The next step in green bond financing*

Dion Bongaerts†and Dirk Schoenmaker‡

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Abstract

In recent years, green bonds have gained popularity as the investment industry is looking for environmentally friendly instruments. Yet, green bonds fragment bond issues, which reduces liquidity and thereby increases financing costs. Moreover, most green bonds are used to refinance existing activities. As a result, the *growth* in environmentally-friendly initiatives is limited. Finally, the product and market design of green bonds is such that prices are unlikely to reflect environmental performance accurately. This makes it hard for investors to differentiate among green bonds and allows firms to get away with window-dressing (greenwashing). We propose to split green bonds into regular bonds and green certificates. We show that this design 1. makes market prices more informative about environmental performance, 2. leads to more liquid securities and therefore lower financing costs, and 3. provides incentives to start new environmentally friendly projects rather than refinance existing ones.

Keywords: Liquidity, bond pricing, OTC markets, search model, ESG, green finance, security design, financial engineering

JEL Classification: G11, G12, G14, Q50

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†Rotterdam School of Management, Erasmus University, dbongaerts@rsm.nl

‡Rotterdam School of Management, Erasmus University and CEPR, schoenmaker@rsm.nl

1 Introduction

In recent years, environmental concerns have led to a widespread range of measures and developments to fight climate change and transition to environmentally friendly business models. One of the initiatives is the Bloomberg Taskforce on Climate-Related Financial Disclosures, which requires investment funds to report on the environmental footprint of their investments.[1]

The aforementioned initiatives have given rise to a new asset class, namely green bonds. Green bonds are very similar to regular bonds and can be issued by both (semi) governments as well as corporates. Cash flow and collateral rights for green bonds are the same as those for regular bonds issued by the same party. The main difference between green bonds and regular bonds is that the money raised by green bonds is earmarked for environmentally friendly purposes. The market for green bonds has grown exponentially in recent years. To maximize the financial and environmental revenues resulting from this green finance wave, optimizing market and security design is of first order importance.

While green bonds have contributed significantly towards the transparency of investment mandates with regards to environmental impact, they are not undisputed (Berensmann et al. 2018, Zerbib 2019). There are three issues of dispute (explained in more detail in Section 2). First, most green bond issues refinance existing green projects that were previously financed with regular bonds. This lack of so called "additionality" compromises the promise of green bonds to increase the volume of environmentally friendly activities. Second, lower yields on green bonds compared to comparable regular bonds are required to provide economic incentives for issuers to undertake environmentally friendly projects. Currently, this reduction in financing costs is small and largely offset by other costs such as issuing costs and cost associated with low bond liquidity due to fragmentation. Third, the market and product structure of green bonds is not well-suited for information aggregation on environmental performance of the projects financed with green bonds. As a result, there is substantial scope for windowdressing or greenwashing.

We propose to split green bonds into regular bonds and green certificates that ensure

[1] See `https://www.fsb-tcfd.org/`.

earmarking for green purposes (Section 3). Splitting features of fixed income securities is common and called 'stripping.' Another example of stripping is splitting credit risk off a corporate bond by virtue of a credit default swap (CDS).

The green certificate structure has several advantages. First, green earmarking is exclusively achieved by the green certificates. As a result, the value of green earmarking is made transparent and more precisely identified. Consequently, market prices and returns of green certificates represent environmental performance better than those of green bonds (Section 4). With green certificates, investors also have a stronger incentive to acquire and trade on information regarding environmental performance. This contributes to prices that reflect information regarding environmental performance of issuers better and more timely. In turn, this leads to increased managerial discipline and improved asset allocation decisions of investors.

Second, the green certificate structure allows to pool fundraising for green and regular investments, thereby preventing fragmentation of bond issues. Fragmentation deteriorates liquidity because of which investors demand higher expected returns on their bond investments, which in turn increases financing costs. Hence, funding costs for environmentally-friendly projects can be further reduced by preventing fragmentation.

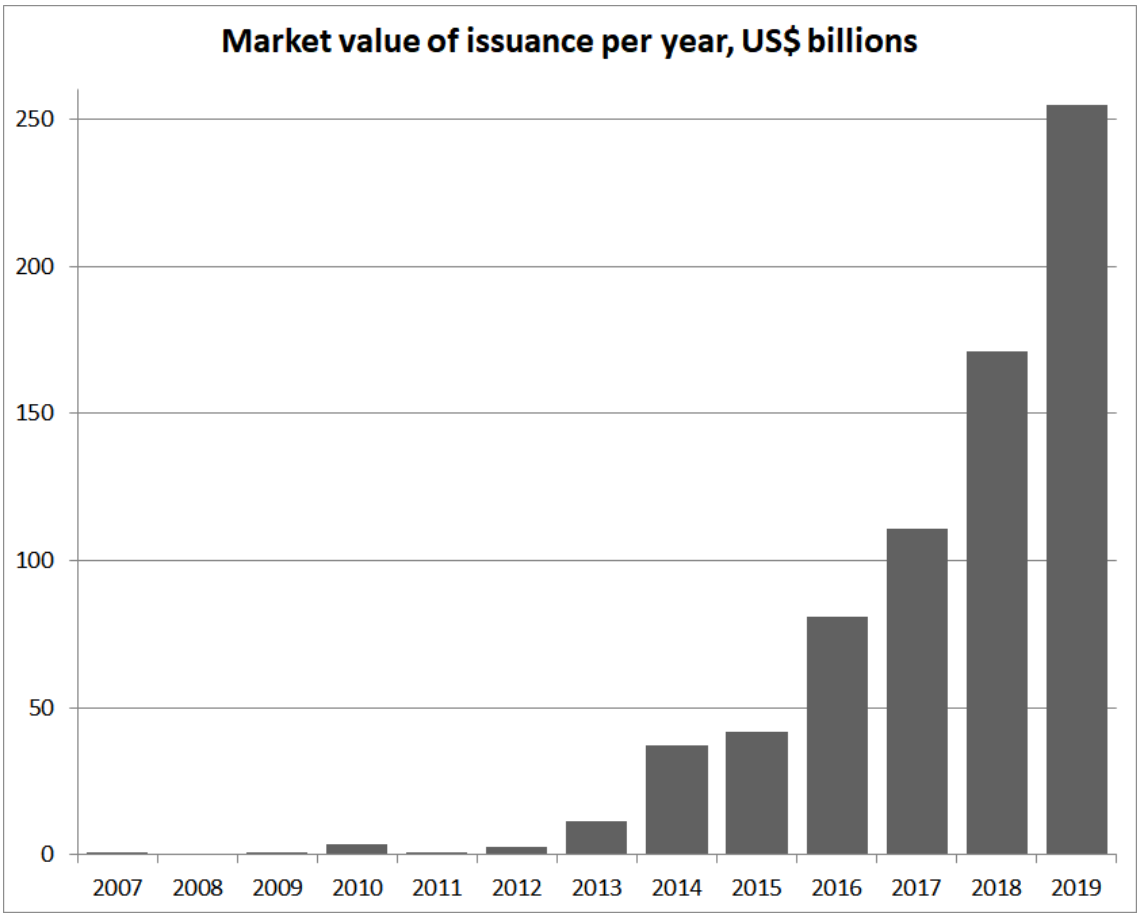
Third, for new projects, green certificates also improve the liquidity of other bonds, thereby lowering *effective* funding costs further. By contrast, using a green bond to finance an new project leaves the cost of other bonds unaffected. Hence, green certificates stimulate issuers to undertake new environmentally friendly projects and thereby foster additionality as opposed to green bonds. The results on funding costs and additionality both originate from reduced fragmentation and are shown using an analytical model (Section 5).

In Sections 6 and 7 we discuss implementation issues and longer-term benefits of adopting such a bond/green certificate structure by default for all bond issues.

2 Green bonds and their issues

The market for green bonds has been growing exponentially in recent years. Figure 1 shows the developments of issuance size in the green bond market over the past years.

Figure 1: The figure shows the global annual issuance volumes of green bonds.
Source: Climate Bonds Initiative



As mentioned there are three issues that compromise the promise that green bonds hold for stimulating debt investment in new environmentally friendly projects. The first issue is additionality. Ultimately, green bonds only yield an environmental payoff if they at the margin increase the probability that a certain project is undertaken in an environmentally friendly way (i.e., there is additionality). To illustrate, a corporate green bond issue to refinance regular bonds that were used to finance an energy-efficient waste management system is unlikely to have any additionality as the waste management system would most likely have been maintained irrespective of the option of refinancing it with a green bond. By contrast, if the choice for a new energy-efficient, but more expensive waste management system is influenced by its financing cost, there is scope for additionality of green finance instruments provided that they come with reduced financing costs (as long as the reduction in financing costs more than offsets the cost increase for the energy-efficient version of the system). Berensmann et al. (2018) argue that a sizable share of green bond issuance is tied to refinancing. Thereby, the size of the green bond market may grossly overstate its actual contribution to reducing humanity's environmental footprint.

The second issue concerns doubts on financing costs reductions for environmentally friendly projects. The discussion above indicates that lower funding costs are pivotal in realizing environmental payoffs. Green bonds have the same cash flow rights as regular bonds and on top of that entail a desirable feature that proceeds are earmarked for environmentally friendly projects. Hence, one would expect the demand for green bonds to exceed the demand for regular bonds, resulting in a yield discount and therefore lower financing cost (this is called a "clientele effect"). Yet, empirical studies have found this discount to be in the order of a few basis points and therefore relatively small (Baker et al. 2018, Zerbib 2019, Gianfrate and Peri 2019). The small yield discount is in line with claims made by the sell-side industry that one can invest in green bonds without additional cost.[2] As a result, green bonds provide little (additional) economic incentive for issuers to undertake environmentally friendly projects.

The doubts on reduced financing costs for environmentally friendly projects are aggravated by hidden costs. To start with, issuing a green bond entails additional issuance and reporting costs. These costs are estimimated to increase effective yield by approximately 5 bps (Gianfrate and Peri 2019) and are not visible from bond yields. Moreover, green bonds fragment liquidity. As a result, green bonds are relatively illiquid. As investors prefer liquid securities, demand suffers, which increases yields (Amihud and Mendelson 1986, Bongaerts et al. 2017). On top of that, the liquidity of other bonds issued by the

[2]As an example, VanEck writes in a note on green bonds: "Given that there is no clear systematic pricing difference between green bonds and conventional bonds, the case for holding green bonds begins with the rationale for holding any fixed income investment"; see https://www.vaneck.com/vaneck-green-bond-etf-guide-source.pdf

same issuer may also suffer because of the fragmentation, leading to an additional liquidity spillover effect and thereby increasing the yield on those other bonds.

The third issue with green bonds is a concern regarding the environmental performance and materiality of the projects financed with green bonds (i.e., a governance issue). Evaluating the (expected) environmental performance of these projects is difficult. Yet, ex-ante assessments and ex-post verification of environmental performance are crucial governance mechanisms to prevent greenwashing and windowdressing.[3] At the moment, green/ESG ratings primarily fulfil this role. Yet, the existing green/ESG ratings show relatively low correlations across ratings produced by different agencies. For example, Berg et al. (2019) show an average correlation of 0.6, which is much lower than correlations among credit ratings produced by different rating agencies. Measures based on market prices of green debt instruments could provide a suitable alternative for environmental ratings. A useful measure would be the yield difference between a green bond an a perfectly matched regular bond (we call this a reference bond). This yield difference is also called the green spread. Intuitively this measure would indicate the yield reduction due to green earmarking. If investors appreciate issuers using their earmarked investments for projects with high environmental performance, this yield reduction should reflect the current and anticipated environmental performance of the issuer. Yet, matching green bonds to reference bonds is far from straightforward (e.g., due to the absence of proper matches). As a result, the green spreads contain large amounts of estimation error and therefore are poor indicators of environmental performance of the issuers.

Besides estimation noise in (changes in) green spreads due to matching difficulties, green bond prices may also not properly reflect information on environmental performance due to hurdles to trade on private information. As an example, consider a green bond for which only an imperfectly matched regular bond is available. Moreover assume that a risk-averse speculator would suspect the green bond to yield a low environmental payoff, because of which its price would drop upon disclosure. Ideally, the speculator would short

[3] An example of such a green bond for window dressing purposes is https://www.reuters.com/article/us-china-greenbonds-coal/china-provides-1-billion-in-green-finance-to-coal-projects-in-first-half-of-the-year-idUSKCN1V90FY

the green bond and cover the credit and interest rate risk with a long position in the regular bond. Moreover, if the speculator is sufficiently confident about his information, he would like to take a position that is as large as possible. This speculator runs into several frictions when setting up such an arbitrage strategy: 1.) the green and regular bond do not match perfectly because of which the arbitrage strategy results in residual interest rate and credit risk. Since the speculator is risk-averse, this is undesirable and the speculator will scale back his position. 2.) Both bonds are illiquid, while relatively large short and long positions are required to trade on the environmental performance information. As a result, the speculator incurs relatively large transaction costs, shorting costs, and costs associated with margin (given the size of his information). These may be prohibitively large, preventing the arbitrage to be conducted in the first place. This is true even if transaction, shorting, and margin costs on green and reference bonds are low in absolute sense.

3 Green certificates as alternatives to green bonds

The exponential growth of the green bond market shows that there is market demand for debt instruments with revenues earmarked for environmentally friendly purposes. We propose a different security design to preserve the ability to cater to this market demand and at the same time address several of the issues mentioned in Section 2. To this end, we propose to issue a regular bond plus a green certificate instead of a green bond. A green certificate ensures its holder that the proceeds of one of the bonds issued will be invested in an environmentally friendly way. As these green certificates do not entail any downside, they should be issued at a positive price, which reflects the market demand for the expected environmental payoff or reporting benefit. The bonds associated with green certificates need not be issued separately, but can be pooled with other bond issues that also finance other, not necessarily environmentally friendly, projects. This prevents fragmentation and thereby preserves liquidity.

The market demand for green certificates can be internally motivated (genuine concern about the environment, positive self-image), or regulation-induced. In particular in case of the latter, the way in which green certificates are incorporated into environmental/integrated reporting is important. We propose to give the holder of a certificate the *sole right* to report the face value of the associated bond as invested in an environmentally friendly way, even if no associated bond is held. Such a structure would allow for 'naked positions' in green certificates in which investors green other investors' investments.

The structure suggested in this section is an example of financial engineering in which cash flow rights of bonds are split from earmarking features. The splitting of features in fixed income markets is not uncommon and is called 'stripping.' For example, a credit default swap (CDS) plus a treasury equals a credit risky corporate bond and a floating rate bond plus an interest rate swap equals a fixed rate bond. The difference with most other forms of stripping is that what we propose is done with a positive net supply security, while most other forms of stripping are done with derivatives (which are typically in zero net supply). As a result, this way of stripping is much more likely to resort real effects at the issuer level.

4 Transparency and information efficiency

In this section, we show how our proposed security design in Section 3 can improve transparency and the informativeness of prices (and price changes) of green debt instruments. If markets were perfectly liquid, holding a regular bond plus a green certificate would be equivalent to holding a green bond. This would make the pricing of a green certificate trivial. Let us denote the yield on a green bond at time t as $r_{d,t}^{GB}$, the yield on a reference bond $r_{d,t}^{ref}$, and the annualized earmarking cost per dollar face value ξ_t^{GC} (we call this the green certificate premium). Moreover, we assume that the annualized non-monetary benefit that (at least some) investors in the market get from each dollar of investment in green debt securities equals ζ_t. We have by no-arbitrage that the annualized earmarking cost is the yield differential between a regular and a green bond, which in turn is equal to the non-monetary benefit of green investment.

$$\xi_t^{GC} = r_{d,t}^{ref} - r_{d,t}^{GB} = \zeta_t. \tag{1}$$

We call $r_{d,t}^{ref} - r_{d,t}^{GB}$ the green spread. If investor preferences are assumed to be constant, any time variation in the non-monetary benefit of green investment ζ_t is due to time variation in current and anticipated environmental performance.

We continue by showing that in the presence of market imperfections (changes in) green certificate premia provide better transparency and reflect (changes in) environmental performance better than (changes in) green spreads. Moreover, we show that informed investors are less likely to acquire and trade on information regarding environmental performance in the green bond market than in the green certificate market.

4.1 Informativeness of market prices (levels)

The green certificates premium, ξ^{GC} (an annualized expected return discount) directly follows from the prices of the green certificate and its associated bond (which by design is perfectly matched). The green spread however needs to be constructed from a green bond and a perfectly matched reference bond. Since perfectly matched reference bonds are often not available, one typically looks at either the closest match or takes an estimate from a yield curve. For sovereign bonds, the latter method is deemed most accurate. We now illustrate this yield-curve matching procedure with a numerical example calibrated to realistic values.

We assume a non-monetary benefit of green investment of 5 bps per annum, aligning with the average green spread reported as by Zerbib (2019). Moreover, we assume that the matched reference bond yield is obtained from a yield curve with some fitting error. The fitting error is assumed to have a volatility of 4bps, which aligns with the calibration error volatility[4] in Nymand-Andersen (2018).[5] One can see that the volatility of the fitting error is in the same order of magnitude as the non-monetary benefit of green investment, which makes (observed) green spreads unsuitable as an environmental performance metrics. This observation confirms the anecdotal evidence highlighted in Section 2 that the yield on a green bond is not significantly different from the yield on a matched reference bond. By

[4]Measured by Residual Mean Squared Error (RMSE)

[5]Note that the yield curve fitting error is calibrated to estimates based on European treasury market data of extremely high quality.

contrast, the price of a green certificate is directly observable and hence does not suffer from this problem.

4.2 Informativeness of market prices (changes)

Even if there are inaccuracies in the observed *level* of the green spread, observed *changes* in the green spread may accurately reflect news regarding environmental performance as systematic biases in price levels cancel out. We show in this subsection that that is not the case either and that changes in green certificate premia reflect changes in environmental performance much better changes in green spreads. To this end we look at the information ratio, which is defined as the ratio of the variance of environmental performance changes (i.e., changes in ζ_t) over the variance of empirically observed green spread or green certificate premium changes. We assume that changes in the environmental performance of an issuer have an annualized volatility of 4 bps with zero autocorrelation.[6] We also assume that yields of green bonds are observed without error and yield curve estimates for reference bonds again have fitting errors with a standard deviation of 4bps. We also assume that fitting errors are serially uncorrelated and also uncorrelated with changes in environmental performance. Under these assumptions, we derive that only 33% of the annualized variance and 11% of the quarterly variance of changes in empirically observed green spreads is driven changes environmental performance and that respectively 67% and 89% is due to yield curve fitting noise (see Appendix A.1 for a calculation). One should note that this low information ratio is purely driven measurement error resulting from the need to find a proper match to a green bond, which is difficult in practice. This problem is absent for green certificates.

Our analysis above using sovereign bonds yields conservative estimates on the proportion of noise contained in observed return variances. A similar exercise can also be performed for corporate bonds. The information ratio is likely to be even lower as data is not available in such abundance due to fewer outstanding bond issues, and more heterogeneity across bond issues (e.g., due to embedded options) and issuers.

[6]We deem this order of magnitude very large in view of the mean of 5bps.

We continue by showing that even if we can find perfectly matched reference bonds, observed green spread changes are likely much less informative than changes in green certificate premia. The reason for this is that securities transactions are typically subject to transaction costs and that historical price series are usually based on transactions. Part of the observed return variance is simply due to some trades taking place at the bid (investor sells to a dealer) and others at the ask price (investor buys from a dealer). This phenomenon is called a bid-ask bounce (see e.g., Roll 1984). We quantify the effect of these transaction costs on the information ratios of observed green spread and green certificate premium changes. Again, we use the sovereign bond market to get conservative estimates on the noise components.

Table 1: Information ratios of changes in green spreads vs green certificate premia

	Green spread	Green certificate premium
Annual	33.33%	100%
Quarterly	11.11%	100%

The table shows the ratio of the variance in environmental performance over the variance of observed price green spread and green certificate premia changes at a an annual and quarterly horizon. Reference bond yields are used to construct green spreads and are assumed to have a fitting error standard deviation of 4bps. The annualized standard deviation of environmental performance is set to 4 bps per annum.

We now assume that for each green bond a perfect reference bond is available. However, we assume that green bonds, reference bonds, and green certificates are subject to transaction costs. Moreover, we assume that only transaction prices are available without any knowledge of whether transactions were buy- or sell-initiated, such that transaction costs effectively act as observation noise. We calibrate sovereign bond transaction costs (one way) at 3.5 bps of face value, which aligns with estimates in de Roure et al. (2019) for small inter-dealer volumes in the German Bund market. Moreover, we assume a non-monetary benefit of green investment ζ_t of 5 bps per annum, such that the frictionless value of a green certificate attached to a 5 year Bund at par with a coupon rate of 1% per annum would equal less than 25 cents. It follows from our calculations that the informativeness of green spread changes (measured again by the information ratio) is lower than that of green certificate premium changes unless transaction costs of green certificates are about 600 times as large as for green and reference bonds (calculations in Appendix A.2).

This would correspond to relative transaction costs of about 20% of the green certificate value, which we deem unreasonably high. Hence, even if green certificates are relatively illiquid, their value changes will be much more representative of changes in environmental performance than what can be deduced from the price changes in some of the most liquid bonds one can find. The reason is that the value of green earmarking is very small compared to the rest of the bond. Moreover, since a green spread consists of a long and short position in a bond, transaction costs give rise to measurement noise on both positions. As a result, small imperfections in observed bond prices have a large impact on green spreads. This intuition is presented in Figure 2.

Once again, our analysis based on sovereign bonds gives conservative estimates with regards to the contribution of bid-ask bounces to return variance. We can conduct a similar analysis for corporate bonds, in which case matters are much worse. Bongaerts et al. (2017) report an average one-way transaction cost of 50 bps for corporate bonds. For a 5-years corporate bond priced at par with a coupon of 2%, the value of a green certificate is less than 22 cents. It follows that the informativeness of green spread changes is lower than that of green certificate premium changes unless transaction costs of green certificates are about 601 times as large as for green and reference corporate bonds, equivalent to 300% of the green certificate value (Calculation in Appendix A.2).

Table 2: Transaction cost hurdles for green certificates to be less informative

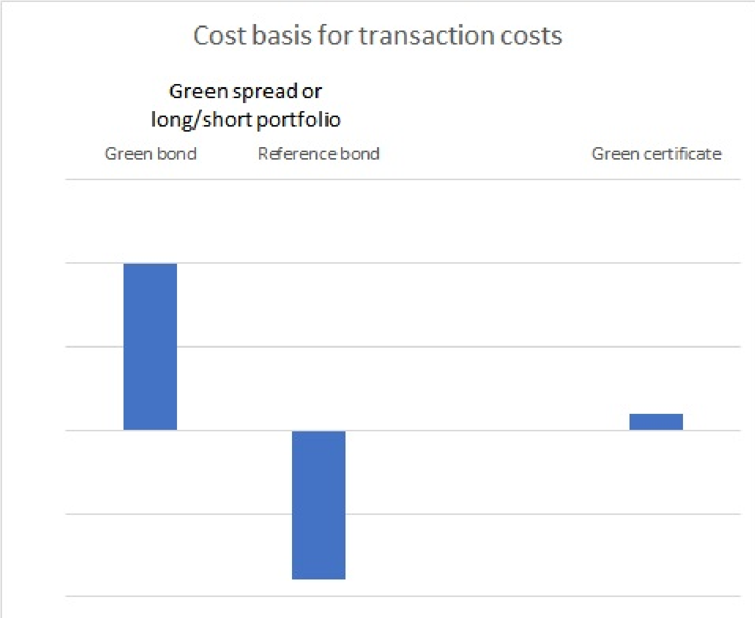
	Green certificate hurdle
Sovereign	20.42%
Corporate	300%

The table shows the minimal relative (one-way) transaction costs on green certificates that are required to make observed price changes of green certificates less informative about changes in environmental performance than observed changes in green spreads. Sovereign green and reference bonds are assumed to have average one-way transaction and shorting costs of 3.5 bps. Corporate green and reference bonds are assumed to have average one-way transaction and shorting costs of 50 bps. Figures are for reference bonds priced at par with a maturity of 5 years and a yield of 1% for sovereign and 2% for corporate bonds.

4.3 Incentives for informed trading and information acquisition

In this section, we derive results on incentives for informed traders to engage in speculative trading based on their information. This analysis is important, as it will provide guidance

Figure 2: Cost base for transaction costs



The figure presents the cost bases for relative transaction costs. The two positions to the left together isolate the green earmarking. The position on the right, in a green certificate achieves the same. Bars are not to scale for expositional purposes (right bar should be much lower for realistic calibrations).

on the degree to which markets will incorporate information regarding environmental performance into prices. We will show that in green certificate markets, the hurdles to engage in trading upon having information are much lower than in green certificate markets. As a result, investors are also more likely to look for information that can be exploited in green certificate markets. Both mechanisms contribute to green certificate prices that reflect environmental performance information much better than green bond prices. A broad body of literature has shown that informative market prices are likely to help in fostering governance on issuers and to improve asset allocations among investors.

For our analysis, we assume that a speculator is informed about an issuer engaging in greenwashing, which would reduce the environmental payoff of its green investments to zero. As a result, the full non-monetary benefit of green investment (ζ_t) would reduce to 0 upon public disclosure. We assume that markets are illiquid in the sense that there are fixed proportional transaction costs to trading as well as some price impact.[7] Under

[7] For our analysis we can disregard the exact size of the price impact. We only assume it to be strictly positive in order to have information impounded to prices.

these assumptions, the speculator in the green certificate market optimally takes a short position, unless transaction and shorting costs amount to 100% of green certificate value (which is unlikely). By trading, the information of the speculator is slowly revealed to the market and impounded to prices.

An informed speculator in the green bond market would need to short a green bond and go long in the reference bond to profit from his information. However, transaction and shorting costs are incurred on both positions proportional to the size of each position, even though the value of the net position is very small. For a 5-year bond, the speculator would optimally not trade on his information if the average fixed transaction and shorting costs per bond exceed 12 bps. Note that in the example, the information advantage of the speculator is almost as large as it can be. For less extreme information, such as a reduction in the green spread/premium to 3 bps (i.e., a drop of 2 bps), the thresholds on transaction costs that would preclude informed trades would equal 40% (4000 bps) for green certificates and 4.8 bps for green and reference bonds. Hence, with relatively strong information (representing 40% of the green certificate value), trading in some of the most liquid securities would likely not be attractive. Once again, for corporate (green) bonds such a strategy would never pay off with the average transaction and shorting costs in that market (about 50 bps; for calculations, see Appendix A.3).

The aforementioned hurdles to informed trading create a disincentive to produce or acquire information on the environmental performance of green debt, since information is likely to be costly to obtain. If one wants to use market prices of green debt instruments as additional measures of environmental performance, investors should produce this information and information should be impounded into prices through trading. Green certificates foster this much better than green bonds because informed trading is likely to be profitable and thereby there are incentives to produce information.[8] Ultimately, informative market prices will help improve asset allocation decisions of investors and impose discipline on management.

[8]Credit default swaps tend to incorporate information on the issuer's creditworthiness earlier than the underlying bonds for similar reasons.

Table 3: Transaction cost hurdle to trade on information

Information advantage	Green and reference bonds	Green certificates
2 bps	4.8 bps	40%
5 bps	12 bps	100%

The table shows the proportional fixed transaction and shorting costs beyond which it is suboptimal to trade on information regarding environmental performance for green and reference bonds and for green certificates.

5 A model of fragmentation, liquidity, and funding costs

In the sections above, we looked at the effect of transaction costs on price informativeness and transparency of green debt instruments. In doing so, we took transaction costs as given. In this section, we show that the use of green certificates instead of green bonds reduces fragmentation of bond issues and thereby preserves liquidity (and hence lowers transaction costs). Because more liquid securities are in higher demand, they have lower yields and are therefore cheaper ways to finance investments. We present the outlines of a model that formally proves this intuition. In our analysis, we show that there is a direct effect (financing for new activities is cheaper), but also an indirect effect (refinancing of other, existing activities is cheaper too). Both effects are absent for green bond financing and contribute to a lower *effective* financing costs for green certificate financing. As such, we show that green certificates are better at fostering additionality. Finally, we show that these effects result in more green projects being undertaken. As such, we show that green certificates are better at fostering additionality. The main results from the model are also summarized in Table 4.

5.1 Model setup

In this subsection, we provide an intuitive description of the fully fledged theoretical model that we present in Appendix B. We start with an issuer that acts purely out of financial motives. This can be a corporation that is purely profit-driven, or a sovereign that realizes that most effects of environmentally unfriendly policies are borne by other countries. The issuer considers undertaking a project that can be done in a green or traditional mode. One can think about using materials that can be recycled or not, or building a power plant based on renewable energy instead of fossil fuels (oil, gas or coal). We ssume the green mode of a project to be more costly than the traditional mode. This higher cost base is reflected in a higher per period operating cost. The investments required to run the project are independent of the mode, in order to leave the demand for external capital at initiation unaffected. Moreover, to isolate the effects of funding costs, we assume that gross revenues of the project are unaffected by the mode in which it is undertaken.

The project at hand is considered by an issuer that has a portfolio of other (legacy) projects that cannot be greened. We assume that the issuer needs refinancing for existing projects as well as additional financing for the project at hand in case it is undertaken. We assume that the firm has a pre-set capital structure that it intends to maintain and also that the cost of equity capital is unaffected by neither project nor financing mode. Hence, the project will be partially financed with debt. The only differences in profitability between the green and traditional mode will come from operating costs and the cost of debt. We assume that the issuer can organize its debt finance in three possible ways. It can issue a traditional bond which it can pool together with all its other refinancing needs. Alternatively, and only if the green mode is chosen, the issuer can either issue a green bond for the project at hand and a regular bond for all refinancing, or it can issue a regular bond for all its financing needs and issue green certificates to earmark the part of the bond issue that is used to finance the project.

The next assumption is on investor preferences. We assume that there are two types of investors: regular investors and impact investors. Regular investors purely care about financial returns. Impact investors have identical preferences to regular investors except for the fact that they also receive non-monetary utility from investing in green securities. This additional non-monetary utility could originate from regulatory requirements, preferences of investors/investment managers,[9] or PR-considerations. As before, we assume that the annualized non-monetary utility derived from every 100 dollars investment in green projects equals ζ. We also assume that there is an over-supply of capital such that the

[9]Some pension funds, for example, aim to reduce the carbon footprint of their portfolio. An example is the Dutch pension fund for health care PGGM: `https://www.ipe.com/esg-pggm-gets-serious-on-carbon-reduction/10013495.article`

issuer can capture all surplus from catering to impact investors. We make this assumption to maximize the scope for green debt instruments to affect environmental outcomes.

The final step is to make some realistic assumptions about liquidity in bond markets and about how such liquidity affects the cost of debt. For this we draw on key insights from the academic literature on over-the-counter (OTC) markets (Duffie et al. 2005) and the effect of liquidity on asset prices (Amihud and Mendelson 1986, Bongaerts et al. 2017). In particular, we assume that green bonds and regular bonds are traded in an OTC market in which investors need to search for dealers (which is costly) and bargain with dealers over prices. In particular, we assume that the bargaining power of dealers for a given bond is inversely proportional to issue size as larger markets are likely to attract more dealers and foster more competition. We then apply results from Duffie et al. (2005) to obtain the result that long run average proportional transaction costs are inversely related to issue size. Amihud and Mendelson (1986) show theoretically that expected returns and therefore the cost of debt increase in expected transaction costs since investors need to be compensated for those. In particular, the liquidity premium equals the expected transaction costs times turnover. Bongaerts et al. (2017) confirm this prediction empirically in the market for corporate bonds. We make the same assumption.

5.2 Model results

In this subsection, we present the results from our model in Appendix B.

Because of our assumption of an over-supply of capital, issuers can place their green bonds or green certificates with impact investors at a yield that is ζ percentage points lower than the yield that regular investors deem acceptable. We call this the clientele effect. This clientele effect is absent if the project is only financed with regular bonds. Hence, the clientele effect can only lower the financing costs for the project if it is undertaken in the green mode.

Next, we work out the effects on liquidity. There are two effects: a direct and an indirect effect. The direct effect relates to the financing of to the project. If the issuer chooses for a green bond, the issue size equals the required project investment. By contrast, if a regular bond or a regular bond together with green certificates are chosen, the issue size is equal to the required project investment plus the required rollover volume. Since larger issues are more liquid and more liquid issues come with lower yields, issuing one large bond issue gives better liquidity and therefore lower yields. Hence, the financing costs for the project are lower if the bonds used to finance it are part of a larger bond issue. The direct liquidity effect is particularly large for issuers with a large rollover volume, since the cost of debt for the project improves by a lot due to higher liquidity compared to stand-alone financing (as is done with a green bond).

The indirect effect relates to the cost of debt on the bonds that need to be rolled over. By doing a large bond issue (irrespective of whether green certificates are issued) the new bond issue will be larger than the one that is being rolled over. As a result, it will be more liquid and have a lower yield. Hence, the new project imposes a positive externality on other projects if these are refinanced with the same issue. This fosters additionality. By contrast, if a green bond is issued, the bond issue that is used to refinance will be as large as the previous one and the cost of debt for the legacy projects will remain unchanged.

We now continue by analyzing how the aforementioned pricing effects factor into the corporate decisions whether or not to undertake the project, if so in what mode, and if so, how financing should be organized. To this end, we first incorporate the indirect liquidity effect of a large bond issue into an *effective* cost of debt financing. There are two important elements in this calculation. First, there is the price component, which is size of the reduction in cost of debt on rollover bonds. The larger this reduction, the larger the indirect effect. If the debt volume to be rolled over is already large, each additional dollar matters relatively little for the liquidity premium since the bonds are already very liquid. Yet, there is also a second component which we call the leverage component. The idea is the following. Each additional dollar added to a bond issue increases the liquidity of that bond issue by only a bit, but this small improvement is leveraged since the existing volume is so large. It turns out that under our model assumptions, the price and leverage component work in opposite directions and exactly offset each other. As a result, the reduction in effective cost of debt due to the indirect liquidity effect only depends on

Table 4: Summary of model results

Project financing	Clientele effect	Liquidity improvement project bonds	Liquidity improvement other bonds
Separate green bond	✓	×	×
Part of large issue with green certificates	✓	✓	✓
Part of large issue	×	✓	✓

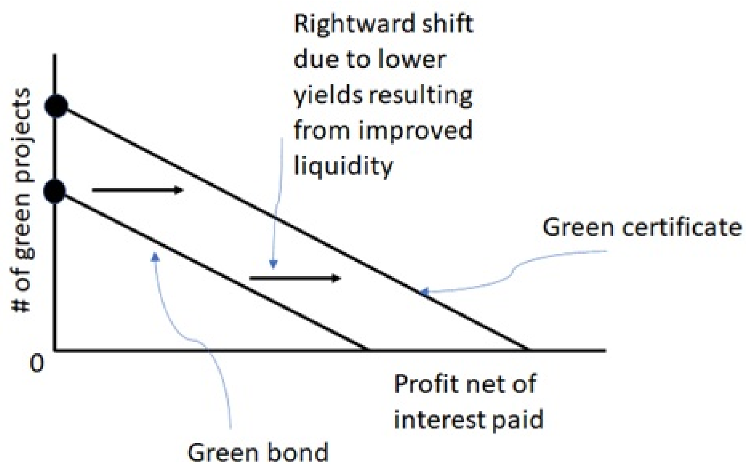
turnover and the difficulty of finding counterparties in OTC markets.

We can now add everything together to compare the effective cost of debt associated with different financing modes. If the project is financed by a regular bond issuance, the effective financing costs equal frictionless cost of debt,[10] plus a small liquidity premium, minus a discount resulting from the indirect liquidity effect. If the project is financed by a regular bond paired with green certificates, the effective cost of debt is reduced by ζ as well due to the clientele effect. If the project is financed by a green bond, the effective cost of debt equals the frictionless cost of debt, plus a large liquidity premium, minus ζ due to the clientele effect. Hence, green certificate debt financing dominates green bond financing and both the direct as well as indirect liquidity effects contribute to this advantage. As a result, green bonds are optimally replaced by regular bonds plus green certificates.

Green certificate financing also dominates regular bond financing due to the clientele effect. Yet, running the project in the green mode comes with higher operating costs and therefore lower profits. There is still a positive business case for the green mode if the operational cost increase is more than offset by the clientele effect in the financing cost. We show that the maximum cost differential that can be overcome is increasing in the size of the clientele effect (naturally) as well as in the corporate leverage rate (since it increases the role of debt in total financing costs). Figure 3 shows graphically how this leads to an increase in the number of projects that are undertaken in the green mode.

[10]The frictionless cost of debt is the cost of debt that would materialize in the absence of transaction costs.

Figure 3: Number of projects that are undertaken in the green mode



The graphs plot number of green mode projects that exceed the profitability on the x-axis for green bond and green certificate financing.

6 Green certificate financing as standard

In this section, we work out additional long-term effects that may arise when green bonds are stripped into green certificates and regular bonds. In particular, we address the long run implications that arise if new standards for issuing bonds by default stipulate which percentage of the issue is earmarked for environmental purposes and therefor accompanied by green certificates. We list several advantages of such standards below.

6.1 Environmental reporting and standards

Currently, environmental reporting is often at a voluntary basis and without clear standards. When green certificates are a standard part of a bond issue, there is a clear scope for making environmental reporting mandatory. Moreover, just as with financial figures it is natural then to impose common standards that foster comparability. It also becomes natural to incorporate environmental reporting, environmental prospectuses, producing environmental ratings, underwriting of the certificates, etc. into the standard workflow of the periodic audit, rating, or issuance process. This leads to a common improvement in disclosure quality as well as to reduced issuance and maintenance costs due to efficiency gains. Moreover, costs associated with environmental ratings, reporting, underwriting, etc.

become fixed costs this way. As a result, these are not (at the margin) a hurdle anymore to enter the market for green debt finance. Finally, there will be no separate green bond desk involved, but everything will run through regular procedures with familiar account managers. This lowers the operational and psychological hurdle to get involved in green debt financing, especially for small issuers.

6.2 Mobilizing funds in passive investment mandates

Following the introduction of exchange traded funds (ETFs), the market share of passive mandates has risen consistently over time (see e.g., Appel et al. 2016). Mobilizing this capital would mean a massive boost for environmental investments. If every bond issue is accompanied with some green certificates, it becomes very easy to construct passive environmentally friendly bond funds. One simply takes a standard bond index, say BarCap US IG Corporate, and includes for each bond the associated green certificate; this would comprise a green version of a regular index on which an ETF could trade. Consequently, the tracking error of this ETF with regards to the regular index would be low. It is also possible to cater to investors with different preferences for green investments this way. One could for example construct a "double green" ETF that for each bond includes two certificates. Since the construction of such indices and ETFs is straightforward, management costs can remain low. In case of an active market for green certificates with informed trading, as described in subsection 4.3, there will be demand for shorting green certificates. As a result, ETFs are likely to generate additional income from shorting fees (Duffie et al. 2002), driving management costs down further. Finally, if under such a structure there is a scarcity of certificates associated with a certain issuer/issue, these certificates will be in high demand and trade at a premium. This in turn creates a financial incentive for the issuer in question to increase investment in green projects (additionality).

7 Institutional preconditions and market acceleration

In order to support the green certificate market, a supporting ecosystem of regulations and institutions is required. Below we list important pre-conditions as well as crucial parties that can move this market forward.

7.1 A common institutional language and treatment

A common language and agreement on definitions of what is green and what is not constitute a starting point. The current process of establishing green standards at the EU level is a major contributor to this process. Having a common framework for green investments allows to report on a more consistent basis on those, improve environmental ratings, and helps in developing a consensus view on the value of green investment earmarking. This is a precondition for speculative trading on environmental performance information and the associated welfare gains described in Subsection 4.3. A similar standardization in the form of the 1999 ISDA Credit Derivatives Definitions helped the CDS market to establish itself.

7.2 Reporting allocation of green earmarking

A second important issue is the question who can include the green earmarking benefit in reporting. To fully separate the earmarking rights from the cash flow rights, the holder of the green certificates should receive the sole right to report the face value of the underlying bond as invested in an environmentally friendly way. To achieve this, green reporting standards need to be modified.

7.3 Attaining critical mass

Third, green certificates will be most successful if there is a flourishing and liquid market. For a market to function well, one typically needs sufficient demand and supply (critical mass), as well as sufficient intermediation activity by dealers or market makers. We describe below which parties would be most influential in getting a market for green certificates started.

7.3.1 Supply side

In order to gain critical mass quickly, large issuers that commit to this security design are needed. Sovereigns are among the largest issuers and therefore natural candidates. Moreover, sovereigns issues are special (Feldhütter and Lando 2008) and safe. In view of the scarcity of safe assets (Caballero et al. 2017), it is hard to ignore sovereigns as issuers. Finally, sovereigns have a certain amount of discretion in their allocation decisions in case of over-subscriptions (which are common). As such, they can reward primary dealers that are more willing to purchase, underwrite, and/or make a market in green certificates. In view of these arguments, it is therefore no surprise that the first party (to our knowledge) to seriously consider green certificates is the Sovereign debt issuance office of the Danish Central Bank.[11]

7.3.2 Demand side

Similar to the supply side, the involvement of large investors is likely to help this market attain critical mass quickly. Naturally, investors with a fundamental demand for green investment instruments, in particular with debt features, would be good candidates to drive this transition. Pension funds and large insurance companies would be natural candidates due to their natural demand to hedge interest rate risk originating from their liability side. Sovereign wealth funds would also be candidates with a sufficiently large impact to accelerate this market. Especially those funded by cash flow with a high environmental footprint such as Norway's Oil Fund, may find this appealing because environmentally friendly investments may partially hedge their cash flow risk originating from climate policies.

7.4 Converting outstanding green bonds

Issuers could consider offers to convert existing green bonds to corresponding regular bonds plus green certificates. This could be done in order to help the green certificate market grow further, to pool with a new issue (and thereby let the new issue benefit from liquidity

[11] See `http://www.nationalbanken.dk/en/governmentdebt/IR/Pages/Model-for-sovereign-green-bonds.aspx`

improvements), or simply as a service to investors to not let them feel left out. In view of the superior properties of green certificate financing compared to green bond financing, investors should not have little to no objections. To the extent that a minority of investors for whatever reason would, such a conversion would impair the liquidity of outstanding green bonds even further, providing additional incentives for them to convert.

8 Conclusion

In this paper, we show that we can design debt market instruments that facilitate the financing of green projects at a lower cost and with better additionality characteristics than the existing and popular green bonds. Moreover, we show that (changes in) market prices of these instruments are likely to be much more informative about the environmental performance of the projects these proceeds are used for. This helps investors to allocate their portfolio according to expectations and imposes governance on issuers.

The mechanisms we put forward in this paper show clear advantages of using green certificates rather than green bonds for earmarking proceeds from bond issues for environmentally friendly purposes. That having said, we are also aware of some resistance against this idea. We would encourage a further discussion on potential advantages and disadvantages of green certificates that have not been covered in this paper as well as a further discussion on implementation details. Together with the experience from the Danish experiment to issues such securities we hope to see green certificates play a positive role in fostering green debt markets and ultimately a reduced environmental footprint.

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Appendices

A Transparency calculations

A.1 Yield curve fitting errors

Denote the yield curve fitting error at time t by ϵ_t^{yc} and the green spread by gs_t. We have that

$$gs_t = \zeta_t + \epsilon_t^{yc}, \Rightarrow \tag{A.1}$$

$$\Delta gs_t = \Delta\zeta_t + \epsilon_t^{yc} - \epsilon_{t-1}^{yc}. \tag{A.2}$$

We are interested in

$$\frac{Var(\Delta\zeta_t)}{Var(\Delta gs_t)} = \frac{Var(\Delta\zeta_t)}{Var(\Delta\zeta_t + \epsilon_t^{yc} - \epsilon_{t-1}^{yc})}. \tag{A.3}$$

Since $corr(\Delta\zeta_t, \epsilon_s^{yc}) = 0, \forall s$ by assumption and $Var(\epsilon_t^{yc}) = Var(\epsilon_{t-1}^{yc}) = Var(\epsilon^{yc})$, we have that

$$\frac{Var(\Delta\zeta_t)}{Var(\Delta\zeta_t + \epsilon_t^{yc} - \epsilon_{t-1}^{yc})} = \frac{Var(\Delta\zeta_t)}{Var(\Delta\zeta_t) + 2Var(\epsilon^{yc})}. \tag{A.4}$$

Substituting $SD(\Delta\zeta_t)$ =4 bps per annum and $SD(\epsilon^{yc})$ =4 bps yields

$$\frac{Var(\Delta\zeta_t)}{Var(\Delta\zeta_t + \epsilon_t^{yc} - \epsilon_{t-1}^{yc})} = \frac{16}{3 \times 16} = 33.33\%. \tag{A.5}$$

On a quarterly level, we have that

$$SD(\Delta\zeta_t^{quart}) = \frac{SD(\Delta\zeta_t)}{\sqrt{4}} = 2\text{bps}. \tag{A.6}$$

Substituting gives

$$\frac{Var(\Delta\zeta_t^{quart})}{Var(\Delta\zeta_t^{quart} + \epsilon_t^{yc} - \epsilon_{t-1}^{yc})} = 11.11\%. \tag{A.7}$$

A.2 Transaction costs

Denote the fixed components of the relative transaction costs for green bonds, reference bonds and green certificates by s^{GB}, s^{ref} and s^{GC}, respectively (expressed as a percentage of their market value). We assume that $s^{GB} = s^{ref} = s = 3.5$ bps. Moreover, we assume that ζ_t =5 bps per annum. We assume that trade directions are serially uncorrelated and also uncorrelated across assets. We have for green certificates that

$$p_t^{GC} = \tilde{p}_t^{GC}(1 - s^{GC} + 2s^{GC}X_t^{GC}), \Rightarrow \tag{A.8}$$

$$ret^{GC} = \tilde{ret}^{GC} + 2s^{GC}X_t^{GC} - 2s^{GC}X_{t-1}^{GC}. \tag{A.9}$$

where $X \sim$ Bernoulli(0.5 is a trade sign indicator (1 for buy, 0 for sell), p_t^x and ret_t^x are, respectively, the transaction price and transaction-based (log) returns of security x at time t, and $\tilde{p}_t^x$ and $\tilde{ret}_t^x$ are, respectively, the true value (cleaned of transaction costs) and true (log) returns of security x at time t. For the portfolio that is long a reference bond and short a green bond, we have that

$$p_t^{ref} - p_t^{GB} = \tilde{p}_t^{ref}(1 - s + 2sX_t^{ref}) - \tilde{p}_t^{GB}(1 - s + 2sX_t^{GB}) \Rightarrow \tag{A.10}$$

$$ret^{ref-GB} \approx \tilde{ret}^{GC} + \frac{\tilde{p}_t^{ref}}{\tilde{p}_t^{GC}}2sX_t^{ref} - \frac{\tilde{p}_t^{GB}}{\tilde{p}_t^{GC}}2sX_t^{GB} - \frac{\tilde{p}_{t-1}^{ref}}{\tilde{p}_{t-1}^{GC}}2sX_{t-1}^{ref} + \frac{\tilde{p}_{t-1}^{GB}}{\tilde{p}_{t-1}^{GC}}2sX_{t-1}^{GB}. \tag{A.11}$$

We have that

$$Var(ret^{GC}) > Var(ret^{ref-GB}) \Rightarrow \tag{A.12}$$

$$2(s^{GC})^2 > Var(\frac{\tilde{p}_t^{ref}}{\tilde{p}_t^{GC}}2sX_t - \frac{\tilde{p}_t^{GB}}{\tilde{p}_t^{GC}}2sX_t - \frac{\tilde{p}_{t-1}^{ref}}{\tilde{p}_{t-1}^{GC}}2sX_{t-1} + \frac{\tilde{p}_{t-1}^{GB}}{\tilde{p}_{t-1}^{GC}}2sX_{t-1}). \tag{A.13}$$

We have that $\tilde{p}_t^{ref} \approx \tilde{p}_{t-1}^{ref} \approx \tilde{p}_t^{GB} \approx \tilde{p}_{t-1}^{GB}$ since $\tilde{p}^{GC}$ and its innovations are small. We can approximate (A.13) by

$$2(s^{GC})^2 > 4\left(\frac{\tilde{p}_t^{ref}}{\tilde{p}_t^{GC}}\right)^2 s^2, \Rightarrow \tag{A.14}$$

$$s^{GC} > \sqrt(2)\frac{\tilde{p}_t^{ref}}{\tilde{p}_t^{GC}} s. \tag{A.15}$$

Hence, if the illiquidity of green certificates is $\frac{\tilde{p}_t^{ref}}{\tilde{p}_t^{GC}}$ as high as green and reference bonds, green certificate price changes are less informative of fundamentals. Substituting bond and green certificate values at a face value of 100, a maturity of 5 years and a yield of 1%, this factor equals 412.7; multiplied with $\sqrt{2}$ this gives 583.63. Multiplying with 3.5 bps transaction costs for green and reference bonds gives a threshold of 2042 bps or 20%.

For corporate bonds, yields are likely to be higher. We assume a yield of 2% on a reference bond. For a 5-year corporate bond priced at par, this results in $\frac{\tilde{p}_t^{ref}}{\tilde{p}_t^{GC}} = 425$. Multiplying with $\sqrt{2}$ yields 601. Multiplying with an average one-way transaction cost of 50 bps yields a transaction cost threshold for green certificates of 300%.

A.3 Hurdles to informed trading

We assume that each transaction in green bonds, reference bonds, and green certificates incurs fixed proportional transaction cost s^{GB}, s^{ref}, and s^{GC}, respectively. Moreover, assume that there are price-impact-related transaction costs that are quadratic in net demand with coefficients $\lambda^{ref-GB} = \lambda^{GC} = \lambda > 0$. Assume that a speculator has (correct) private information that the value of a green certificate/price difference between a green and reference bond equals $\hat{p}^{GC}$ instead of the market consensus price $\tilde{p}^{GC} = \tilde{p}^{GB} - \tilde{p}^{ref} > \hat{p}^{GC}$. If the informed speculator trades in the green certificate market, his demand equals

$$q^{GC} = -\frac{(\tilde{p}^{GC} - \hat{p}^{GC}) - s^{GC} p^{GC}}{2\lambda}. \tag{A.16}$$

It follows that q^{GC} is strictly negative iff $s^{GC} < 100\%$.

If the speculator trades in the (green) bond market, his demand equals

$$q^{GB} = -q^{ref} = -\frac{(\tilde{p}^{GC} - \hat{p}^{GC}) - s^{GB}\tilde{p}^{GB} - s^{ref}\tilde{p}^{ref}}{2\lambda}. \tag{A.17}$$

We assume that $s^{ref} = s^{GB} = s$ and use the following approximation: $s\tilde{p}^{GB} \approx s\tilde{p}^{ref}$. Substituting yields

$$q^{GB} = -q^{ref} \approx -\frac{(\tilde{p}^{GC} - \hat{p}^{GC}) - 2s\tilde{p}^{ref}}{2\lambda}. \tag{A.18}$$

It follows that demand for green bonds (reference bonds) is strictly negative (positive) if

$$(\tilde{p}^{GC} - \hat{p}^{GC}) > 2s\tilde{p}^{ref}. \tag{A.19}$$

We assume the reference bond to be priced at par such that $\tilde{p}^{ref} = 100$. With a market consensus on a green certificate premium of 5 bps, a green certificate on an associated bond priced at par with a yield of 1% and a maturity of 5 years has a price of 24 cents. Now assume that the speculator privately knows that the non-monetary benefit of green debt investment ζ equals zero due to greenwashing (implying that $\hat{p}^{GC} = 0$). We get

$$(\tilde{p}^{GC} - \hat{p}^{GC}) > 2s\tilde{p}^{ref}, \Rightarrow \tag{A.20}$$

$$s < 12\text{bps}. \tag{A.21}$$

If the information is less extreme and the green premium is only 3 bps instead of 5, we have that $\hat{p}^{GC} = 0.145$. The value of the information is 9.6 cents per green certificate. As a result, with average bond transaction and shorting costs of 4.8 bps, the speculator optimally does not trade on his information.

B Formal model on liquidity fragmentation and green debt

B.1 Model Setup

Consider a firm with a project of a given size that can either be undertaken in the traditional (t) or green (g) mode. These modes are mutually exclusive. The green mode results in an expected annual CO_2 emission reduction which we standardize at 1 ton per dollar invested. We assume that the project mode does not affect corporate credit risk and that mode does not affect the risk profile of the project. Finally, we assume that the return on invested capital (ROIC) r^k depends on mode k.

The firm maximizes the NPV of undertaking the project by choosing the size project mode k and financing mode l. This NPV is maximized by maximizing

$$(r^k - r^l_{WACC}), \tag{B.1}$$

where r^l_{WACC} corresponds to the weighted average cost of capital that corresponds with financing mode l. We consider three possible financing modes: traditional (b), green bond (GB), and traditional bonds combined with green certificates (GC). These translate into weighted average costs of capital equal to r^b_{WACC}, r^{GB}_{WACC}, and r^{GC}_{WACC}, respectively. To focus on financing channels in the debt market, we assume that

$$r^l_{WACC} = \frac{E}{V} r_e + \frac{D}{V} r^l_d, \tag{B.2}$$

where D, E and V are debt, equity and total firm value (without the project), respectively, r_e is the cost of equity capital (which is financing and project mode invariant), and r^l_d is the cost of debt corresponding to financing mode l. We also assume that the leverage ratios $\frac{D}{V}$, $\frac{E}{V}$ are constant. We assume that the firm cannot engage in greenwashing such that r^{GB}_{WACC}, and r^{GC}_{WACC} are only available for mode g. We assume that all debt is raised or rolled over simultaneously to the extent that the financing mode allows for that. We denote the amount of debt financing that is required by the project by S.

We now micro-found the costs of debt associated with different financing forms. There are two types of debt investors in the market: regular investors and impact investors. Regular investors have homogeneous preferences and an over-supply of capital. Impact investors also have homogeneous preferences and an over-supply of capital, similar to regular investors, but derive an additional benefit annualized ζ per ton CO_2 reduction.

In reality, bonds trade in OTC markets that are illiquid due to search frictions. Duffie et al. (2005) show that the steady-state bid-ask spread s^j for security j as a fraction of the fair value of the bond in an OTC market with search frictions is given by

$$s^j = \frac{\delta_j z_j}{r + (1 - z_j)\rho_j}, \tag{B.3}$$

where δ_j is a holding cost, z_j is the bargaining power of the market maker, r is the risk-free interest rate, and ρ_j is the intensity with which investors meet market makers.[12] We assume δ_j and ρ_j to be identical across security types and independent of issue size, such that bond turnover, denoted by Q, is unaffected by issue type or size. Moreover, we assume that market maker bargaining power z_j has the following form

$$z_j = \frac{a}{S_j} \tag{B.4}$$

where a is a positive constant and $S_j \in [a^{-1}, \infty)$ is the issue size of security j. Intuitively, one would expect smaller markets to be more concentrated.[13] Substituting (B.4) into (B.3) immediately gives that

$$s_j = \frac{\delta_j a/S_j}{r + (1 - a/S_j)\rho_j}, \tag{B.5}$$

$$= \frac{c}{d + S_j}, \tag{B.6}$$

where c is a strictly positive constant and d is a strictly negative constant. These constants are identical across security types because δ_j and ρ_j are.

[12] This is under their assumption that investors can only trade through market makers and not with one another.

[13] This could be the result of fixed operating costs for market makers to be present in a market for a given security.

B.2 The effect of financing mode on cost of debt

In this section, we derive the consequences for choosing a certain financing mode on the cost of debt.

Since there is an over-supply of capital among both investor groups, both types of investors break even in expectation. As a result, issuers can capture all surplus generated by impact investors' preferences. As a result, the cost of debt in the absence of frictions equals $\tilde{r}_d^b$ for brown financing, and $\tilde{r}_d^b - \zeta$ for green bond and green certificate financing.

Since all investors break even in expectation, the yield increase that investors demand for any security j due to illiquidity equals Qs^j, which corresponds to their expected losses due to transaction costs.[14]

We can now derive the *effective* cost of debt for all three financing modes. With traditional and green certificate financing, the financing is raised along with all other debt financing in one large bond issue (LB). The direct cost of debt for traditional financing equals

$$r_d^b = \tilde{r}_d^b + Qs^{LB}, \tag{B.7}$$

where

$$s^{LB} = \frac{c}{d + D + S}. \tag{B.8}$$

The cost of green certificate financing is identical to that of regular financing minus a clientele-induced discount:

$$r_d^{GC} = r_d^b - \zeta. \tag{B.9}$$

With regular and green certificate financing,r_d^b and r_d^{GC}, respectively, not only represent the cost of debt for the project, but also the cost of debt for all other company-issued debt. With the project, this cost of debt is lower than without it, since the size of the

[14]This is similar to Amihud and Mendelson (1986) when liquidity-related clientele effects (relating to patient vs impatient investors) are ignored.

combined debt issue is now larger than the small bond issue (SB) that would take place without it. Hence, there is a spillover effect of the project on the other debt. When the project at hand is the marginal investment, we can attribute this cost saving on all other corporate debt to this project. As a result, the *effective* cost of debt of the project is lower than the observed cost of debt. We can derive the additional spillover-induced reduction for the effective cost of debt analytically.

Lemma 1 *Under regular and green certificate financing, the per dollar liquidity spillover of the project investment on other debt financing equals*

$$\frac{D}{d+D} Q s^{LB} \tag{B.10}$$

Proof. See Appendix C. ■

Lemma 1 shows that spillover effects are project size invariant. Hence, even small projects generate sizable liquidity spillover effects. The reason is that even though small projects do not increase the size of the bond issue by much, the positive spillovers are applicable to a much larger capital base, which allows for leveraging liquidity benefits from small projects. Note that these costs savings are hidden and not reflected in lower direct financing costs of the project, but should be included by decision makers. Therefore, one should add these to the direct financing costs of the project to end up with the *effective* financing costs.

We now also derive the financing costs for green bonds. Green bonds also allow to capture a yield discount due to clientele effects. Yet, the use of green bonds fragments bond issues. As a result, the green bonds themselves are relatively illiquid since the issue size is relatively small. The cost of debt is then given by

$$r_d^{GB} = \tilde{r}_d^b - \zeta + Q s^{GB}, \tag{B.11}$$

where

$$s^{GB} = \frac{c}{d+S}. \tag{B.12}$$

In contrast to green certificate and regular bond financing, there are no positive liquidity spillovers on all the other debt. Therefore, Equation (B.12) also represents the *effective* cost of debt.

Having derived the (*effective*) cost of debt financing for all debt instruments considered, we can now present the main result of the paper.

Proposition 1 *The effective costs of debt for regular bond, green bond, and green certificate financing are respectively given by*

$$r_d^b = \tilde{r}_d^b + (1 - \frac{D}{d+D})Qs^{LB}, \tag{B.13}$$

$$r_d^{GB} = \tilde{r}_d^b + Qs^{GB} - \zeta, \tag{B.14}$$

$$r_d^{GC} = \tilde{r}_d^b + (1 - \frac{D}{d+D})Qs^{LB} - \zeta. \tag{B.15}$$

Proof. See Appendix C. ■

It is immediately clear from Proposition 1 that green certificate financing strictly dominates the other two forms of financing (everything else equal). It then follows that with green certificate financing, a larger green mode profitability deficit (defined as $r^t - r^g$) can be overcome than by green bond financing.

Corollary 1 *With green certificate financing, a green mode profitability deficit of (at most)* $\frac{D}{V}\zeta$ *can be overcome. For green bonds the maximum green mode profitability deficit that can be overcome equals* $\frac{D}{V}(\zeta + (1 - \frac{D}{d+D})Qs^{LB} - Qs^{GB})$.

Proof. See Appendix C. ■

C Proofs

Proof of Lemma 1. The monetary amount of annual interest savings on the regular debt equals

$$DQ(s^{SB} - s^{LB}), \tag{C.1}$$

where s^{SB} is the bond illiquidity if the project had not been undertaken. Dividing by project size gives the spillover-induced savings per dollar of debt financing raised for the project:

$$\frac{D}{S}Q(s^{SB} - s^{LB}). \tag{C.2}$$

We have that

$$s^{SB} = \frac{c}{d+D}, \qquad s^{LB} = \frac{c}{d+D+S}. \tag{C.3}$$

Substituting gives

$$\frac{D}{S}Q(s^{SB} - s^{LB}) = -\frac{D}{S}Q\frac{c(d+D) - c(d+D+S)}{(d+D)(d+D+S)}, \tag{C.4}$$

$$= \frac{D}{S}Q\frac{cS}{(d+D)(d+D+S)}, \tag{C.5}$$

$$= \frac{D}{d+D}Qs^{LB}. \tag{C.6}$$

■

Proof of Proposition 1. Since investors break even, each investor needs to earn at least $\tilde{r}_d^b$ to be compensated for opportunity costs. Since issuers can capture all surplus, green bonds and green certificates can reduce the financing costs by ζ. Additionally, investors need to be compensated for expected transaction costs. For a security j, expected per period transaction costs are given by Qs^j. s^j is given by (B.8) for regular and green certificate financing, and by (B.12) for green bond financing. Finally, the per dollar spillover cost savings, if any, need to be subtracted. These are given by Lemma 1 for regular and green certificate financing and absent for green bond financing. Putting all these elements together yield (B.13) to (B.15). ■

Proof of Corollary 1. The green mode of running a project with green bond and green certificate financing is optimal if respectively

$$r^g - r^t - r^{GB}_{WACC} + r^b_{WACC} \geq 0, \tag{C.7}$$

$$r^g - r^t - r^{GC}_{WACC} + r^b_{WACC} \geq 0. \tag{C.8}$$

Substituting for $r^{GB}_{WACC}, r^b_{WACC}, r^{GC}_{WACC}$ yields

$$r^g - r^t \geq \frac{D}{V}(r^{GB}_d - r^b_d), \tag{C.9}$$

$$r^g - r^t \geq \frac{D}{V}(r^{GC}_d - r^b_d). \tag{C.10}$$

Substituting for $r^l_d \forall l$ from Proposition 1 yields

$$r^g - r^t \geq -\frac{D}{V}(\zeta - Q(s^{GB} - (1 - \frac{D}{d+D}s^{LB}))), \tag{C.11}$$

$$r^g - r^t \geq -\frac{D}{V}\zeta. \tag{C.12}$$

■