium in the primary market, however it adds to the supporting evidence of greenium in the secondary market.

The advantages of this yield curve spread analysis technique are that it enables us to break down trends in spreads on a monthly (or even daily) basis, given a sufficiency of data. Furthermore, unlike traditional regression analysis, the NSS yield curve fitting method allows us to maximize the utility of a limited number of data points by allowing us to construct yield curves across a broader range of maturities than we would otherwise have data for, especially in the early years of labelled green municipal bond issuance (2014-2015). Nevertheless, we also conducted regression analysis on this data to see if the findings were complementary, as discussed below in Section 7.3.

7.3 Regression Analysis

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

$$PrimaryYield_{it} = f(Tenor, Year, GreenBond, Rating, Sector, State, Year, IssueAmount) \tag{7.3}$$

$$\begin{aligned} SecondaryYield_{it} = f(&RemainingLife, Date, Year, GreenBond, Rating, \\ &Sector, State, Year, IssueAmount, TradeAmount) \end{aligned} \tag{7.4}$$

For the primary market, the issued yields for the bonds in our sample were regressed against their tenor in years. For the secondary market, we regressed traded yields against the remaining life of the bond at the time of the trades. In these specifications, as shown in Eqs. 7.3 and 7.4, we captured the green bond status of each bond using a *GreenBond* dummy variable, which was set to "1" for all labelled green bonds, and zero otherwise. *Rating* consisted of a value from 1 to 10 corresponding to the S&P or Moody's credit rating, with 10 corresponding to the highest rating, or AAA/AA+. *Sector* was a value corresponding to the use of proceeds for each bond, where Energy = 1, Multi-sector = 2, Water = 3, Transport = 4, Waste and Pollution Control = 5, and Natural capital = 6. *State* consisted of the two-letter United States postal abbreviation for the issuing state. *Year* is the year in which the bond was issued. *IssueAmount* is the size of the bond in USD. In the secondary market regressions, we also include *TradeAmount*, or the amount of each individual trade, and *Date*, the date the trade was executed. These factors were used in our regression in order to fully capture their potential effects on the yields of the bonds in the sample, in order to help isolate the effects of the green bond status, and also to help the model have the highest correlation to the data as possible.

Importantly, we used the Bloomberg BVAL municipal yield benchmarks (Bloomberg, 2018) in order to normalize our yield data. We subtracted out the BVAL yield for the appropriate tenor or time remaining for each of our yield values before running the regressions. This is a key step that some previous works have missed out: unless the yields are normalized in this manner, the regressions are in actuality being run on yield curves, which are, by definition, non-linear, as shown in Fig. 7.9. By subtracting out the base curve, we linearized our yield data before regressing, which yields more robust results.

Previous studies (Baker et al., 2018; Karpf and Mandel, 2018) have run their regressions on the straightforward yields against the life remaining on the bonds, which is essentially a linear regression over a non-linear yield curve. These studies benefit from artificially high statistical significance scores due to the fact that the yield curves exhibit a strongly functional form, albeit not linear. It is the differences

PRIMARY SERIES						
Year	Bonds	Green Factor	Error	t-value	p-stat	r^2
Overall	1,425	-0.0329	0.0155	-2.710	0.007**	0.55
2014	133	0.0166	0.0307	2.118	0.0361*	0.56
2015	159	-0.0207	0.0218	-0.946	0.345	0.72
2016	368	-0.0308	0.0323	0.443	0.658	0.82
2017	742	-0.0509	0.0158	-3.227	0.00131**	0.56
PRIMARY PAIRS						
Year	Bonds	Green Factor	Error	t-value	p-stat	r^2
Overall	880	0.0111	0.0120	0.927	0.35434	0.66
2014	50	0.0402	0.0305	1.318	0.194	0.56
2015	133	0.004	0.0169	0.243	0.808	0.74
2016	254	0.0025	0.0351	0.072	0.942	0.83
2017	435	0.006	0.0172	0.352	0.725	0.70

Table 7.6: The results of a fixed effects regression of primary issuing yield spread against tenor for the series and the paired bonds in our data set, both pooled and broken down by year.

between the green bond yields and their conventional counterparts that is measurement being investigated, much like the daily returns are the significant variable for the index regressions. In order to best unpack the trends in the green premiums from the bond yields, it is important to subtract out the underlying general bond yields in order to de-trend the data and attain a more linear data set of spreads. We did this by subtracting out the Bloomberg aggregated municipal bond yields for the appropriate tenors. Once this was done, we then performed the regression analysis in order to explore the yield differences between the green bonds and the conventional bonds. Studies that do not normalize their data in this way are giving misleading statistics.

We performed fixed effects linear OLS regression analysis on the yields at issue for the primary market, and panel regressions (pooled by CUSIP and trade date) on traded yields in the secondary market. The determinants that correspond to the “green bond” factor from these regressions are shown in Table 7.6 (for the primary results), and 7.7 (for the secondary results). These tables show the green regression coefficient for the entire pooled data set across all years, and then broken down for each year from 2014 to 2017, for both the entire green and vanilla series data set, and for the strict pairs only.

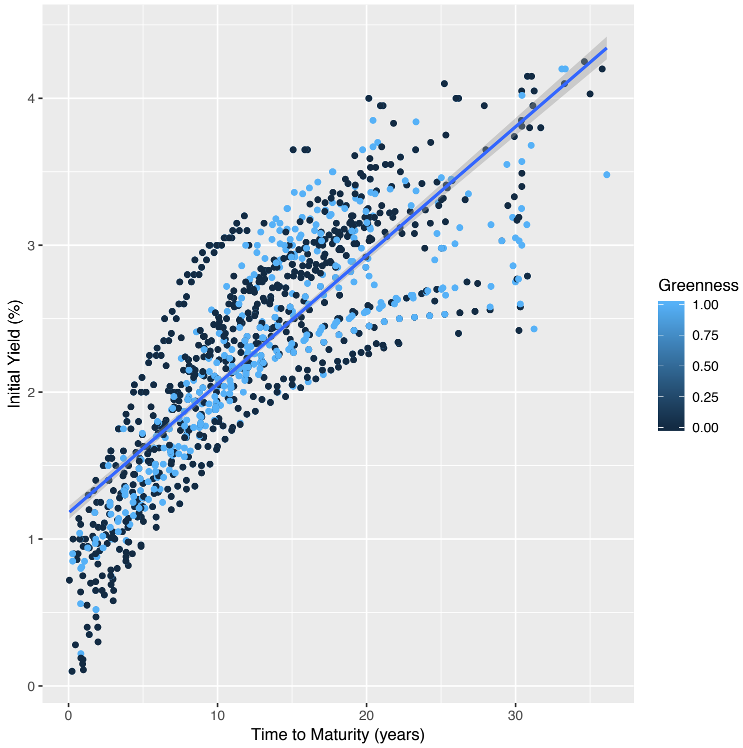
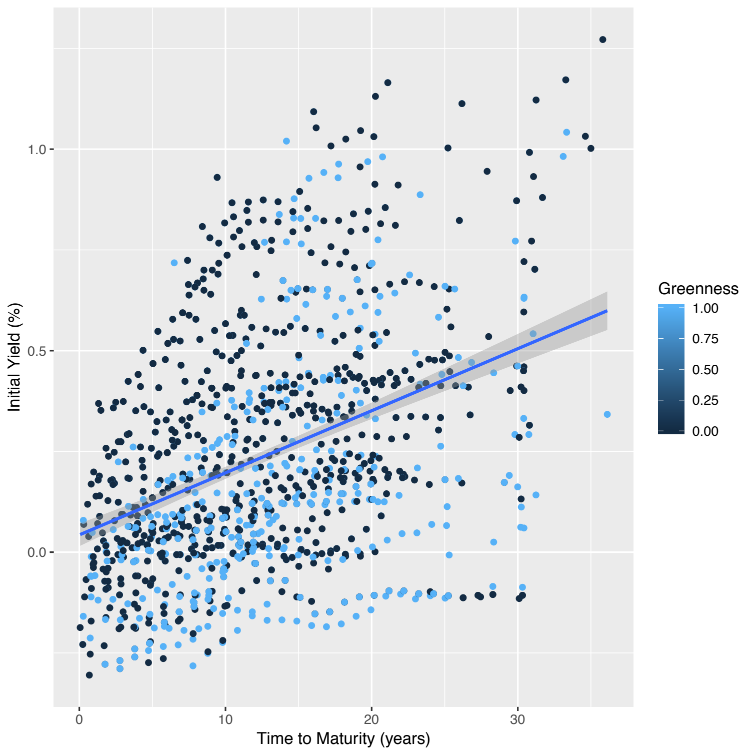


Figure 7.8: Regression over raw yield data (top) compared with a regression on the spreads of the same data with the base yield curve subtracted out (bottom). The yield curves at top are non-linear, so that performing an OLS regression on top of this unnormalized data could lead to spurious results. The normalized data is much noisier, so that has a lower $r^2 = 0.26$ compared with 0.71 for the unnormalized regression.



SECONDARY SERIES							
Year	Bonds	Trades	Green Factor	Error	t-value	p-stat	r^2
Overall	1,387	20,828	-0.0233	0.005	-4.3850	1.165e-05***	0.21
2014	149	388	-0.0269	0.0377	-0.7123	0.4767	0.26
2015	334	2,810	-0.0101	0.0096	-1.0478	0.2948	0.15
2016	626	5,315	-0.0184	0.0122	-1.5430	0.1229	0.17
2017	1,372	12,184	-0.0382	0.0066	-4.1018	4.127e-05***	0.32
SECONDARY PAIRS							
Year	Bonds	Trades	Green Factor	Error	t-value	p-stat	r^2
Overall	812	12,093	0.0155	0.0074	1.7816	0.075	0.29
2014	48	48	0.0730	0.0409	0.6594	0.513	0.20
2015	194	1,403	0.0138	0.0102	1.3477	0.17798	0.25
2016	382	3,312	0.0668	0.01337	0.0325	0.974	0.18
2017	806	7,330	0.0175	0.0079	2.1469	0.0318*	0.38

Table 7.7: The results of a pooled panel OLS regression of yield spread against time remaining for the secondary traded bond series and pairs in our data set, both pooled and broken down by year.

As shown in Table 7.6, there was an overall negative green bond factor of -0.0329, indicating an overall tendency towards greenium at issue, however this result only has moderate statistical significance (t-value = -2.710). Negative green coefficients are also found in all individual years except 2014, but with low significance until 2017. When looking solely at the green and vanilla matched pairs, there is no clear signal for greenium at issue, which is consistent with our yield spread analysis findings.

For the secondary market, pooled OLS regression was performed on the traded yields for the green and vanilla series bonds, and also the green and vanilla paired bonds. To do this, the price data for each bond was sampled on the tenth of each actively traded month over the years 2014-2017. First, a regression was done over the entirety of the pooled data, and then was also performed for each year in the sample for both the series and the paired bonds.

The resulting secondary market green factors are shown in Table 7.7. The overall pooled panel regression had a resulting green bond factor of -0.0233, indicating a greenium in the secondary prices, with strong statistical significance. There is a consistently negative green factor for all years in our sample, with 2017 showing the strongest value of -0.0382 with high statistical significance. This is in alignment with our findings from the yield curve spread analysis. However, the pair analysis has only positive green bond coefficients, indicating that there seems to be no strong greenium signal in the secondary paired market data, despite our other findings to the contrary.

Part of the difference in these findings is likely to be attributable to the the fact that annual data is insufficiently granular for bond performance analysis. Also, these regressions only help to quantify trends in the spreads, and do not decompose the spread into green and vanilla contributions, unlike yield curve analysis. Annual yields generally do not have enough resolution to gain practical insight into bond trading trends, therefore the regressions were also done on the secondary data for each month in 2017, the results of which are shown in Table 7.8. These regressions also indicate a statistically significant greenium signal in the majority of the months of 2017, with the coefficient and significance getting stronger as the year progresses.

When a fixed effects regression is performed over the entire data set on yields at issue, we find that there are significant relationships between tenor, rating, and state where issued, with marginal relationships with the year of issue and the green status of the bond, as shown in Table 7.9. The panel regression on the secondary trade data shown in Table 7.10 also indicates that issuing state, time remaining, rating, and notably, green bond status are significant determinants. Issue amount was also significant, but with a magnitude of nearly zero, as in the primary regression, and similarly for trade amount. Both of these regressions exhibit an overall greenium.

7.4 Conclusions

Yield curves allow us to take a more detailed view about the performance of a set of related bonds at a particular point in time, and in particular can pick up differences in pricing/yield between bonds (or a set of bonds) both at time of issue in the primary market, and after issue in the secondary market. While spread analysis via yield curves cannot easily capture the evolution in prices over time like an index can, it enables us to see differences in yield across tenors at a given time, which in turn

Month	Number	Green Factor	Error	t-value	p-stat	r^2
January	722	0.0011	0.0348	0.3467	0.729	0.33
February	747	0.0275	0.0305	1.0132	0.311	0.34
March	836	-0.0078	0.0270	-0.3328	0.8297	0.35
April	881	-0.0153	0.0249	-0.1210	0.2626	0.36
May	965	-0.0146	0.0224	-0.3308	0.1836	0.38
June	1,044	-0.0208	0.0234	-0.8250	0.068	0.40
July	1,083	-0.0147	0.0232	-0.784	0.433	0.43
August	1,114	-0.0202	0.0238	-1.3095	0.211	0.44
September	1,109	-0.0377	0.0191	-1.0661	0.0992	0.45
October	1,109	-0.0238	0.0187	-1.2469	0.2126	0.44
November	1,226	-0.0482	0.0211	-2.6733	0.0076 **	0.42
December	1,348	-0.0429	0.0187	-2.2851	0.0225 *	0.40

Table 7.8: The results of fixed effects regressions of secondary yield spread against tenor for the 2017 bonds in our data set, broken down by month.

Coefficient	Estimate	Error	t-value	p-stat
Tenor	1.626e-02	9.571e-04	16.987	< 2e-16***
Rating	-5.623e-02	6.629e-03	-8.483	< 2e-16***
State	1.202e-02	1.578e-03	7.622	4.56e-14 ***
Year	1.539e-02	7.255e-03	-2.122	0.0340*
Green Bond	-3.130e-02	1.155e-02	-2.710	0.007**
Sector	-1.301e-02	5.527e-03	-2.354	0.0187*
Issue Amt	3.231e-10	2.450e-10	1.318	0.1876

Table 7.9: The results of a fixed effects regression of the primary yield data, pulling out the significance of factors like state, issue amount, etc. This regression has $r^2 = 0.56$.

Coefficient	Estimate	Error	t-value	p-stat
Remain	1.247e-02	3.950e-04	31.569	< 2e-16 ***
Rating	-5.316e-02	2.390e-03	-22.246	< 2e-16 ***
Year	1.873e-04	1.904e-04	0.984	0.325
Green Bond	-4.653e-02	5.605e-03	-8.301	< 2e-16 ***
Sector	-2.172e-02	2.659e-03	-8.170	3.25e-16 ***
State	1.399e-02	5.910e-04	23.674	< 2e-16 ***
Issue Amt	-1.419e-09	1.068e-10	-13.281	< 2e-16 ***
Trade Amount	-7.154e-10	7.902e-10	-0.9054	0.365

Table 7.10: The results of a panel regression of the secondary yield data, pulling out the significance of factors like state, issue amount, etc. This regression has $r^2 = 0.40$.

can give better resolution for detecting greenium, especially at issue in the primary market.

We used yield curves to assess the performance of seasoned green labelled muni bonds in the secondary market relative to their vanilla counterparts, and also at the differences in their initial offering yields compared with yields at issue for the green and vanilla bonds in the primary market. Any presence of a greenium in the primary markets could be a signal that investors are willing to pay more for green bonds, and in turn could enable green bond issuers to leverage this demand and could lead to a cheaper cost of borrowing, therefore ultimately saving taxpayers money (Stringer, 2015; Chiang, 2017). 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 recent volume of issuance of green muni bonds enabled us to undertake the most rigorous survey of green bond premiums so far. When looking at the spreads in the green muni market, there is a downward trend in the green series spreads present from the beginning of 2015 in the primary and the secondary markets, as shown in Figures 7.4 and 7.5. It is also of note that the primary linear regression line crosses the x-axis, indicating an overall average greenium, in early 2017, which is also indicated in Table 7.3. 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. The greenium results from the analysis of secondary market prices also support the 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 (Karpf and Mandel, 2018; Baker et al., 2018), along with the findings from our index benchmarking in Chapter 6.

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 amount of activity in the US muni bond market, we were able to identify several instances of these for pair analysis. There is no other known study out there that has completed the same like-for-like analysis of green vs vanilla bonds, although a similar approach has been used for BABs (Luby, 2012), and an approach using synthetic pairs is used by Zerbib (2016, 2018), however this analysis is based on synthetic bonds rather than actual traded bond data. This means that our dataset gives us the unique ability to quantitatively and rigorously check for greenium in this market based on real transactions.

Looking 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 indeed slightly lower than their vanilla counterparts. At issue in the primary market, an weighted average overall greenium of over 2 bp emerges in 2017 (see Table 7.4). The greenium signal in the secondary market is even clearer. As shown in Figure 7.7, there is a trend towards greenium from the beginning of the data set, with an actual greenium signal materializing in late 2016. By contrast, the trend of the green spreads in the primary market as shown in Figure 7.6 is relatively flat, however it has consistently remained below the x-axis, indicating a possible small but consistent greenium at issue. Table 7.5 summarizes these observations by showing that the slope coefficient for the secondary green muni market line is more negative than the primary. Both, however, are negative, and the secondary green slope has high statistical significance.

We also performed regression analysis to help provide further evidence for these findings. While regression seems to be the main method used in the previous literature (Karpf and Mandel, 2018; Baker et al., 2018; Febi et al., 2018; Zerbib, 2016, 2018) for detection of greenium, in this research it was not our primary approach because regression analysis does not have sufficient time resolution to pick up greenium as it arises. The previous literature breaks down their findings into years, but a year is not a small enough time frame in order to truly capture trends in yields for a bond market. This is why we relied on measuring yield spreads on a monthly basis, and also why we constructed indices which have daily resolution to capture the time series nature of pricing changes in the market.

Nevertheless, the findings from the regressions are consistent with the evidence from the yield curve analysis. Table 7.6 shows both an overall primary greenium for the total series data set, and that this greenium gets stronger from 2015 onward. The secondary market (see Table 7.7) also shows an overall greenium, with the largest magnitude arising in 2017. These regressions picked up no clear evidence for greenium for the pairs, however.

In fact, while there seems to be support for the presence of a recent greenium in the secondary market using multiple analysis techniques, the evidence for greenium in the primary market, where most of the interest in this subject lies, is much less conclusive. The best evidence for primary greenium would be to see a consistent signal for lower yields at issue for green bonds in a like-for-like paired analysis. While there is some sign of a possible greenium at issue in Table 7.4, it is very inconclusive due to lack of clear signal in the data. This is further shown in Table 7.6, where while there is some potential primary greenium at issue for the overall series data set, there is no sign of this for the strictly paired data. The lack of clear primary greenium signal in the pair analysis could be attributed to paucity of data, both due to lack of overall issuance of eligible bonds, and also due to short time horizons given the possible pool of bonds only started in late 2013. Overall, for the strict pairings in our whole sample (2014-2018), 51 issued with a greenium, and 82 with an anti-greenium. When broken down by year for the past couple of years, as shown in Table 7.11, there could be a possible inflection point in 2017 where more bonds in these pairs issued with a greenium than an anti-greenium. Unfortunately, the data is too sparse to draw hard conclusions from, and this could be one of the reasons why there is more observable greenium in the secondary market, where there is more trade data, than in the primary market, or even why there is more

Year	Green #	Vanilla #	Total Pairs
2016	8	31	139
2017	27	26	237
2018	6	1	103

Table 7.11: The number of like-for-like green and vanilla paired bonds issued per year, and how many of these issued with a greenium or vanillium (all others being issued at equal prices).

potential evidence for primary greenium in the series non-paired analysis, which also draws from a larger sample ($N_{series} = 1519$, 47% green; $N_{pairs} = 944$, 50% green) .

Future work could build on the regression results shown in Tables 7.9 and 7.10. Both of these regressions indicate that the greenium factor is not strongly correlated to issue amount or trade amount indication no strong support for a size premium, however it would be interesting to perform a Fama-French multi-factor analysis (Fama and French, 1992) on the paired sets of bond data in order to further unpack the effects of bond issue size on any potential greenium. We are again constrained by the amount of data available at present: when we look at the average issuing yield for the large bonds in our pair samples versus the small bonds, any differences in yield are consistent with accompanying differences in tenor and/or credit, namely that the largest bonds have an average tenor nearly twice that of the small bonds. We would need enough bonds in our pair data to be able to draw a sufficiently large sample of small bonds of a particular tenor against large bonds with the same tenor issued at the same time (to ensure a consistent interest rate environment), and the data is insufficient for that approach at this time.

Taken altogether, the green and vanilla bond spread analysis generally indicates a small possible 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 any detectable 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 the future, but if it holds consistent with the trends of the past couple of years, there could be an overall primary greenium of 3-5 bp in 2018. 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.

This chapter outlined our yield curve analysis techniques and details the findings from this analysis. The search for greenium has been an important motivation in recent literature (see Section 4.2) because it can both demonstrate whether or not the market is willing to pay more for green bonds, and as a result, issuers of green bonds could potentially leverage this demand to secure a lower cost of capital when issuing new bonds. The next chapter will bring our findings together and discuss future trends and recommendations for policies to help expand the green municipal bond market.

Chapter 8

Discussion and Conclusions

The last two chapters have described how we have used two difference analysis techniques, index benchmarking and yield curve analysis, to assess the performance of the green municipal bond market over the past few years. This chapter will bring together the results of that analysis and provide further context for the implications of these findings.

8.1 Context

Green municipal bonds are an increasingly important financial instrument where the use of proceeds of these bonds goes specifically to finance more sustainable and resilient infrastructure. This bond market provides insight into the financing activities of urban areas in the United States, since American cities use municipal bonds extensively to fund the development of their infrastructure. This work has provided a comprehensive summary of the development of this market, case studies where these bonds have been used to raise funds for more sustainable infrastructure, and an analysis of how green muni bonds have performed in the market so far.

Labelled green bonds have only existed in the US muni market since 2013, and this research leverages the subsequent four years of market data to assess the performance of these bonds in comparison with conventional muni bonds. If green municipal bonds perform well and hold their value relative to the overall market, then this could encourage more investors to buy them. A green premium at issue would be advantageous for issuers of green muni bonds, because this could lead to an overall cheaper cost of capital. Investors willing to pay higher prices for green bonds means that issuers can repay with lower interest rates, therefore ultimately saving tax payers money. Furthermore, strong performance by green muni bonds can also enable municipal and state authorities to advance support for localized green policies. Increased demand could lead to more green muni bonds being issued, which feeds directly back to financing greener and more sustainable infrastructure for American cities.

Green muni bonds are also a way to mitigate the current climate of policy uncertainty under the current American political regime, especially where infrastructure spending and tax cuts coincide. Municipalities have significant political and fiscal power in the United States, and as such American cities could be key to reducing emissions in the US. Indeed, as a result of the Trump administration pulling out of Paris Agreement in 2017, the US Conference of Mayors issued a press release reaffirming their commitment to sustainable investment and climate change mitigation, stating that "mayors will continue to harness their collective power to continue to lead the nation on this critical issue, regardless of what happens at the national level" (United States Conference of Mayors, 2017). The green muni bond market is a natural extension of this movement in that they enable these American cities to directly finance their climate-related efforts.

8.2 ESG Motivations

One advantage of green muni bonds is that there can be differentiation across this product sector that allows the issuers to tailor their offerings to the meet the needs of investors because the use of proceeds is tracked much more closely for labelled green bonds. Specifically targeting ESG investors is a key point of issuing green bonds: it allows an issuer to market themselves to a broader segment of potential investors, and overall a larger pool of investors can lead to a lower cost of capital through more competition. The fact that green bonds are generally more oversubscribed at issue than conventional bonds are (Climate Bonds Initiative, 2018b) is evidence of this.

One of the best ways to help grow the market is to show that sustainable investing does not have to be a compromise. To this end, we don't actually have to demonstrate the that green muni bond market outperforms the conventional muni bond market, but rather it is sufficient to show that they perform equivalently, so that the need to balance ESG returns against financial returns is negated.

In the fixed income universe, bonds prices are generally driven by the buyers (investors), however issuers look to the prices paid in the marketplace in order to determine the pricing structure of new issuances by judging what the market will bear. As stated by Saha and D'Almeida (2017), and as actually happened with the SSE green bond issued in 2017 (John, 2018), because demand currently outstrips supply, green muni bonds can help leverage demand to achieve better bond terms. To this end, the presence of greenium could further enable issuers to access lower costs of capital, and as long as there is greenium in the secondary markets, then issuers can adjust their primary market issuance terms to take advantage of this.

Therefore, greenium, or at least pricing at par, is fundamental for making or breaking the green bond market . That is why this research focused on the detection of greenium in the primary and secondary markets through two different methods: index benchmarking and yield curve analysis. These methods are two of the most commonly utilized methods for assessing the financial performance of an asset or an asset class, and they allow us to gain insight into the performance of the green and climate-aligned municipal bond market.

8.3 Data and Liquidity

This research focused on the municipal bond market in the US for a few reasons. Firstly, the bond data was more readily accessible for the US muni bonds as opposed to other bond markets. Secondly, the US muni bond market is large and mature, so that there was more likely to be significant amount of green muni bond issuance. Thirdly, our motivation was to explore financing green infrastructure for cities, and so municipal bonds, which are bonds issued by cities, enabled us to have direct insights into to the debt capital market that underpins infrastructure investment in

American cities. By collecting data on green and climate-aligned muni bonds, we were able to assess the performance of this asset class relative to the overarching municipal bond asset class. The main advantage of looking at the US muni bond market is that the sheer number of bonds being issued enabled us to have a larger sample size than the corporate bond market would. Because municipal bonds are usually issued in series, this means that we were able to collect nearly 5,000 green and climate-aligned bonds on which to base our analysis.

Our index data is unique in that it includes unlabelled but climate-aligned bonds from 2014-2016 (our bond data collection terminated in mid-2016, although price gathering continued until October 2017), as detailed in Section 5.2. As can be seen in Table 5.1, there has consistently been many more climate-aligned bonds issued than green-labeled bonds, so their exclusion would have meant only looking at a fraction of the potential market. Hitherto, no other green bond study has captured the climate-aligned muni bond aspect of this market. Our findings are more robust as a result of doing the manual data mining that was required to collect this data and create a climate-aligned index.

Furthermore, the labelled green bonds in the data set are bonds that have explicitly self-labelled as such. Other research has included what they refer to as "green" bonds, but these bonds may actually not necessarily be identified as green by the issuers themselves, but rather labelled as such by data syndication services such as Bloomberg (Karpf and Mandel, 2018; Baker et al., 2018), much in the same manner in which we have identified our climate-aligned bonds. However, we have not asserted that climate bonds are identical to labelled green bonds because they have not gone through the due diligence of labelling as such, and have not as a result agreed to the higher levels of transparency and reporting. Therefore our green bond database includes only those bonds which the issuer has very intentionally labelled as green, signalling their commitment to the GBP. The combination of data mining for climate-aligned bonds along with respecting the integrity of the green label of the issuer-declared labelled bonds means that our dataset captures these distinctions more clearly than other similar data sets, and enables us to more accurately capture the market dynamics of this class of bonds.

The bond data set used for the yield curve analysis is similarly unique, in that it captured every green municipal bond that has ever been issued in the US from 2013 to 2017 in conjunction with one or more vanilla bonds, as described in Section 5.3. This allowed us to take snapshots of the market and compare the performance of bonds that are issued by the same issuer on the same day with the same Official Statement, and means that we can compare like-for-like much more rigorously than any previous study. We found 42 series of issuances that were comprised of both green and vanilla bonds, totalling 1,215 bonds, 548 of which were green. Within this dataset, 521 green and vanilla bond pairs were found where the issuer, time of issuance, maturity date, and coupon were identical. The only variation allowed was in the green label, issue size, and, the focus of this study, price.

Questions have arisen around the liquidity of green bonds compared with non-green bonds, because some attribute any potential greenium to a liquidity premium arising from less liquidity in the green bond sector, as described in Section 5.4. Our bond data indicates that overall the liquidity of the green muni bonds is similar to that of the non-green muni bonds. Overall, the data indicates that, at least when using a volume-based metric, the liquidity of the green labelled bonds is similar to that of the non-labelled bonds, and therefore no significant differences in liquidities should arise when comparing the green index against a similar benchmark. These results carry the caveat that volume-based liquidity metrics are best used as estimates since they may or may not reflect the true market dynamics as would be expected compared with bid-ask prices (which we did not have access to). We also compared the zero traded days (ZTDs) frequency and the Amihud ratio between the two groups of bonds and also found these measures to be similar, as shown in Table 5.11 and 5.12. This implies that the green premium will largely arise from other factors besides liquidity, since by these metrics, the liquidity is comparable for the green and vanilla bonds in our sample.

8.4 Market Performance of Green Muni Bonds

The main focus of this research was to benchmark the performance of the green municipal bonds against the prevailing conventional municipal bond market. Two techniques for analysis were used to perform this benchmarking: index analysis and yield curve analysis.

We describe our index construction and benchmarking analysis in Chapter 6. The main indices that we benchmarked were the climate index, consisting of green-labelled and climate-aligned bonds, and the green index, consisting of only the green-labelled bonds. These indices were compared with the S&P Investment Grade municipal bond index, a commercial index that is a market standard benchmark.

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 6.3). 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 calculate their Information Ratios, the resulting values range from 0.01 to 1.39, with alphas ranging from 2.8 to 5.3%, as shown in Table 6.5. The overall climate indices also exhibited smaller drawdowns than the S&P index, however as shown in Table 6.9, the sector subindex drawdowns were greater.

The reliability of our risk-adjusted returns are hampered by the fact that our index is based on actual transaction prices rather than matrix pricing, in the way that commercial bond indices are. This leads to the appearance of lower volatility in our climate indices, however their trends and performance can still be benchmarked. 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.

As a complementary technique to index benchmarking, we also created a data set of green municipal bonds that were issued in the same series as conventional (vanilla) muni bonds. This data enabled us to perform a like for like analysis of any differences in yield through yield curve analysis, as described in Chapter 7.

Across a set of over a thousand bonds, 548 of which were green and 667 were vanilla, spanning the years 2014 through 2017, we found strong evidence for greenium in the secondary markets (shown in Fig. 7.5 and Table 7.10), and more tentative evidence for the first signs of greenium in the primary markets (see Fig. 7.4 and Table 7.9). Tables 7.3 and 7.5 summarize our overall findings from the analysis of monthly yield spreads between the green bonds and the vanilla bonds. Further, we performed linear regression analysis that confirmed these findings (see Tables 7.6 and 7.7). The regression results also indicate a statistically significant greenium in the secondary market in 2017, and slight support for greenium in the primary market in 2017, but overall no support for greenium at issue in the matched pairs analysis.

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 no portfolio allocation analysis or rebalancing was performed. This was done explicitly so as not to introduce any investment strategy or optimization in order to get a broad and unbiased view of market activity. If the index portfolios were optimized or rebalanced, they would be likely to produce even higher returns.

Index benchmarking and yield curve analysis both indicate that there is a present and growing greenium in the secondary market. The index technique only focuses on secondary market prices, but those findings are in alignment with the secondary market greenium signals that the yield curves also indicate to be present since 2015. The yield curve analysis allowed a closer look at greenium occurring on issue in the primary markets, but the results there were much less conclusive, with no clear signal for greenium at issue in the matched pair analysis.

Both analysis techniques show that the green bonds in our data set have not only held their value with respect to conventional muni bonds, but have generally experienced a premium (greenium) in the secondary markets. This demonstrates that green muni bonds can provide stable returns and outperform the market, even when compared on the level of sectors and states. These findings echo those of the greenium research outlined Section 4.2, most of which also found signals for greenium in their analyses. The combination of a potential small premium in the primary market combined with a larger premium in the secondary market presents an ideal buy-and-hold ESG investment strategy if these market conditions hold. By buying green muni bonds at issue, they then generally experience better price returns compared with their vanilla peers. This is supported by evidence from both the green and climate indices outperforming the S&P and from the increasingly clear greenium signals from the secondary market yield curves. By buying these bonds at issue, investors are in effect getting ahead of the curve.

An increasing 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, 2018b), “when green bond curves have a handful of maturity points, they could be used as a reference for pricing new green bonds. If green bonds were trading tighter than vanilla bonds, we would reasonably expect to see a consistent greenium emerging”. According to Zerbib (2016), “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”, which is what our yields demonstrate towards the end of the sample.

In the primary market, it is the issuers that benefit from a greenium at issue. However, in the secondary markets, the beneficiaries of green bonds selling onwards at higher prices are the existing holders of those bonds who are selling them on, not the original issuer. It could be that bond traders are better at leveraging the resale secondary market for higher prices on green bonds due to relative scarcity of available green bonds, whereas the issuers of green muni bonds and the banks constructing their offering deals have not had sufficient data yet to achieve similar levels of performance in their offers. This is supported by the fact that any sign of greenium at issue did not appear until 2017 in our analysis.

As a caveat, some issuers and investors are concerned about the potential 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.” Issuers and investors are worried that an obvious greenium coming into the dynamics of the muni market could potentially trigger a flight to yield, acting as a deterrent for green bond investment. However, Zerbib (2018) follows up on these comments in their most recent paper, stating, “a [low] premium should therefore not constitute a disincentive to invest in green bonds,” but rather, ”it demonstrates investors’ appetite for green bond issuance.”

Therefore, while the existence of greenium at issue 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.

8.5 Why is there a Greenium?

Given our observation of a greenium in the secondary market and the first possible “green shoots” of greenium in the primary market brings rise to the question: why would there be a pricing difference for the green bonds in our sample if they are constructed the same as the non-green bonds in our data? Assuming that we have successfully ruled out any other sources of premium (such as liquidity, credit, size, etc.), and holding all other things to be equal, the factor that remains as the source of the greenium is market demand. Because green bonds are constructed the same as their vanilla counterparts, the class of possible buyers between the two classes is the same. However, there is an additional class of buyers of green bonds that consists of individuals and institutional investors that have an ESG/SRI mandate which specifies that they must invest in more sustainable assets. These buyers will be specifically targeting green bonds, therefore adding additional price pressure to that sector of the bond market. In short, conventional bond buyers will be happy to buy a bond that fits their criteria, regardless of if it is green or not, whereas more targeted sustainable investors will be specifically looking at green bonds that fit their mandates, so they are in effect competing against the conventional investors for the same assets, but with more demand pressure with their specialist mandates. Even if these investors are a much smaller segment of the investors, the fact that they would be restricted to the smaller number of green bond assets means that they could be the source of the greenium. The most obvious example of this effect could possibly be seen from the fact that green bonds are not excluded from the standard bond indices, but green bond indices exclude anything not qualifying as green.

This is consistent with the findings from Baker et al. (2018), who state that given a simple asset pricing framework, two predictions arise: That green bonds will sell for a premium, and that green bond ownership is more concentrated. Their work finds evidence for both of these assertions, and states that the greenium in their green muni bond sample is “a natural flip side to the Hong and Kacperczyk (2009) result that sin stocks are associated with higher returns.” This is also consistent with other findings that increasing investor appetite for more environmentally sustainable investment can increase investment flows to this sector. Riedl and Smeets (2017) found that social preferences and social signalling play a role in SRI decisions, and that financial motives were secondary, suggesting that “investors are willing to forgo financial performance in order to invest in accordance with their social preferences." Similarly, Hartzmark and Sussman (2017) found evidence that investors value sustainability, and Brodback et al. (2018) give survey evidence that "personal values have an impact on individual investment decisions, in particular preferences for socially responsible investing."

The investor base for green bonds at present includes all of the traditional bond investors such as pension funds, mutual funds, insurance companies, and banks, in addition to those who have ESG mandates. The municipal market will also include individuals who will also have their own investment preferences, which could have a pricing impact. As a path to future research, it would be an interesting to investigate the types of investors that are buying green muni bonds to try and unpack their motivations and try and measure their effects on this market.

It could come to pass in the future that green muni bonds that are issued as a result of the business models described in Chapter 3 achieve a scale that could affect the pricing of this sector of the bonds market. However, at present, there are currently no green-labelled municipal project bonds, and the majority of green muni bonds are general obligation and not revenue bonds (Saha and D'Almeida, 2017). Furthermore, where deals are constructed around private industry contractual arrangements like PPAs, they usually lose their tax-exempt status (Kreycik, 2011), which means that they were not eligible for our yield analysis. Therefore, these special types of green muni bonds are not, at present, the source of any pricing differential.

8.6 International Perspectives

While our data focuses on the US, our key findings can be more broadly applicable, since the US municipal bond market can serve as a potential model for other countries and regions that are looking to tap into the debt capital markets to finance their own infrastructure. Indeed, some of the case studies outlined in Section 3.9 have been replicated in other countries, such as South Korea and the United Kingdom, who looked to these models for inspiration. In general, other countries have shown interest in the successes of the US municipal bond market and have established similar local lending markets.

Internationally, the use of green bonds is growing in popularity as a finance mechanism for renewable energy and energy efficiency in cities and regions around the world, such as Paris, Sweden, and London (FMDV, 2014). This is a much-needed growth sector, as "climate-friendly assets in the portfolios of EU institutional investors is tiny– at best it is between 1-2%" (Financing the Future Consortium, 2015). However, despite some bond issuance activity from European cities, "the region's municipal green bond market is still at an embryonic stage, and faces challenges including a lack of large-scale green infrastructure projects and a lack of market standardization" (Moody's, 2016).

In Europe, some regions have set up municipal bond agencies so that they can pool their resources and access cheaper financing in order to better leverage their assets. In Sweden and Finland, municipal bond agencies have been instrumental in the use of bond financing to invest in their local infrastructure. Finland's MuniFin currently has a lending portfolio of EUR19.2 billion and has stable Aaa and AA+ credit ratings. It invests in schools, hospitals, and other infrastructure on the behalf of over 300 Finnish municipalities (MuniFin, 2014). In Sweden, Kommuninvest (2015) manages a lending portfolio of SEK 222.8 bn on behalf of 280 regional members, and has a credit rating of Aaa/AAA, and Gothenburg was one of the first cities to issue a green municipal bond (OECD, 2017a). Their successes are inspiring other countries, such as the UK and France, to create their own municipal bond agencies (Local Government Association, 2014; Agence France Locale, 2015).

In many markets, municipal bonds are classified as sub-sovereign bonds, a sector which has been growing in recent years. In 2014, sub-sovereign bond debt totalled about EUR500 billion for the top seven most active EU countries (Vetter and Zipfel, 2014). At present, the European sub-sovereign market is only about 15% of the size of the US municipal bond market, which could mean that it has growth potential, especially for European cities that are searching for capital for infrastructure development. In fact, it is not only European regions that may be seeking to expand their municipal bond reach, but this seems to be a global trend that is developing in China, India, Latin America, and in other regions, such as the green city bonds issued by Cape Town and Johannesburg in South Africa (Climate Bonds Initiative, 2017d).

Green bonds are especially seeing growth in the Asian markets, especially in China (Kidney and Oliver, 2014), which was the largest issuer of green bonds in 2016 (Climate Bonds Initiative, 2016). Ng and Tao (2016) state that for Asian countries, “green bonds could also improve overall publicity and improve organization image, thereby broadening their access to capital,” and that “one way to encourage broader participation of SME RE players in the bond market and deepen the capital market is to facilitate retail bond issuance.” According to a report on green bond issuance in the emerging markets by the Sustainable Banking Network et al. (2018), “as of June 2018, China is the largest issuer with USD57.1 bn in issuance, followed by Mexico with USD6.7 bn and India with USD6.6 bn.”

8.7 Recommendations

In order for green bonds in general, and green municipal bonds in particular, to be adopted both by issuers and investors they will have to prove their worth in the capital markets both in terms of financing climate-friendly projects and in terms of making solid financial returns. While there is clear demand for socially responsible investing (SRI) (Chandler, 2018), even the greenest of the institutional investors and asset managers are subject to fiduciary duty, such that their investment strategy must put priority on returns before sustainability. The fact that fiduciary duty is biased towards a solely profit-driven regime is currently under question at present, especially in the context of the state-run pension funds and their responsibilities to their stakeholders (Kidney and Oliver, 2014; Global Commission on the Economy and Climate, 2014; Ellsworth and Spalding, 2013).

Climate risk, particularly the risks due to damages from natural disasters triggered by climate change, along with the risk of stranded assets, is not priced into the current investment universe. This has the dual effect of leaving sustainable investments short changed and unprotected assets such as vulnerable infrastructure at risk (Ellsworth and Spalding, 2013; Global Commission on the Economy and Climate, 2014). For example, the carbon credit markets are an attempt to try and limit emissions while assigning a monetary value to them as one way to try and capture some of this financial risk. In some cases, such as in Europe, these markets are now appreciating at a rate faster then their fossil fuel counterparts despite a rocky start. As mentioned in the case studies (Section 3.9.1), there are state SREC markets in the US, of which New Jersey has the largest. It is an interesting example of climate federalism that there is not an overarching national carbon market, the creation of which would run counter to the prevailing doctrine of the current Trump regime. However, a national US carbon market would perform more efficiently, and also open the market to those states that hitherto do not have carbon markets. The creation of a national carbon market would be a step forward in accordance with the Stern review's recommendation for there to be a global carbon market set up (Stern, 2007).

All of these factors would tie into the green municipal bond market: with a national carbon market, this would enable new cashflows to help kick start more clean energy projects, and these revenues could be leveraged by green muni bonds to finance more sustainable infrastructure projects. Additionally, changing the fiduciary duty mandate of institutional investors to consider sustainability as well as profitability would increase investor demand in green muni bonds.

These are top down means of encouraging growth, but bottom up growth also must be considered. On the supply side, there needs to be more bankable green infrastructure projects in the pipeline in order to meet increasing investor appetite for green bonds. A common problem is that many green infrastructure projects, particularly clean energy related ones, are too small or segmented for efficient bond financing. However, with standard contracting and aggregation, this can be overcome in certain contexts, as is illustrated by the PACE bonds (Section 3.9.4). The larger institutional investors such as pensions and insurance funds generally only like to invest in large, benchmark size bonds ($250M and up), so aggregation is the best way to bridge the gap between smaller scale clean energy projects and larger scale institutional investors (Fulton and Capalino, 2014).

To this end, the establishment of more green banks is also key to growing the green muni bond market. Although it is currently unlikely that a national US green bank would be established in the current political climate, if every state instead established their own, these green banks could act as warehouses for projects and aggregate them into larger bond issuances. This would be especially helpful to achieve scale in the clean energy sector. While transport and water infrastructure projects are generally monolithic, renewable energy and energy efficiency projects are more fragmented, especially at the MUSH (municipal, university, school, and hospital) level that is most active in the muni bond market. There are already a few green banks that have been established in a few states with proven successes in this sector, as discussed in Section 3.9.5. These state green banks could work in tandem with state-established sustainable energy utilities (see Section 3.9.3) in order to foster more clean energy projects and bring them to market.

Another important mechanism to increase the green municipal bond market would be to establish and leverage more tax credits to help encourage more sustainable infrastructure projects. The use of CREBs, QECBs, and BABs (see Section 3.8) has demonstrated that both issuers and investors are receptive to tax credit bonds, and more of these types of bonds could be used to help establish momentum by leveraging an increasing appetite for sustainable investing.

Finally, while there is already awareness and political will in the larger cities and states (especially California and New York) that creates demand for green infrastructure and the subsequent issuing of green muni bonds to finance it, sustainability and climate change is a matter of either ignorance or outright antipathy in the less-populous regions of the US. In this context, it would be helpful to shift the dialogue away from climate change and more towards the creation of green collar jobs and their resulting economic benefits for those regions (Gessesse et al., 2017). Additionally, amongst the smaller states, there is an overall lack of education about ways to access the green muni bond market. For example the CREBs and QECBs were underutilized in many states, despite benefiting from a subsidy from the federal government. An outreach push to the smaller states about the advantages of investing in sustainable infrastructure and its green collar job growth benefits would help to build out the green bond markets in these areas, and potentially save taxpayers a considerable amount of money, while curbing carbon emissions.

8.8 Conclusions

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 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. We also performed yield curve analysis of a set of green muni bonds that were issued simultaneously with as conventional "vanilla" bonds to look for evidence of greenium or other pricing differences.

The overarching objective of this research was to help foster more investment in green infrastructure for cities via green muni bonds by demonstrating that bond investors can reliably buy climate and green muni bonds without affecting their returns. We show that in doing so they can fulfill both their fiduciary duty and meet ESG investment mandates. At the same time, the continued presence of greenium helps to incentivize bond issuers to take advantage of the more favorable terms for green muni bonds by building out a more sustainable infrastructure pipeline and then bringing these projects to the bond market.

The evidence of a pricing differential in the market between the green municipal bonds and conventional muni bonds shows that there is increasing demand from investors for these green bonds. This early success in the market should be leveraged as much as possible by issuers who could take advantage of the current buyer's market in order to help push through a greener, more sustainable infrastructure agenda, and potentially access the debt markets with a lower cost of capital. This could improve quality of life in American cities, cut carbon emissions, improve infrastructure resilience, and save taxpayer money. The presence of greenium demonstrates that better, more sustainable infrastructure can be developed in the US, and can be more attractive to investors than conventional infrastructure investments. This is an excellent opportunity for investors and issuers to work together to improve the daily lives of millions, both in the US and around the world.

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