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Julien Xavier Daubanes, Shema Frédéric Mitali and Jean-Charles Rochet

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Why Do Firms Issue Green Bonds?*

Julien Xavier Daubanes
University of Geneva (GSEM) and MIT (CEEPR)

Shema Frédéric Mitali
Ecole Polytechnique Fédérale de Lausanne (CDM)

Jean-Charles Rochet
University of Geneva (GSEM), Swiss Finance Institute, and Toulouse School of Economics

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Abstract

Corporate green bond announcements generate positive abnormal stock returns. We suggest this might be because green bonds signal the profitability of the climate-friendly projects they finance. First, we build a signaling model of green bond issuance. It predicts that firms' incentives to decarbonize are amplified by the interest of their managers in their stock price. Second, we provide supporting empirical evidence, using cross-country variations in effective carbon prices and cross-industry differences in the stock-price sensitivity of managers' compensation. Our results suggest that green bonds are not substitutes for but rather complements to carbon pricing.

Keywords: Green bonds; Green finance; Climate policy; Carbon pricing; Managerial incentives.

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I. Introduction

Green bonds commit issuers to using the bond proceeds to finance a certified climate-friendly project.[1] For example, Unilever announced on March 19, 2014, one of the most famous green bond issues, earmarking about $400m to new CO2-reducing production capacities. This commitment generated positive abnormal stock returns[2] of more than 5%. Similarly, Apple issued more than $4.5bn of certified green bonds between 2016 and 2019, to develop its use of clean energy sources and improve its energy efficiency. In the past few years, a rapidly increasing number of firms have made similar commitments, leading to a boom in the global green bond market, whose volume has nearly doubled every year since 2013 to around already 3.5% of total corporate bond issuance in 2020 (DIW [2021]).

Even if green bond issuance is voluntary, it seems to be environmentally effective. In a recent yet influential paper, Flammer (2021) finds that firms issuing certified green bonds significantly reduce their CO2 emissions[3] and argues against the possibility of greenwashing.

This paper is about the potential of certified green bonds, although voluntary instruments, to provide firms with additional incentives to decarbonize. We suggest that firms' green finance commitments induce them to undertake more climate-friendly initiatives both because of investors' preferences and because green commitments signal future profits to investors. We build a signaling model in which green bond issuance generates positive stock returns. Our theory points to the role of firm managers' interest in stock prices, which we also examine empirically, with implications for the relation between green bonds and public policies.

In the face of the climate problem, economists often recommend to price carbon. In practice, however, this direct approach faces political barriers.[4] Similarly, public subsidies to climate-friendly initiatives and technology regulation are constrained by governments' indebtedness, and limited information and expertise. The urgency of the climate challenge, therefore, calls for examining all instruments that are feasible and potentially effective. This need is reflected, for example, by recent studies on other options such as energy-efficiency standards (Jacobsen, Knittel, Sallee, and van Benthem [2020]). As a matter of fact, the green bond boom is receiving increasing attention from governments and financial institutions.[5]

1. Certified green bonds must finance projects that satisfy the Climate Bond Standards or the Green Bond Principles, including an external verification scheme. Noncompliance with green bond commitments seems costly, probably because it causes a reputational loss. For instance, when Repsol's $500m green bond, initially certified, was finally deemed noncompliant with the Climate Bonds Standards, it was excluded from green indexes. This also suggests that current certification standards are relatively consensual among investors, despite controversies (Environmental Finance [2017]).

2. See Appendix D for details on our event-study estimation of abnormal stock returns.

3. Flammer (2021) takes a matching approach to estimate that firms issuing certified green bonds reduce their CO2 emissions by 13% over the course of the next two years.

4. Even in developed countries, the effective price of most CO2 emissions is far below the social cost of carbon (OECD [2018]).

5. "Over the last few years, the ECB raised the share of green bonds in its own-funds portfolio to 3.5%

Our paper examines the mechanism that makes green bonds work and the role that green finance commitments can play in the structure of climate policy.

Before anything else, shareholders immediately benefit from green bonds: Firms' stock price increases when they announce the issuance of certified green bonds. Baulkaran (2019), Tang and Zhang (2020), and Flammer (2021) find abnormal stock returns of 0.5-1.5% around the announcement of certified green bonds.[6] This is unlike conventional bonds (Eckbo [1986]; Mikkelson and Partch [1986]; Antweiler and Frank [2006]), which do not generate abnormal stock returns. Moreover, certification of green bonds is critical: So-called "self-labeled" green bonds are not associated with either stock market reaction or CO2 reduction (e.g., Flammer [2021]).

Several reasons may explain that green bonds generate positive stock returns. First, public policies penalize CO2 emissions (OECD [2018]) through carbon taxes or emission trading schemes if any, and excise taxes on carbon energy sources. Although these policies are not as stringent as economists prescribe, they enhance the expected performance of green projects. Second, investors' climate concerns are growing. Pastor, Stambaugh, and Taylor (2022) suggest that it accounts for a green bond premium, reducing the cost of certified green projects at the benefit of green bond issuers.[7] Moreover, Pastor et al. (2022) show that investors' climate concerns directly increase the equity value of firms that commit to climate-friendly projects.

Our theory complements this literature with the informational role of green bonds, which amplifies the limited incentives that policy and investors induce. Indeed, announcement stock returns show that announced certified green projects are not fully anticipated, indicating that green bonds convey new positive information about the profitability of firms' green projects. We suggest this might be because, for investors, new green technologies underlying current climate-friendly initiatives are more difficult to gauge than usual technologies. The informational role of green bonds is supported by Tang and Zhang's (2020) finding that stock markets react mainly to the first financing of green projects and much less to their

in 2020, while planning to further increase it in the immediate future." (Central Banking [2021])

6. Perhaps interestingly, this is similar to environmental awards (Klassen and McLaughlin [1996]), even though awards announce an achievement rather than a promise.

7. There is no risk difference between green and conventional bonds because both are backed by issuers' entire balance sheet. Green bond premia observed on secondary markets have hitherto generated green bond yield spreads at issuance that remain limited. Existing empirical estimates range from 0 to 0.2% (Zerbib [2019]; Tang and Zhang [2020]; Kapraun and Scheins [2020]; Flammer [2021]). As Marilyn Ceci, Head of Green Bonds at JP Morgan, sums up, green bonds "generally price in line with traditional bonds, but occasionally demand outstrips supply and they can price a few basis points tighter" (Harrison, Partridge, and Tripathy [2020]).

refinancing.

Formally, on top of public policies and investors' concern, our theory combines two main ingredients. First, we model green bonds as a signaling device, conveying positive, although imperfect, information about the expected profitability of firms' environmental projects. Spence's (1973) single-crossing property holds because certified environmental commitments are less costly to firms that are more able to efficiently decarbonize. The information that green bonds reveal generates positive abnormal stock returns.

Second, our model features managers' interest in the stock price of their firm. If managers only cared about long-term shareholder value, signaling would be useless. Managerial concern for short-term stock returns, also sometimes coined "short-termism," has various origins. One is that managers' actual compensation schemes include stock components (Stein [1989]; Georgen and Renneboog [2011]). For example, Edmans, Gabaix, and Landier (2009) measure the sensitivity of managers' compensation to their firm's stock price.[8] Besides their compensation, managers' interest in stock prices results from the risk of takeover (Stein [1988]), short-term investors (Bolton, Scheinkman, and Xiong [2006]), and markets' attention to short-term returns (Summers and Summers [1989]). Summers and Summers (1989) suggest, and Cremers, Pareek, and Sautner (2020) confirm, that investors' short-termism and managerial myopia are reflected by stock share turnover. Cross-industry variations in both managerial compensation sensitivity to the stock price and share turnover are significant. These variations reflect sector-specific informational issues (e.g., Edmans et al. [2009]) or shareholders' incentives (Antón, Ederer, Giné, and Schmalz [2022]) that are arguably unrelated to firms' propensity to undertake green projects.

We model an industry in which expected public policies and investors' environmental preferences are exogenously given and provide firms with incentives to undertake green projects. One of the main insights is that these incentives are amplified by green bonds' informational role, in a way that is more pronounced as managers in the industry are more interested in stock returns. We derive a theoretical prediction that relates the proportion of green bonds issued by firms in the industry to the prevailing carbon penalty, investors' preferences, and managers' sensitivity to their firms' stock price. This relation highlights that managerial incentives play a positive role, but that this role essentially relies on incentives provided by public policy and investors in the first place.

We also provide empirical support for the amplification effect of managerial incentives.

8. Gopalan, Milbourn, Song, and Thakor (2014) show that this is mainly a short- to medium-run sensitivity. They find that the vesting period of most of executives' stock and options grants is less than five years.

We focus our empirical analysis on firms' decarbonization incentives that are induced by public policies. These are captured by effective carbon prices. We link these penalties to public firms' certified green bonds and to the stock-price sensitivity of firm managers' compensation. With respect to tests of the signaling hypothesis in other contexts—see, e.g., Tyler, Murnane, and Willett (2000) on the labor market—the approach that our model inspires is indirect: It is to exploit agents' interest in stock returns that reflect the signal, rather than the signal itself.

The stock-price sensitivity is only available for US firms, but it differs significantly across industries. Therefore, we exploit its variations across industries—at the cost of intra-industry differences—which we combine with inter-country differences in carbon penalties, along the lines of our model's prediction. The resulting combination is used to explain green bond issuance at the industry-country-year level in a fixed effect model.

We find that firms issue more certified green bonds in industries in which managers are more interested in stock prices. This is consistent with our signaling theory, and suggests that the role of carbon penalties is amplified by the informational role of certified green bonds. In turn, this result suggests that green bonds' effectiveness relies on carbon prices.

The first contribution of this paper is to complement the recent empirical literature on green bonds and investors' concern—e.g., Tang and Zhang (2020), Flammer (2021), and Pastor et al. (2022). On the one hand, we provide a model that consistently integrates investors' preferences, announcement stock returns, as well as existing policy-induced decarbonization incentives. On the other hand, our theory and empirical results point to the amplifying role of managers' interest in stock returns.

Second, our results add to the recent literature on second-best climate policy instruments: See, among other examples, Jacobsen et al. (2020) and Dimanchev and Knittel (2020) on energy efficiency standards and their complementarity with carbon pricing; Flammer, Hong, and Minor (2019) and Ritz (2022) on linking executive compensation to climate performance; Davis and Metcalf (2016) on energy-efficiency information. To our knowledge, we are the first to examine green bonds' complementarity with carbon penalties.

Finally, our study is at the intersection of the literature on managerial compensation and the literature on the private and social benefits of firms' socially responsible initiatives. Bénabou and Tirole (2010) hold that firms' corporate social responsibility reflects both the mitigation of excessive managerial short-termism and the expression of stakeholders' and managers' concern about unresolved external effects. Maxwell, Lyon, and Hackett (2000) point to firms' interest in deterring future political action. Heal (2005) and Daubanes and Rochet (2019) further stress that self-regulation avoids costly conflicts with the rest of society.

Similarly, the frameworks of analysis of Magill, Quinzii, and Rochet (2015), Hart and Zingales (2017), and Edmans (2020) imply that firms should adopt a more inclusive perspective. By contrast with this literature, our analysis suggests that the recent boom in certified green bonds might be driven by managers' incentives to signal economic efficiency. Moreover, our results indicate that firms' voluntary green finance commitments are not substitute for public policies.

To present our theory, we use a minimal set of ingredients. We consider that each firm undertakes a single incremental project over two periods of time. In the first period, firms' managers decide whether to undertake their project in a conventional or in a green (CO2 reducing) fashion. We take as given managers' interest in the stock price. Nor do we address the imperfections of environmental certification in order to focus on the mechanism underlying the potential effectiveness of green bonds. We consider that green projects are all financed by green bonds, which perfectly certify the adopted green technology; other projects are financed by conventional securities, among which we do not make any distinction. Bond and equity investors derive a homogenous warm-glow utility respectively from holding green bonds and from holding shares of the firms that issue these bonds. Equity investors cannot perfectly predict the profitability of green projects, but they infer it from managers' commitments through green bonds and their observable incentives, including carbon penalties. They price firms' stock accordingly in the first period, anticipating rationally profits realized in the second period.

The rest of the article is structured as follows. Section II relates our paper to other strands of the literature. Section III presents our model and derives its main testable prediction. Section IV describes data and uses them to test our main theoretical prediction. Section V discusses the policy implications that our results suggest.

Besides, Appendix D provides additional empirical results on two elements of our theory: the stock returns at green bond announcements and the environmental effectiveness of green bonds.

II. Relation to the broader literature

In addition to the studies of corporate social responsibility, green bonds, and second-best environmental policy cited in the Introduction, our findings are related to other strands of the economics literature on certification, managerial incentives, and green finance markets.

Certification.—The literature on certification—e.g., Farhi, Lerner, and Tirole (2005), and Lerner and Tirole (2006)—and on credence goods' labelling for consumers—e.g., Bonroy and

Constantatos (2015), or Bonneton (2020)—focuses on situations in which agents are directly interested in the certified information: production's environmental impact, potential of an innovation, credit risk, etc. In this context, Fischer and Lyon (2014) and Bouvard and Levy (2018) examine how certifiers set standards' stringency and accuracy.

In our model, by contrast, investors are not only directly interested in the certified environmental performance, they also rely on certified commitments because these commitments signal future profits. Moreover, we overlook the choice of standards' stringency so as to focus our analysis on the mechanism that makes green finance effective in practice.

Climate policy instruments.—Much empirical research effort has been devoted to the Pigovian resolution to the carbon externality—e.g., Nordhaus (2017). In the face of large remaining carbon pricing gaps (OECD [2018]), many examine second-best instruments—see, among many others, Jacobsen et al. (2020) on energy efficiency standards—and how these instruments complement carbon pricing (e.g., Dimanchev and Knittel [2020]). Some examine voluntary actions. Voluntary commitments raise the question of their effectiveness. Khanna and Damon (1999) suggest that voluntary programs might be effective because of significant public recognition efforts targeting customer goodwill. Denicolò (2008) suggests that firms' voluntary environmental actions may seek to obtain excessively stringent regulation at their benefit.

Our analysis is complementary to this literature. Green bond certification specifically targets investors, not consumers or regulators. We point to a new mechanism through which voluntary green finance commitments can effectively complement carbon pricing.

Managerial incentives.—Our theory relies on managers' interest in the stock price of their firms. The finance and business literatures have proposed several explanations for this interest: shareholders' preferences (Summers and Summers [1989]; Bolton et al. [2006]; Polsky and Lund [2013]; Bebchuk [2021]) and incentives to compete (Antón et al. [2022]); the need to incentivize managerial efforts (Marinovic and Varas [2019]), especially in a context of competition for executives (Thanassoulis [2013]); the horizon of industry projects and their mispricing (Schleifer and Vishny [1990]); the risk of takeover (Stein [1988]).

Edmans et al. (2009) measure the sensitivity of managers' compensation value to the stock price. This measure is used by Antón et al. (2022) as an explanatory variable capturing managerial incentives. By contrast, our empirical analysis exploits its variations across industries, supposedly exogenous to incentives to undertake green projects.

Green finance.—This paper adds to a rapidly growing literature that examines various other aspects of the recent development of green finance: shareholder activism (Gollier and Pouget [2021]); the selection of green projects (Kotchen and Costello [2018]); equity investors' concern (Gibson, Krueger, and Mitali [2020]; Pastor et al. [2021]; Pastor et al. [2022]); environmental disclosure (Krueger, Sautner, Tang, and Zhong [2021]); the impact of concerned investors (Heinkel, Kraus, and Zechner [2001]; Chava [2014]; Berk and van Binsbergen [2021]; Landier and Lovo [2021]; Oehmke and Opp [2022]; Zerbib [2022]); optimal investors' intervention (Broccardo, Hart, and Zingales [2022]); municipal green bonds (Baker, Bergstresser, Serafeim, and Wurgler [2020]); climate risks (e.g., Barrage and Furst [2019]); stranded assets (e.g., van der Ploeg and Rezai [2019]).

III. A signaling theory of green bond issuance

III.A. Technology

The industry consists of a continuum of firms. Each firm has regular activities (which are given) and one incremental project. Firms' incremental projects are indexed by $i \in [0, 1]$. They take place over two dates $t = 0, 1$.

All firms' incremental projects require one unit of capital at date $t = 0$ and generate some profit at $t = 1$. These projects can be implemented at date $t = 0$ using either a green ($k = G$) or a conventional, i.e., brown ($k = B$) technology. Green and conventional projects generate date-1 CO2 emissions x_G and x_B respectively, with $x_B > x_G > 0$, regardless of their type.

Projects' technology $k = G, B$ also impacts their financial performance and investors' ability to predict this performance. At date $t = 1$, all projects generate a business-as-usual, perfectly known, revenue $v_B > 0$. With a green technology, depending on their type $i \in [0, 1]$, projects generate either a cost if $\Delta v(i) \geq 0$ or an additional benefit if $\Delta v(i) < 0$, private information of the firm's manager. By convention, the type of firms' projects ranks them in decreasing order of their profitability under the green technology: $\Delta v(i)$ is strictly increasing.

To sum up, the incremental project $i \in [0, 1]$ generates date-1 revenue:

$$v_k(i) = \begin{cases} v_B & \text{if } k = B \;\; \text{(known, business as usual)} \\ v_B - \Delta v(i) & \text{if } k = G, \;\; i \in [0, 1] \;\; \text{(unknown, increasing)} \end{cases} .$$

III.B. Public policy, green bond certification, and concerned bond holders

Projects' CO2 emissions x_k, $k = G, B$, are penalized at an exogenous rate $\tau \geq 0$.[9] This does not mean that emissions due to firms' projects are directly observable. Carbon

9. In practice, effective carbon prices include not only explicit carbon penalties such as carbon taxes and allowance prices, if any, but also specific excise taxes on carbon containing energy inputs.

penalties are often applied on carbon containing inputs. Moreover, the estimation of large firms' CO2 emissions at the level of their activities—e.g., in the EU ETS system—relies on an external verification scheme. We assume, accordingly, that emissions caused by firms' incremental projects are not directly observable, so investors need green certification to distinguish between green and brown projects.

We assume that all incremental projects are financed by bonds, and that all green projects are financed by green bonds, perfectly certifying whether firms' projects are green or not.[10] That is, we only consider certified green bonds and ignore so-called self-labelled green bonds, because empirical evidence shows that the latter neither improve the environment nor trigger investors' reaction (e.g., Flammer [2021]).

We allow for the possibility that green bonds cost less to firms than conventional bonds. Conventional bonds repay to bond investors $R_B = R \equiv 1+r$, given by the exogenous interest rate r. By contrast, green bonds repay $R_G = 1+r-\theta\Delta x \leq R_B$, where $\theta \geq 0$ is bond holders' warm-glow valuation of the CO2 reduction $\Delta x \equiv x_B - x_G$. $\theta\Delta x = R_B - R_G \geq 0$ is the theoretical counterpart of the green bond premium.

III.C. Technology choice

To sum up, an incremental project of type $i \in [0,1]$ with technology $k = G, B$ generates an additional profit at date $t = 1$:

$$\pi_k(i) = v_k(i) - R_k - \tau x_k + \varepsilon_k(i), \tag{1}$$

where $\varepsilon_k(i)$ is a technology-specific random term with $\mathbb{E}[\varepsilon_k(i)] = 0$, $k = G, B$. We assume $\mathbb{E}[\pi_B] = v_B - (1+r) - \tau x_B \geq 0$, which ensures that all projects are undertaken, either in a green or in a brown way.

Besides their incremental project, firms may also differ in the profits generated by their regular activities at date $t = 1$: $\Pi + \varepsilon$, where $\Pi \geq 0$ is known firm-specific expected profits, ε is a random term with $\mathbb{E}[\varepsilon] = 0$, and both are independent of projects' type. Profits (1) from firms' incremental project add to profits generated by their regular activities.

Managers correctly anticipate their firm's expected future profit $\Pi + \mathbb{E}[\pi_k(i)]$. By contrast, investors only observe firms' technology choice $k = G, B$, which determines firms' date-0 stock prices $\mathcal{S}_k$, as will be determined further below.

Managers care not only about firms' future expected profits $\Pi + \mathbb{E}[\pi_k(i)]$, but also about their current stock price $\mathcal{S}_k$. The finance literature points to reasons why managers might be

10. Conventional bonds that finance conventional projects, including self-labelled, non-certified green bonds, may be interpreted as regular bank loans.

sensitive to current stock prices, and why this sensitivity might vary across industries. One is that executive compensations based on stock prices, with shares and options with relatively short vesting periods, are common incentive schemes to address informational issues (e.g., Edmans et al. [2009], and Marinovic and Varas [2013]). Another reason is that managers are concerned about risk of takeover (Stein [1988], Summers and Summers [1989]).

We adopt Stein's (1989) modeling of managers' objective. Given the type i of their project, managers choose the technology $k = G, B$ in such a way as to maximize:

$$\mathcal{U}_k(i) = (1-\alpha)\frac{\Pi + \mathbb{E}\left[\pi_k(i)\right]}{1+\rho} + \alpha\mathcal{S}_k, \tag{2}$$

where ρ is the discount rate and the parameter $\alpha \in (0,1)$ captures the stock-price sensitivity of managers that prevails in the industry, which are both exogenous parameters.

III.D. Timing

The timing is represented in Figure I. Prior to date $t = 0$, firms' projects are indistinguishable and the ex ante stock price $\mathcal{S}$ only differs across firms because of their regular profits Π.

At date $t = 0$, managers choose to undertake their incremental projects in a green ($k = G$) or in a conventional way ($k = B$). Green projects are certified and financed through green bonds. At the same time, stock prices integrate this information to become $\mathcal{S}_G$ and $\mathcal{S}_B$ for firms undertaking green and conventional projects respectively.

At date $t = 1$, firms' regular activity takes place and their project is realized under the committed technology, bonds are repaid to bond holders, and the resulting profits accrue to shareholders.

III.E. Green bond supply

Managers perfectly anticipate the stock price reaction to their technological choice, which they take as given.

We focus the analysis on interior equilibria in which the equilibrium proportion of green projects is $0 < i^e < 1$, ruling out unrealistic situations in which firms' incentives to decarbonize are extreme.[11]

11. Despite its rapid growth in the past few years, green bond issuance by non-financial corporations only represents 3.5% of their 2020 total bond issuance. Conditions under which the equilibrium proportion of green bonds in the industry is interior are $\Delta v(0) < \tau\Delta x < \int_0^1 \Delta v(i)di - (\theta+\alpha\eta)\Delta x$ and $\tau x_B \leq v_B - 1 - r$—see Appendix A for details.

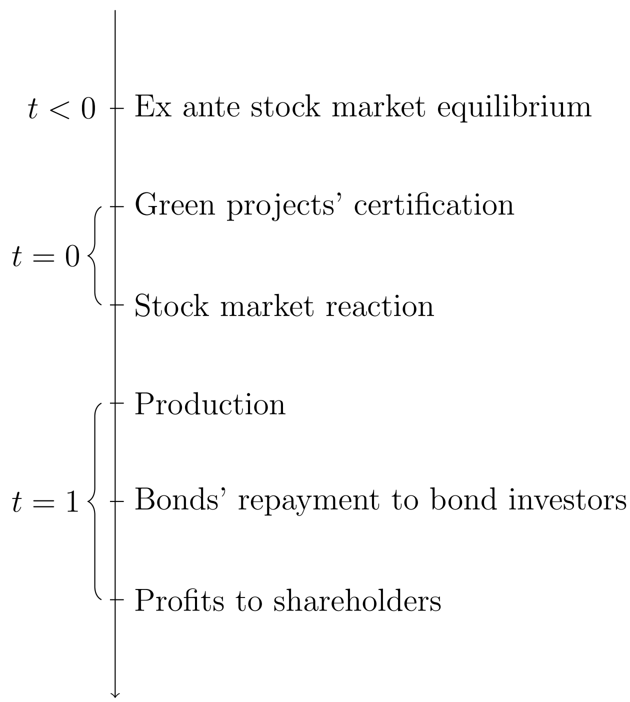

Figure I: Timing

In particular, our setting assumes that $\mathbb{E}[\pi_B] \geq 0$, so that firms are not dissuaded from undertaking conventional projects. We are mainly interested in firms' adoption of green technologies, less so in their decision to implement or not conventional projects which, in general, voluntary approaches do not affect—see, for example, Lyon and Maxwell (2003) in the context of voluntary agreements.

Lemma 1, proved in Appendix A, characterizes managers' technology choice.

Lemma 1 (Green bond supply). *Given $\mathcal{S}_G$ and $\mathcal{S}_B$, a firm with a project of type i chooses a green technology $k = G$ if and only if $i \leq i^e$, where i^e is characterized by:*

$$(1-\alpha)\left[(\tau+\theta)\Delta x - \Delta v(i^e)\right] + \alpha(1+\rho)\Delta\mathcal{S} = 0, \tag{3}$$

where $\Delta\mathcal{S} \equiv \mathcal{S}_G - \mathcal{S}_B$.

The proportion of green projects i^e increases with the stock market reaction $\Delta\mathcal{S}$.

For managers, the impact of an additional certified green project on their firm's profit is $(1-\alpha)\left[(\tau+\theta)\Delta x - \Delta v(i)\right]$. The property that the net benefit from green projects is decreasing is the counterpart of Spence's (1973) critical assumption that signaling costs are negatively correlated with productivity. Lemma 1 tells that managers undertake green projects as long as these projects' impact on their firms is balanced by their individual benefit from stock returns that green bonds generate.

For a given stock price reaction to green bond issuance $\Delta\mathcal{S}$, equation (3) determines the supply of certified green projects i^e, as depicted in Figure II. This relation is increasing: As the stock market reaction $\Delta\mathcal{S}$ is more pronounced, more managers are willing to undertake certified green projects. Green bond supply is also more reactive to stock returns as managers' stock-price sensitivity α is higher. Moreover, all else held unchanged, the supply of green bonds is increased both by the carbon price τ and by the degree of bond investors' environmental concern θ.

The next step of the resolution is to derive the stock price reaction to certified green projects. If there were no green finance certification, investors would not be able to take green initiatives into account. On the bond market, the green bond premium would vanish. Stock prices would not adjust either.[12] Then, the equilibrium proportion of green projects i^0 would be determined by the standard condition that the net marginal benefit reaches zero:

$$\tau\Delta x - \Delta v(i^0) = 0. \tag{4}$$

12. In Section V, Table VI indicates that self-labelled green bonds do not generate abnormal returns that are statistically different from zero, unlike certified green bonds.

In Figure II, this equilibrium is depicted at the intersection between the dotted rising green bond supply curve with $\theta = 0$ and the $\Delta\mathcal{S} = 0$ axis.

Of course, certification may advantage green projects through a green bond premium, if any. This paper mainly examines another—perhaps less expected—benefit from green finance: We will show further below that, regardless of investors' preferences, $\mathcal{S}_G > \mathcal{S}_B$ in equilibrium, so that green bonds always induce managers to undertake "additional" projects, to the extent that they are interested in their firms' stock price.

III.F. Stock market reaction to green bonds

At date $t = 0$, equity investors take as given firms' green commitments, and infer the future profitability of financed projects. Moreover, we allow for the possibility that equity investors attach a warm-glow value $\eta \geq 0$ to CO2 emissions due to incremental projects.

Consequently, equity investors assess date-1 firms' value:

$$\mathcal{S}_k = \frac{\Pi + \mathbb{E}\left[\pi_k(i)|k\right] - \eta x_k}{1+\rho},\ \Pi \geq 0,\ i \in [0,1],\ k = G, B. \tag{5}$$

Prior to date-0 firms' announcements, investors rationally anticipate date-0 equilibrium proportion of green bonds, so ex ante stock prices are:[13]

$$\mathcal{S} = i^e \mathcal{S}_G + (1 - i^e)\mathcal{S}_B. \tag{7}$$

The following results are proven in Appendix A.

Lemma 2 (Stock market equilibrium). *Given the proportion i^e of green bonds, the stock price reaction to firms' green bond issuance is:*

$$(1+\rho)\Delta\mathcal{S}^e = (\tau + \theta + \eta)\Delta x - \mathbb{E}\left[\Delta v(i)|i \leq i^e\right]. \tag{8}$$

This reaction is less pronounced when the proportion of green bonds i^e becomes higher.

13. Ex ante stock prices may also be written:

$$\mathcal{S} = \mathcal{S}_B + \frac{i^e\left((\tau+\theta+\eta)\Delta x - \mathbb{E}\left[\Delta v(i)|i \leq i^e\right]\right)}{1+\rho}, \tag{6}$$

which depend not only on firms' regular expected profit Π but also on the given proportion of green projects i^e. In Appendix A, we show that $\mathcal{S}$ would be maximum if markets anticipated the date-0 equilibrium proportion of green bonds that would prevail if managers were focused on profits ($\alpha = 0$).

Stock returns at green bond issuance stem from the information that green bond commitments signal about the profitability of financed projects. In our model, prior to firms' certified financing decisions, investors cannot make any distinction between firms' projects. After the announcement of green bonds, they take into account that financed projects are more profitable than expected, both because they are better types of projects $i \leq i^e$, and because they will be relatively advantaged by public policies or by bond investors' preference.

The expected additional benefit of green projects (cost, if negative) increases (decreases) with i^e because more green bonds mean that less efficient green projects are undertaken. This translates into a dilution effect of green bonds' signal.

Yet, formula (8) will explain an **amplification effect** of green bond certification: Since stock returns at issuance increase with other incentives to decarbonize, such as carbon penalties and the green bond premium, managers' sensitivity to stock returns will augment these incentives. That is, green bonds will generate additional incentives to decarbonize, which we now examine in equilibrium.

III.G. Equilibrium proportion of certified green projects

In the rational expectations equilibrium, the stock market reaction characterized in (8) is consistent with the supply of green bonds in (3) that this reaction induces. We examine the resulting equilibrium proportion of green bonds in the industry, and its determinants.

The following results are proven in Appendix A.

Proposition 1 (Rational expectations equilibrium).

1. *The rational expectations equilibrium exists and is unique;*
2. *In this equilibrium:*
   (a) *The stock market reaction to green bonds is positive: $\Delta\mathcal{S}^* > 0$;*
   (b) *The resulting proportion of green bonds i^* increases with the carbon penalty τ, and with bond holders' and equity investors' degrees of concern θ and η, in a way that depends on the industry's stock-price sensitivity α.*

The intersection of relationships (3) and (8) determines the unique equilibrium proportion, $i^* = i^*(\alpha, \tau, \theta, \eta)$, as depicted in Figure II. It depends on direct incentives to decarbonize, such as carbon penalties and investors' concern, as well as on managerial incentives.

In this equilibrium, the stock market reaction to green bonds is always positive:

$$(1+\rho)\Delta\mathcal{S}^* = (1-\alpha)\left[\Delta v(i^*) - \mathbb{E}\left[\Delta v(i)|i \leq i^*\right] + \eta\Delta x\right] > 0, \tag{9}$$

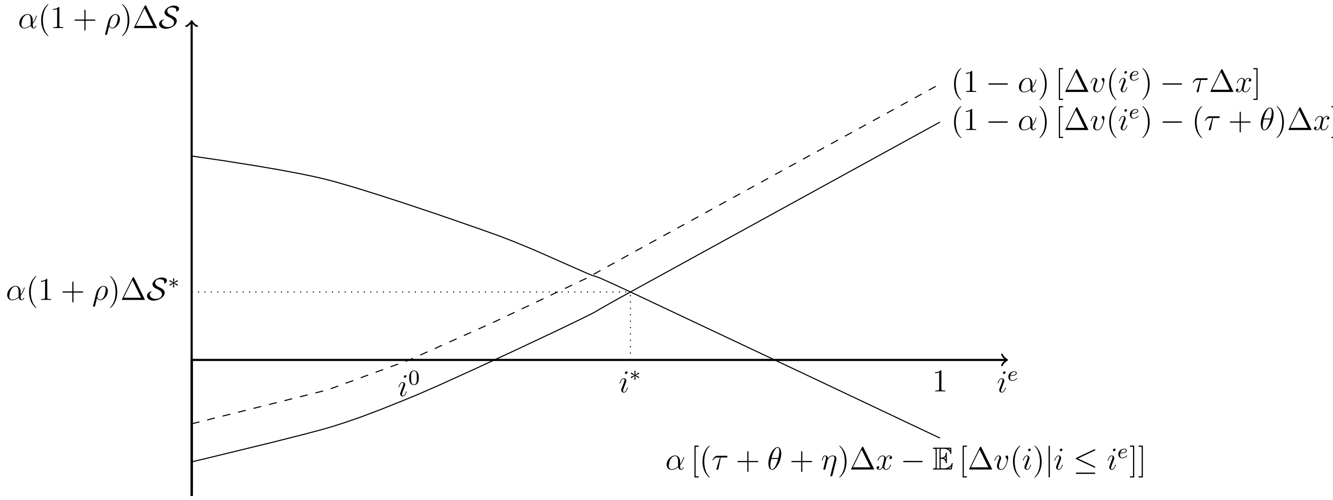

Figure II: Equilibrium proportion of green projects

immediately benefiting the shareholders of firms that issue green bonds. Managers do not issue green bonds as much as to make stock returns vanish.

The resulting proportion of green bonds issued is determined by a zero-net-marginal-cost condition in which the cost of—benefit from, if negative—a green project $\Delta v(i^*)$ is adjusted by managers' benefit from green bond signals:

$$(1-\alpha)\Delta v(i^*) + \alpha\mathbb{E}\left[\Delta v(i)|i \leq i^*\right] - (\theta + \alpha\eta)\Delta x - \underbrace{\tau\Delta x}_{\Delta v(i^0)} = 0. \tag{10}$$

Since $\Delta v(i^0) = \tau\Delta x$ by (4), the property that $\Delta v(i^e) > \mathbb{E}\left[\Delta v(i)|i \leq i^e\right]$ implies that the equilibrium proportion of green bonds is always higher than the proportion of green projects in absence of certification ($i^* > i^0$), regardless of whether there exists a green bond premium at issuance ($\theta > 0$) or not ($\theta = 0$) and of whether equity investors are concerned ($\eta > 0$) or not ($\eta = 0$). Moreover, it follows that the effect of the green bond signal increases with managers' stock-price sensitivity α.

The positive effect of the managerial stock-price sensitivity α on green bond issuance i^* is the main implication of our model. This effect guarantees that the industry undertakes additional green projects, reducing its CO2 emissions more than it would absent green bonds, regardless of investors' concern. It results from the signal generated by green bond certification, which amplifies the impact both of existing policy-induced incentives, and of a green bond premium if any.

It is the role of the sensitivity parameter α that we will exploit empirically, along with the result that its effect amplifies that of the carbon penalty τ. In general, our model characterizes the role of α and τ in $i^*(\alpha, \tau, \theta, \eta)$ implicitly, as we just described, and in a way that one can show by shifting curves in Figure II. Assuming the functional form of Corollary 1 for the additional cost—benefit, if negative—$\Delta v(i)$ yields an explicit expression for i^*.

Corollary 1 (Testable implication). *When the additional cost—revenue, if negative—due to green projects takes the form $\Delta v(i) \equiv a + bi^\gamma$, with $b, \gamma > 0$, the equilibrium proportion of green bonds in the industry is:*

$$i^* = \underbrace{\left(\frac{\gamma+1}{\gamma+1-\gamma\alpha}\right)^{\frac{1}{\gamma}}}_{amplification} \left[\underbrace{\frac{\tau\Delta x}{b} - \frac{a}{b}}_{(i^0)^\gamma} + \frac{(\theta+\eta\alpha)\Delta x}{b}\right]^{\frac{1}{\gamma}}. \tag{11}$$

Expression (11) stresses that, with green bonds, managerial incentives amplify firms' incentives to undertake green projects.

The first component of the term between brackets captures the proportion of green projects that the industry would undertake in the absence of green bonds: $(i^0)^\gamma = \frac{\tau\Delta x}{b} - \frac{a}{b}$. As discussed already, this proportion positively depends on the carbon penalty τ and is independent of managerial incentives (α). In the term between brackets, i^0 is augmented by bond and equity investors' degree of concern, if any. Regardless of whether investors are concerned ($\theta, \eta > 0$) or not ($\theta, \eta = 0$), the term between brackets is greater than or equal to i^0.

The multiplicative term between parentheses captures the positive role of managerial incentives, regardless of investors' preferences. It is greater than unity if and only if $\alpha > 0$, amplifying the term between brackets.

In the next section, we test the role of managerial incentives and of carbon penalties as this role is indicated by expression (11). We do so by exploiting variations in managerial incentives across sectors and over time as well as changes in effective carbon prices across countries and over time.

As a complement to this section, Appendix B focuses on the functional form of Corollary 1 to present an explicit characterization of the equilibrium.

IV. Empirical evidence

In this section, we confront our model's main prediction—the role of managerial stock-price sensitivity in green bond issuance and its dependence on carbon prices—with data.

IV.A. Data

Our main sample is a panel that relates yearly data on individual firms, the green bonds that they issued, and effective carbon prices that prevail in their countries. The period under review is 2007-2019.

To assemble this sample, we start from data extracted from Bloomberg on all corporate green bonds issued between January 2007 and December 2019: their issuer, amount, yield, maturity, announcement and issuance dates. We use information from the non-profit Climate Bond Initiative (CBI) to eliminate non-certified green bonds. 432 certified green bonds have been issued by public firms between 2013 and 2019.

We consider **all** public firms in countries where green bonds have been issued. We use the above data to relate these firms to the volume of certified green bonds they issued every year. Only a small number of firms issue green bonds. Therefore, the data feature not only differences in green bonds' volume across firms that issue green bonds, but also differences between firms that issue green bonds and those that do not.

Each firm is associated with the effective carbon price that prevails in its country.[14] Effective carbon penalties consist not only of tradeable emission permit prices and carbon taxes, but also of all excise taxes on carbon-based fuels. Estimates of effective carbon prices and their coverage of all sources of CO2 emissions are provided by the OECD for 2012, 2015, and 2018—"the most detailed and most comprehensive account of [the largest and most developed economies'] price of carbon emissions" (OECD [2018]). First, we use these estimates to derive the weighted average effective carbon price in each country in 2012, 2015, and 2018, in current US$. Second, we linearly interpolate to obtain data for intermediate years.

Moreover, each firm is associated with annual financial data extracted from CRSP and Compustat North America and Global: market capitalization, book value, net debt issuance, monthly traded number of shares, number of shares outstanding, as well as the percentage of foreign sales, assets, and income. We add firms' environmental scores and CO2 emissions from ASSET4.

Since our model predicts the proportion of green bonds in total debt issuance, we take the ratio of firms' volume of green bonds over their net debt issuance. For simplicity, we call the obtained, standardized variable "*Green bonds*."

Each firm is associated with its industry category according to the Global Industry Clas-

14. We will address the case of multinationals both with firm fixed effects and with the addition of firms' measures of foreign activities—see Table VII of Appendix C.

sification Standard (GICS). Firms are classified into the 69 industries—in 11 sectors—that are described in Appendix C.

The managerial sensitivity to firms' stock price ("*Incentives*") is captured by two alternative proxies. The first one is the wealth-performance sensitivity, the measure suggested by Edmans et al. (2009), provided by Alex Edmans on a yearly basis, and recently used, for example, by Antón et al. (2022): the $ change in CEO wealth, following a 100 percentage point change in firm value, scaled by annual flow compensation.[15] This directly measures the weight of stock components in managers' financial compensation—a natural interpretation of the sensitivity of managers' objective to the stock price in our model—in a way that allows comparisons across firms and industries. In our model, this sensitivity is represented by the weight $\alpha \in (0, 1)$. Therefore, we divide the wealth-performance sensitivity by its highest value in the sample. For simplicity, we call the obtained variable, "*WPS*." Figure III illustrates that it varies dramatically across sectors. At the more granular industry level, the ANOVA test rejects the hypothesis that industries' means are equal at the 1% level, showing a significant inter-industry variation. The international dimension is essential to our empirical approach, yet *WPS* is not available for firms based outside the US. Therefore, we focus on the cross-industry variation of *WPS* in order to aggregate it at the industry and year level in the US and extrapolate it to the same industries in other countries. This means that we consider, for example, that the *WPS* measure for the Automobiles industry in a given year is the same in the US and in Germany. Our approach comes at the loss of the within-industry variation of *WPS* across firms.

Our second, complementary proxy is based on stock share turnover, which is available for firms in all industries and countries. It reflects not only the focus of stock markets on short-term results, but also the intensity of speculation and the risk of takeover. For example, Summers and Summers (1989) suggest that share turnover is linked to executive myopia. Cremers et al. (2020) confirm that it is associated with the presence of short-term investors. To construct our share turnover variable, first, we divide, for each firm and year, the average number of monthly traded shares by the number of shares outstanding, and, second, we divide it by its highest value. We call it "*Turnover*." Like *WPS*, the ANOVA test rejects the hypothesis that industries' means of *Turnover* are equal at the 1% level. In the main text, for expositional simplicity, we also focus on the cross-industry variation of *Turnover* by aggregating it the industry-year level. We will verify further below, however, that our results survive the inclusion of firm-level variations of *Turnover*.

15. CEO wealth includes shares and stock options, while compensation flows represent salary, bonuses, and new grants of equity (Edmans et al. [2009]).

In Appendix C, we provide more practical details on the way we collected, and assembled, green bond data, as well as summary statistics.

IV.B. Green bonds, managerial incentives, and carbon prices

We now test the main prediction of our theory, that is the positive, amplifying role of managerial incentives. More precisely, we verify that, on average, in an industry, firms' proportion of green bonds increases with managers' sensitivity to their firms' stock price in this industry, in a way that is more pronounced as their country's effective carbon price is higher.

For example, Figure III shows the unconditional relationship between the *Green bonds* and *WPS* variables in sectors that issue green bonds. It illustrates that sectors in which managers' pay is the most stock-price sensitive issue more green bonds.

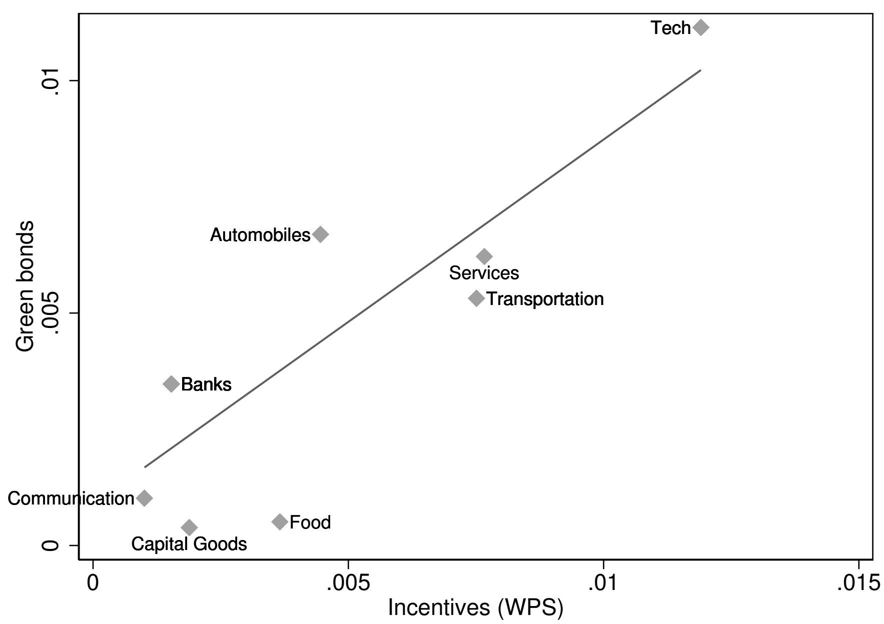

Figure III: Green bonds issuance and stock price sensitivity of managers' compensation (2007-2019)

Closer to the prediction (11) of our theory, we estimate the following model in which the role of managerial incentives includes the interaction with carbon prices:[16]

$$\begin{aligned} \textit{Green bonds}_{i,t} &= \beta_0 + \beta_1 \textit{Carbon price}_{c(i),t-1} \times \textit{Incentives}_{j(i),t-1} + \beta_2 \textit{Incentives}_{j(i),t-1} \\ &+ \beta_3 \textit{Controls}_{i,t-1} + \textit{Fixed effects} + \epsilon_{i,t}. \end{aligned} \tag{12}$$

In this empirical model, the dependent variable is the proportion of green bonds issued in year t by firm i. The independent variables of interest are the degree of managerial incentives in industry $j(i)$ and the effective carbon price that prevails in country $c(i)$, both taken at year $t-1$. For managerial incentives, we alternately use our two proxies. Control variables include firm i's market capitalization and its book-to-market ratio in year $t-1$ as well as its environmental score for year $t-1$. Moreover, we include firm fixed effects (FE), as well as industry, time-varying industry, and time-varying country fixed effects, in order to capture, for example, other incentives to issue green bonds.

We estimate the model of equation (12) using the method of least squares with standard errors clustered at the country level.[17] Table I reports the estimation results. It shows similar estimates whether *Incentives* = *WPS* or *Incentives* = *Turnover*. With *WPS*, for example, we find coefficients for the terms that involve managerial incentives in column (1) that are significantly different from zero at the 1% level and that have signs in line with their theoretical counterparts in our model's prediction (11). The positive contribution of the main interaction term in (12) is confirmed in column (2) where the term in *WPS* alone is replaced by industry-year fixed effects to capture other potentially omitted factors. We obtain comparable estimates with *Turnover* in columns (3) and (4).

IV.C. The total role of managerial incentives

With the estimated coefficients of columns (1) and (3) of Table I, the total contribution of *Incentives* variables appears positive on average, that is, at the average effective carbon price in our sample of \$32;[18] on average, an increase in *WPS* by one standard deviation leads to an increase in firms' proportion of green bonds by 20%.[19] Yet, this effect is not statistically different from zero at this carbon price level.

16. We omit the autonomous role of carbon prices encompassed in i^0 in (11), because it is fully absorbed by the time-varying country fixed effects.

17. In Appendix C, Table III shows estimation results when standard errors are clustered at the country and industry level.

18. Effective carbon prices may seem high because they include various excise taxes.

19. $\frac{(0.017\times 32-0.505)\times 0.018}{0.0035} \simeq 0.2$, where 0.018 is the standard deviation of *WPS* across industries and 0.0035 is the average proportion of green bond issuance across firms in our sample, including many firms that have issued no green bond.

Table I: Green bond issuance, managerial incentives, and carbon price

This table presents estimates from panel regressions of the proportion of green bonds issued by firms on their countries' effective carbon prices and proxies of managers' stock-price sensitivity in their industries. We control for firm size, book-to-market ratio, and environmental score. Standard errors are clustered at the country level. *, **, and *** denote significance at the 10%, 5%, and 1%, respectively.

	Green bonds			
	(1)	(2)	(3)	(4)
Carbon price × Incentives (WPS)	0.017***	0.024*		
	(0.006)	(0.014)		
Incentives (WPS)	-0.505***			
	(0.110)			
Carbon price × Incentives (Turnover)			0.006**	0.005***
			(0.002)	(0.002)
Incentives (Turnover)			-0.158***	
			(0.053)	
Controls	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Industry FE	Yes	No	Yes	No
Industry-year FE	No	Yes	No	Yes
Country-year FE	Yes	Yes	Yes	Yes
Observations	15011	15008	15148	15145
R^2	0.335	0.358	0.335	0.358

Like formula (11), the results of Table I indicate that the total role of managerial incentives is more pronounced as the effective carbon price is higher. In Appendix C, for example, we consider the \$81.75 average effective carbon price in the EU, where the green bond market is the most developed, accounting for about 50% of the current global volume. We find that the total contribution of *Incentives* is positive and significantly different from zero at the 5 or 10% level respectively when *Incentives=Turnover* and when *Incentives=WPS*. At this level of the effective carbon price, an increase in *WPS* by one standard deviation multiplies firms' proportion of green bonds by more than four.

Our estimates may also be interpreted in terms of how carbon penalties and managerial incentives contribute to green bond commitments by firms in a particular industry. For example, German car manufacturers have issued green bonds in the past few years. In the Automobiles sector, on average, managers' pay is moderately sensitive to the stock price: $WPS_{Automobiles} = 0.0002$. The effective carbon price in Germany in 2018 was \$74, slightly below the EU average. Our estimates imply that firms in this industry issue around 4% more green bonds than the average firm.[20]

In general, where carbon emissions are sufficiently penalized, firms issue more green bonds in industries in which managers are more sensitive to their stock price. Moreover, this relation is more pronounced as carbon penalties become higher.

Consistent with theory, our results stress the key role of the interaction between managerial incentives and carbon prices. First, it means that one should expect more green projects for a given carbon price, than there would be otherwise in the absence of green bond certification. But, second, this interaction implies that green bond commitments depend on the level of carbon pricing.

IV.D. Firm-level variation

The model of Section III and the estimated equation (12) assume that firms' managers in the same industry are equally sensitive to their firms' stock price. Indeed, both *WPS* and *Turnover* vary significantly across (US, for *WPS*) industries, and our main approach exploits this variation, at the loss of intra-industry variations across firms. For share turnover, however, variations across firms can also be exploited because *Turnover* is available for firms in all industries and countries. In Appendix C, we verify that the central role of the interaction between carbon prices and managerial incentives survives when *Incentives=Turnover*

20. $\frac{(0.017\times 74-0.505)\times 0.0002}{0.0035} \simeq 0.043$, where 0.0035 is the average proportion of green bond issuance across firms in our sample.

is measured at the firm level, along with industry-year fixed effects—see Table V.

In the same firm-level regression, we include measures of foreign activity in *Controls* (firms' shares of foreign sales, assets, and income) besides other firms' characteristics captured by fixed effects in equation (12).[21] Table V of Appendix C shows how our results accommodate this inclusion.

V. Conclusion

This paper develops a theory for why firms issue green bonds. Besides policy-induced incentives and investors' environmental concerns, we suggest that green bonds convey positive information to markets, reflected by positive announcement stock returns. Our model implies that firms issue more green bonds in industries in which managers are more interested in their firm's stock price, and that this mechanism amplifies other decarbonization incentives. This prediction offers a simple way to test the signaling role of green bonds.

Our model of green bond issuance is consistent with stylized facts recently established about the green bond boom, and delivers a simple insight about the amplifying potential of green bond certification. Our empirical results are consistent with this insight. Overall, our analysis suggests the two following policy implications.

On the one hand, the voluntary nature of green bonds does not disqualify them as effective instruments providing firms with incentives to undertake additional climate-friendly efforts. Indeed, their announcement generates stock returns reflecting other incentives, that managerial incentives multiply.

On the other hand, if investors' concern provides limited incentives, green bonds' effectiveness relies on the pre-existence of carbon policy penalties. Indeed, our analysis suggests that green bonds are complementary to carbon penalties, with important practical consequences. With green bonds, governments cannot dispense with carbon penalties; on the contrary, the latter are instrumental in the effectiveness of the former. At the same time, if carbon prices are sufficiently high, green bonds are likely to make them more effective.

If carbon pricing remains a limited option for governments, the urgency of the climate problem will require that all alternatives to reduce CO2 emissions be examined. Our analysis points to the critical, perhaps paradoxical, role of managerial incentives, and calls for more research on the design of managerial compensation as a climate policy tool.

21. We have assumed that firms are only applied the carbon price of the country where they are based. Although it seems questionable for multinationals, one can defend our approach by invoking Ben-David, Kleimeier, and Viehs' (2020) finding that it is environmental policies where multinationals are based that play the most significant role.

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Appendix to "Why Do Firms Issue Green Bonds?" (For Online Publication)

Julien Xavier Daubanes
University of Geneva (GSEM) and MIT (CEEPR)

Shema Frédéric Mitali
Ecole Polytechnique Fédérale de Lausanne (CDM)

Jean-Charles Rochet
University of Geneva (GSEM), Swiss Finance Institute, and Toulouse School of Economics

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A. Model: Proofs

Proof of Lemma 1

The manager of the firm with the project of type i chooses the green technology if and only if $\mathcal{U}_G(i) \geq \mathcal{U}_B(i)$ in which $\mathcal{S}_G$ and $\mathcal{S}_B$ are parametric. By the managerial objective (2), with (1), this is equivalent to the marginal condition (3) in the lemma.

The rest of the lemma immediately follows from the property that $\Delta v(i^e)$ is increasing with i^e, so (3) implicitly defines i^e as an increasing function of $\Delta \mathcal{S}$.

Proof of Lemma 2

In the main text, for a given proportion of green bonds issued at date $t = 0$, we show date-0 stock price formula (5)—where projects' profits are given by (1). The formula indicates the stock price of firms that issue a green bond and of firms that undertake their project in a conventional way. It is a function of the technology of firms' incremental projects $k = G, B$ and of firms' size Π.

We call the stock market reaction to a green bond $\Delta\mathcal{S}$ the difference between the stock price of a firm when it issues a green bond and the stock price of the same firm—i.e., Π held unchanged—when it does not. Using (5) along with (1), we obtain expression (8).

Before date $t = 0$, consider that markets expect a given proportion of green bonds i^e at date 0. Proportion i^e is the probability that any firm will issue a green bond at date $t = 0$, and $(1 - i^e)$ is the probability that it does not.

With these probabilities, a given firm's ex ante stock price (7) is the average of its anticipated stock prices at date 0 depending on whether it will choose a green or a conventional technology. It is a function of Π and of the given expectation i^e.

(6) follows from (7) and (8). Let us now show that (7) is maximum when the anticipated proportion of green projects i^e is the proportion of green projects that would prevail if managers were not sensitive to stock prices at all. In (6), only the numerator of the term on the right depends on i^e. Its derivative simplifies to $(\tau + \theta + \eta)\Delta x - \Delta v(i^e)$, which is decreasing with the anticipated i^e. This derivative is equal to zero for $i^e = \hat{i} \geq i^0$, where $\hat{i}$ is the proportion of green bonds that would be issued if α were zero: $(\tau+\theta+\eta)\Delta x - \Delta v(\hat{i}) = 0$, in Figure II, at the intersection between the rising green bond supply with $\alpha = 0$ and $\theta \geq 0$, and the horizontal axis $\alpha\Delta\mathcal{S} = 0$.

Note that if investors anticipated the corner equilibrium $i^e = 1$, then, by (7), the ex ante stock price would become $\mathcal{S} = \mathcal{S}_G$, so that there would be no stock market reaction to green bonds at all.

Proof of Proposition 1

(3) and (8) are relations between the proportion of green bonds i^e and the stock market reaction $\Delta\mathcal{S}^e$ that are respectively increasing and decreasing, as we show in the main text. Therefore, their intersection yields a unique proportion of green bonds

$$i^* = i^*(\alpha, \tau, \theta, \eta),$$

and expression (9) of the equilibrium stock market reaction to green bonds. Since $\Delta v(i^e) > \mathbb{E}\left[\Delta v(i) | i \leq i^e\right]$, (9) implies that this reaction is always positive.

Moreover, (3) and (8) implies that $i^*(\alpha, \tau, \theta, \eta)$ can be characterized by (10). Since both $\Delta v(i^e)$ and $\mathbb{E}\left[\Delta v(i)|i \le i^e\right]$ are increasing in i^e and $\Delta v(i^e) > \mathbb{E}\left[\Delta v(i)|i \le i^e\right]$, the comparative-static effects of α and τ follow immediately.

The main prediction of our theory is the positive contribution of the managerial stock-price sensitivity α to the industry's green bond issuance i^e. Totally differentiating (10) with respect to i^e and α, holding τ, θ, and η unchanged, and rearranging terms, we obtain:

$$\frac{\partial i^*(\alpha, \tau, \theta, \eta)}{\partial \alpha} = \frac{\Delta v(i^*) - \mathbb{E}\left[\Delta v(i)|i \le i^*\right] + \eta \Delta x}{(1-\alpha)\Delta v'(i^*) + \alpha \frac{d\mathbb{E}[\Delta v(i)|i \le i^*]}{di^*}} > 0, \tag{A.1}$$

which, for example, depends on carbon pricing positively through the stock market reaction in the numerator.

Similarly, one obtains:

$$\frac{\partial i^*(\alpha, \tau, \theta, \eta)}{\partial \tau} = \frac{\Delta x}{(1-\alpha)\Delta v'(i^*) + \alpha \frac{d\mathbb{E}[\Delta v(i)|i \le i^*]}{di^*}} > 0, \tag{A.2}$$

indicating that carbon pricing contributes to increase the proportion of green projects, in a way that depends on managerial incentives.

Conditions for the equilibrium to be interior are $i^0 > 0$ and $i^* < 1$. The former is guaranteed by $\Delta v(0) < \tau \Delta x$; that is, the carbon price is sufficiently high to induce some green projects even in the absence of green bond certification and stock market reaction. The second inequality $i^* < 1$ requires, first, that some projects are not certified green, i.e., $\mathbb{E}\left[\pi_B\right] = v_B - (1+r) - \tau x_B \ge 0$, and, second, that i^* as characterized by (10) is less than 1, which is guaranteed by $\mathbb{E}\left[\Delta v(i)|i \le 1\right] = \int_0^1 \Delta v(i) di > (\tau + \theta + \alpha\eta)\Delta x$.

Expression (11) obtained under the functional form $\Delta v(i) = a + bi^\gamma$, $b, \gamma > 0$, is derived in Appendix B.

B. Model: An example with explicit solutions

In this appendix, we assume the following functional form for the additional cost—revenue, if negative—due to green projects:

$$\Delta v(i) \equiv a + bi^\gamma, \ \ b, \gamma > 0.$$

The resulted expected revenue from certified green projects $i \le i^e$ is:

$$\mathbb{E}\left[\Delta v(i)|i \le i^e\right] = a + b\frac{(i^e)^\gamma}{\gamma + 1}.$$

The supply of green bonds (3) becomes:

$$i^e = \left[(i^0)^\gamma + \frac{\theta \Delta x}{b} + \frac{\alpha}{1-\alpha} \frac{(1+\rho)\Delta \mathcal{S}}{b} \right]^{\frac{1}{\gamma}}, \tag{B.1}$$

where

$$i^0 = \left(\frac{\tau \Delta x - a}{b} \right)^{\frac{1}{\gamma}}.$$

The stock market reaction to green bonds (8) becomes:

$$(1+\rho)\Delta \mathcal{S}^e = b \left[(i^0)^\gamma + \frac{(\theta+\eta)\Delta x}{b} - \frac{(i^e)^\gamma}{\gamma+1} \right]. \tag{B.2}$$

Replacing (B.2) into (B.1) and rearranging, one obtains the rational expectations equilibrium proportion of green bonds:

$$i^* = \left(\frac{\gamma+1}{\gamma+1-\gamma\alpha} \right)^{\frac{1}{\gamma}} \left[(i^0)^\gamma + \frac{(\theta+\alpha\eta)\Delta x}{b} \right],$$

in which the amplification effect of signaling is reflected by the fact that the first term between parentheses is greater than one. Moreover, the equilibrium proportion of green bonds is increasing in α in a way that is more pronounced when τ is higher.

C. Empirics

Mode details on the green bond data

Green bonds' data are extracted from the fixed income Bloomberg database. Corporate green bonds are indicated by the use of proceeds "Green Bond/Loan" and asset class "Corporate." Identifiers used are bond ISIN, company ISIN, and CUSIP. The unique bond ISIN identifier is used to merge Bloomberg green bonds' data with CBI's certification information.

We include all public firms with codes 10 and 11, which makes a total for our analysis of 19844 distinct firms.

We merge bond information with CRSP and Compustat using firms' CUSIP and ISIN identifiers.

We define industries using the Global Industry Classification Standard (GICS), which is provided with the green bond dataset. It is divided into 69 industries which can also be categorized into 24 industry groups and 11 sectors.

Industry classification

Code	Industry
code101010	Energy Equipment and Services
code101020	Oil, Gas and Consumable Fuels
code151010	Chemicals
code151020	Construction Materials
code151030	Containers and Packaging
code151040	Metals and Mining
code151050	Paper and Forest Products
code201010	Aerospace and Defense
code201020	Building Products
code201030	Construction and Engineering
code201040	Eletrical Equipment
code201050	Industrial Conglomerates
code201060	Machinery
code201070	Trading Companies and Distributors
code202010	Commercial Services and Supplies
code202020	Professional Services
code203010	Air Freight and Logistics
code203020	Airlines
code203030	Marine
code203040	Road and Rail
code203050	Transportation Infrastructure
code251010	Auto Components
code251020	Automobiles
code252010	Household Durables
code252020	Leisure Products
code252030	Textiles, Apparel and Luxury Goods
code253010	Hotels, Restaurants and Leisure
code253020	Diversified Consumer Services
code255010	Distributors
code255020	Internet and Direct Marketing Retail
code255030	Multiline Retail
code255040	Specialty Retail

Code	Industry
code301010	Food and Staples Retailing
code302010	Beverages
code302020	Food Products
code302030	Tobacco
code303010	Household Products
code303020	Personal Products
code351010	Health Care Equipment and Supplies
code351020	Health Care Providers and Services
code351030	Health Care Technology
code352010	Biotechnology
code352020	Pharmaceuticals
code352030	Life Sciences Tools and Services
code401010	Banks
code401020	Thrifts and Mortgage Finance
code402010	Diversified Financial Services
code402020	Consumer Finance
code402030	Capital Markets
code402040	Mortgage Real Estate Investment Trusts (REITs)
code403010	Insurance
code451020	IT Services
code451030	Software
code452010	Communications Equipment
code452020	Technology Hardware, Storage and Peripherals
code452030	Electronic Equipment, Instruments and Components
code453010	Semiconductors and Semiconductor Equipment
code501010	Diversified Telecommunication Services
code501020	Wireless Telecommunication Services
code502010	Media
code502020	Entertainment
code502030	Interactive Media and Services
code551010	Electric Utilities
code551020	Gas Utilities
code551030	Multi-Utilities
code551040	Water Utilities
code551050	Independent Power and Renewable Electricity Producers

Table II below shows summary statistics of all green bonds obtained from the Bloomberg database. Panel A shows a stable growth in the volume of green bonds issued from 2007 to 2019—see also Figure 1 of the introduction. Most green bonds are issued by private industrial companies followed closely by banks.

Other variables' description

This section describes firm and country-level variables' sources and construction.

Book-to-market ratio.—To obtain book equity from Compustat, we subtract from the shareholders' equity the preferred stock value, using redemption, liquididating or carrying value in that order (items PSTKRV, PSTKL, PSTKQ). For shareholders' equity we use the item SEQ, or Total Common Equity plus Preferred Stock Par Value (CEQ, PSTKQ) if SEQ is missing and Total Assets minus Total Liabilities minus Minority Interest if CEQ or PSTKQ is missing, using items ATQ, LTQ, and MIBQ. We then divide by the market value of the firm, which is obtained as the number of shares outstanding multiplied by the stock price, as in CRSP, and Compustat Global for international firms.

Effective carbon price.—It is a weighted average of effective carbon prices across all sectors (Road transport; Non-road transport; Industrial facilities; Households, commercial and public services; Electricity) weighted by the amount of emissions of each sector and each coverage type (permit prices and/or taxes). We obtain these data from the OECD for years 2012, 2015 and 2018 and we linearly interpolate the resulting estimates to obtain data for intermediate years.

CO2 emissions.—We collect firm-level carbon emissions from ASSET4 (item ENERDP023, Total Carbon dioxide (CO2) and CO2 equivalents emission in tonnes, i.e., scopes 1 and 2).

Environmental score.—We collect firm-level environmental scores from ASSET4 (item ENSCORE; notes: "Refinitiv's Environment Pillar Score is the weighted average relative rating of a company based on the reported environmental information and the resulting three environmental category scores").

Exchange rate.—We use yearly exchange rates from the OECD to convert all carbon prices to US$ denominated prices. More specifically, the exchange rate is the price of one country's national currency units in relation to US$ as of the end of each year.

Foreign sales, assets, an income.—We collect the proportion of foreign sales, assets, and income from Worldscope, which is defined as international sales, assets, and income, divided by net sales, total assets or revenues (item WC08731).

GDP.—We collect international data for GDPs from the World Bank.

Market capitalization.—We compute market capitalization as the number of shares outstanding multiplied by the stock price using CRSP and Compustat Global data.

Net debt issuance.—We define net debt issuance following Lian and Ma (2021). We compute it as long-term debt issuance (Compustat item DLTIS) minus long-term debt reduction (Compustat item DLTR).

Wealth-performance sensitivity.—This measure is obtained from Alex Edmans' website. It is defined as the $ change in CEO wealth for a 100 percentage point change in firm value, standardized by the annual flow compensation (Edmans et al. [2009]).

Share turnover.—For each firm and each year, it is the sum of the monthly number of shares traded in a given year (trading volume), divided by the number of shares outstanding as of the end of the year. We take the average of this ratio for each industry and year.

Trading volume.—We collect trading volumes from CRSP and Compustat Global and adjust them for stock splits.

Total debt (country-level).—We collect country-level total debt from the BIS database. We consider gross issues of debt in a given country (domestic market) and year by all institutions except governments, central banks, and international institutions.

The following table presents some summary statistics, including Alex Edmans' original wealth-performance sensitivity and share turnover, before they are normalized to fit with our model as explained in Section IV.

Panel B: Distribution of green bonds by company type

	N	Total (MM)
N/A	177	24,068
Private	1557	356,571
Public	461	188,090

Table II: Summary Statistics

This table presents summary statistics on Bloomberg's Corporate Green Bonds data. The sample is restricted to bonds with a green bond indicator that equals one according to Bloomberg and with a use of proceeds that includes Green Bond/Loan.

Panel A: Distribution of green bonds by issuance year

	N	Total (MM)
2007	1	808
2008	7	427
2009	13	920
2010	50	4,229
2011	22	975
2012	21	2,047
2013	36	13,642
2014	123	31,314
2015	301	43,758
2016	225	85,477
2017	377	103,996
2018	457	113,946
2019	562	167,189

Panel C: Distribution of green bonds by (Bloomberg) industry

	N	Total (MM)
Bank	866	240,350
Financial	162	62,091
Industrial	933	227,183
Insurance	7	2,563
Municipal	2	945
Real Estate	195	20,101
Utility	30	15,495

Panel D: Distribution of green bonds by country

	N	Total (MM)
China	275	109,085
France	193	39,585
Italy	21	10,267
Japan	69	10,762
Mexico	9	12,186
Netherlands	81	53,496
Norway	34	8,188
Others	578	159,694
SNAT	445	85,766
Sweden	220	18,548
UK	22	8,005
US	248	53,147

Panel E: Summary statistics of the main variables

	mean	sd	min	p25	p50	p75	max
Green bonds (proportion)	17.009	24.179	0.070	0.742	5.043	21.332	92.589
Carbon price ($)	32.480	37.202	0.882	8.042	11.364	55.519	163.147
Environmental score	48.998	23.079	0.000	29.480	47.340	67.560	99.310
Firm size ($B)	239.843	5,422.056	0.000	0.102	0.641	3.981	4.48e+05
Wealth-performance sensitivity (original)	529.688	15771.873	0.992	7.096	13.615	40.943	8.69e+05
Share turnover (original)	142.685	407.876	0.000	71.814	97.905	135.681	7,880.690
Firm CO2 emissions (Mt)	4.00	10.8	0.000	0.082	0.359	2.14	99

Moreover, the obtained proxies *WPS* and *Turnover* both vary significantly across industries. For both variables respectively, the ANOVA test rejects the hypothesis that industries' means are equal at the 1% level.

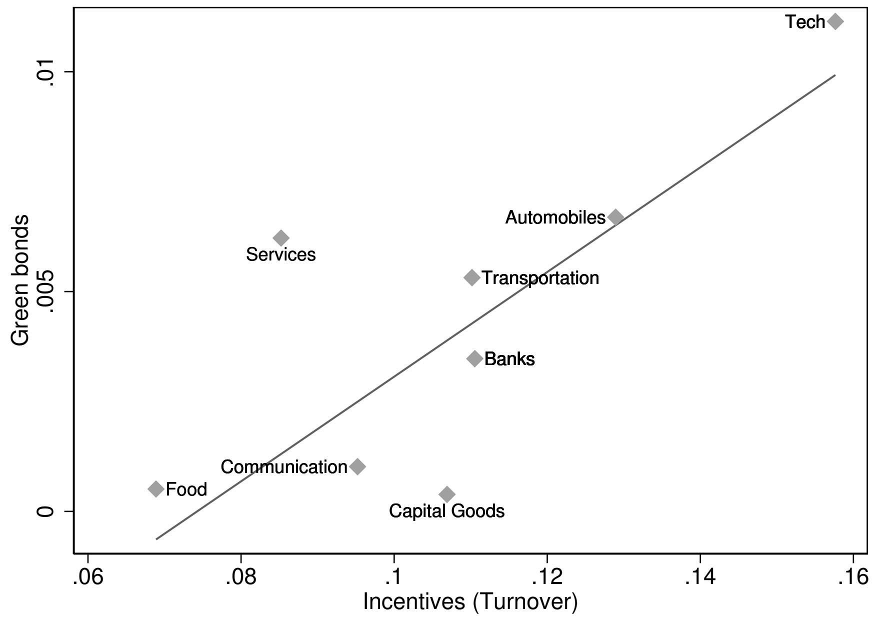

Figure IV: Certified green bond issuance and stock share turnover (2007-2019)

Replication and additional robustness exercises

The following estimation results complete those presented in Table I.

Table III shows how the results of Section IV are modified when standard errors are clustered at the country-industry level. In particular, when *Incentives*=*WPS* and in the presence of industry-year fixed effects, the coefficient of the interaction component of (12) becomes significantly different from zero at the 11% level. The difference with results presented in Table I raises the possibility that an unobserved variable affect green bond issuance at the industry level.

We now examine the total impact of managerial incentives according to the regression results presented in Table I of Section IV. According to these results, the total effect is positive on average, i.e., at least for any effective carbon price greater than the OECD average of $32.

In order to test whether the total effect of managerial incentives is statistically different from zero at a given threshold level $\overline{\textit{Carbon price}}$, we rewrite the empirical model (12) by

Table III: Green bond issuance, managerial incentives, and carbon price: alternative clustered standard errors

This table presents estimates from panel regressions of the proportion of green bonds issued by firms on their countries' effective carbon prices and proxies of managers' stock-price sensitivity in their industries. We control for firm size, book-to-market ratio, and environmental score. Standard errors are clustered at the country-industry level. *, **, and *** denote significance at the 10%, 5%, and 1%, respectively.

	Green bonds			
	(1)	(2)	(3)	(4)
Carbon price × Incentives (WPS)	0.017	0.024		
	(0.010)	(0.021)		
Incentives (WPS)	-0.505**			
	(0.220)			
Carbon price × Incentives (Turnover)			0.006***	0.005**
			(0.002)	(0.002)
Incentives (Turnover)			-0.158***	
			(0.048)	
Controls	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Industry FE	Yes	No	Yes	No
Industry-year FE	No	Yes	No	Yes
Country-year FE	Yes	Yes	Yes	Yes
Observations	15011	15008	15148	15145
R^2	0.335	0.358	0.335	0.358

reducing countries' effective carbon prices by this threshold level, which yields:

$$\begin{aligned} \textit{Green bonds}_{i,t} &= \beta_0 + \eta_1 \textit{Incentives}_{j(i),t-1} \\ &+ \eta_2 \left(\textit{Carbon price}_{c(i),t-1} - \overline{\textit{Carbon price}} \right) \times \textit{Incentives}_{j(i),t-1} \\ &+ \beta_3 \textit{Controls}_{i,t-1} + \textit{Fixed effects} + \epsilon_{i,t}, \end{aligned} \tag{C.1}$$

where $\eta_1 \equiv \beta_1 \times \overline{\textit{Carbon price}} + \beta_2$ becomes the coefficient of the total contribution of managerial incentives.

This total effect is not statistically different from zero at the average level $\overline{\textit{Carbon price}} =$ \$32.

Take, for example, the average effective carbon price in the EU, accounting for about 50% of the global volume of green bonds: $\overline{\textit{Carbon price}} = \$81.75$. Table IV shows our regression results with this threshold. The coefficient of the total contribution of managerial incentives is statistically different from zero at the 5% and 10% level when *Incentives=Turnover* and *Incentives=WPS* respectively.

Table V presents various regressions that extend those of Section IV. It examines the firm-level variation in share turnover by using $\textit{Turnover}_{i,t}$ rather than the industry-level aggregate $\textit{Turnover}_{j(i),t}$ used in Section IV. Moreover, it includes firms' *Foreign sales*, *Foreign assets*, and *Foreign income*, on top of firm fixed effects, to deal with the case of multinationals.

D. Empirical analysis of green bonds' effectiveness and of stock market announcement reactions

Our theory mainly deals with the factors explaining corporate green bond issuance. It mainly focuses on the role both of managerial incentives and of carbon penalties, which we examine empirically in Section IV.

In this appendix, we empirically examine two other aspects of our theory. The first one is green bonds' effectiveness at inducing decarbonization. The second one is green bond announcement stock returns.

D.A. Stock price reaction to green bonds

Positive stock price reactions to events like green bond announcements reflect that these events reveal information about firms' future profitability that investors could not anticipate. In practice, these reactions are measured by abnormal stock returns around green bond announcements that are left unexplained by other factors.

Table IV: Green bond issuance, managerial incentives, and carbon price: total impact of managerial incentives at the average EU carbon price average

This table presents estimates from panel regressions of the proportion of green bonds issued by firms on their countries' effective carbon prices reduced by the average EU carbon price and proxies of managers' stock-price sensitivity in their industries. We control for firm size, book-to-market ratio, and environmental score. Standard errors are clustered at the country level. *, **, and *** denote significance at the 10%, 5%, and 1%, respectively.

	Green bonds			
	(1)	(2)	(3)	(4)
Incentives (WPS)	0.908*			
	(0.454)			
$\overline{\textit{Carbon price}}$ × *Incentives (WPS)*	0.017***	0.024*		
	(0.006)	(0.014)		
Incentives (Turnover)			0.340**	
			(0.144)	
$\overline{\textit{Carbon price}}$ × *Incentives (Turnover)*			0.006**	0.005***
			(0.002)	(0.002)
Controls	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Industry FE	Yes	No	Yes	No
Industry-year FE	No	Yes	No	Yes
Country-year FE	Yes	Yes	Yes	Yes
Observations	15011	15008	15148	15145
R^2	0.335	0.358	0.335	0.358

Table V: Green bonds issuance, managerial incentives, and carbon price: robustness

This table presents estimates from panel regressions of the proportion of green bonds issued by firms on their countries' effective carbon prices and their share turnover. We control for firm size, book-to-market ratio, environmental score, and measures of firms' foreign activities. Standard errors are clustered at the country level. *, **, and *** denote significance at the 10%, 5%, and 1%, respectively.

	Green bonds			
	(1)	(2)	(3)	(4)
Carbon price × *(Firm-level) Turnover*	1.463**	1.588**	0.403*	0.441*
	(0.637)	(0.682)	(0.235)	(0.240)
Foreign sales		0.250		
		(0.230)		
Foreign assets			229.362*	
			(121.177)	
Foreign income				2.191
				(2.510)
Controls	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Industry-year FE	Yes	Yes	Yes	Yes
Country-year FE	Yes	Yes	Yes	Yes
Observations	15145	14008	11912	11260
R^2	0.358	0.359	0.428	0.429

We first express our model's stock market reaction in terms of stock returns, and examine this theoretical prediction. Then, we run an event-study estimation of abnormal stock returns.

D.A.1. Stock market returns at green bond issuance

In our model, firms' date-0 stock returns are:

$$\mathcal{A}_k \equiv \frac{\mathcal{S}_k - \mathcal{S}}{\mathcal{S}}, \ k = G, B, \tag{D.1}$$

depending on whether they choose a green or a regular technology.

An immediate consequence of (8) is that the stock price of firms issuing green bonds increases at a rate:

$$\mathcal{A}_G^e = (1 - i^e)\frac{\Delta \mathcal{S}^e}{\mathcal{S}} > 0, \tag{D.2}$$

which is the theoretical counterpart of abnormal stock returns at issuance.

It follows that, in our model, positive stock returns at the issuance of green bonds $\mathcal{A}_G$ only differ across firms issuing green bonds because the ex ante stock price $\mathcal{S}$ increases with Π, the firm-specific profit expected from regular activities, diluting stock returns induced by certified projects.[22] In other words, our model predicts that green bond announcement stock returns are higher as green bond volumes are larger with respect to firms' capitalization, which we now attempt to verify empirically.

D.A.2. Event-study estimation of abnormal stock returns at green bond announcement

Various empirical studies examine abnormal stock returns at green bond issuance. For example, Tang and Zhang (2020), Baulkaran (2019), and Flammer (2021) find significant announcement returns.

We first replicate their results on our sample by estimating cumulative abnormal returns from an event-study analysis based on Fama and French (2012), as we describe more precisely shortly below. We then examine how abnormal announcement returns differ when they are estimated over certified green bonds of different sizes.

Data.—We extend the panel data sample that we describe in Section IV to non-certified green bonds. Moreover, we include daily stock prices to firms' characteristics, from which

22. We omit the cost of certification, expertise, and monitoring, because it is probably negligible for the large firms that currently issue green bonds. Admittedly, these costs may limit the supply of green bonds by smaller firms.

we derive stock market daily returns that we will denote by R. Our event study will also use market factors data from Kenneth French.[23]

Event study analysis.—Our event window is [-5;+5] with respect to the announcement date 0. For each company, we estimate the global three-factor model (Fama and French [2012]) to compute abnormal returns using an estimation window of 250 days. We have a gap of 50 days between the end of the estimation window and the beginning of the event window, so that the estimation window can be represented by [-305;-55].

We estimate the following model:

$$R_{i,t} = \beta_{0,i} + \beta_{1,i} R_{m,t} + \beta_{2,i} R_{s,t} + \beta_{3,i} R_{v,t} + \epsilon_{i,t}, \tag{D.3}$$

where $R_{i,t}$ is the daily stock market return of firm i at time t and $R_{m,t}$, $R_{s,t}$, and $R_{v,t}$ are the global market factor, size factor, and value factor respectively. We then obtain the abnormal return as the difference between the observed daily stock return of firm i and the estimated return:

$$AR_{i,t} = R_{i,t} - \hat{R}_{i,t}, \tag{D.4}$$

where

$$\hat{R}_{i,t} = \hat{\beta}_{0,i} + \hat{\beta}_{1,i} R_{m,t} + \hat{\beta}_{2,i} R_{s,t} + \hat{\beta}_{3,i} R_{v,t}, \tag{D.5}$$

with the coefficients estimated from equation (D.3). Finally, the abnormal returns are summed over the event window [-5;+5] to obtain cumulative abnormal returns. This is, for example, the method by which we estimate the stock returns that Unilever's 2014 green bond generated in our introductory example.

We now estimate similar abnormal returns for various categories of green bonds and of corporate issuers, in the same manner as, for example, Tang and Zhang (2020) and Flammer (2021). The "financial" group denotes companies with one of the following Bloomberg industry code: bank, financial, REIT (real estate investment trust), or insurance. The "first issue" group refers to the first green bonds issued by firms. The "large" category refers to certified green bonds of a $ amount standardized by their issuers' market capitalization that is above the median. Table VI shows our results.[24]

On average, firms' valuation increases by approximately 0.68% around the announcement of green bond issuances. The effect is statistically significant at the 1% confidence level. It is further concentrated among firms' first, large, and certified green bonds. For example, the

23. See `https://mba.tuck.dartmouth.edu/pages/faculty/ken.french/data_library.html`.

24. The results presented in Table VI are robust to an alternative event window specification (e.g., [-10;+10]).

Table VI: Event Study: Stock Market Reaction to Green Bond Announcements

This table presents results from event studies around the date of green bonds' announcement.

	CAR	N
All (corporates)	0.68%***	432
	(0.23)	
Financials	0.65%*	194
	(0.35)	
Non-financials	0.68%**	238
	(0.31)	
First issues	0.75%**	215
	(0.32)	
Secondary issues	0.25%	217
	(0.33)	
Certified	0.75%***	282
	(0.23)	
Non-certified	0.46%	150
	(0.43)	
Large certified	0.75%**	141
	(0.37)	
Small certified	0.29%	141
	(0.53)	

effect of certified green bonds is stronger in economic and statistical significance, generating stock returns of approximately 0.75% around announcements. Our results are similar both for firms' first issues and for their large certified green bonds. The effect of large certified green bonds is in line with our model's implication (D.2) of announcement stock returns, suggesting that, in practice, such reactions have to do with the size of financed projects.

D.B. CO2 emissions following green bond issuance, and green bond public policies

We now attempt to examine the relation between green bond issuance and subsequent CO2 emissions. For this, we exploit the implementation of public policy supports to green bonds in some countries.

In a recent yet influential paper, Flammer (2021) uses a matching method to show that firms issuing certified green bonds reduce their CO2 emissions by 13% over the course of the next two years. Although Flammer's result rules out the greenwashing hypothesis, more research is needed to interpret it as a causal effect of green bond issuance.

To reinforce Flammer's result, the following analysis relies on the implementation of green bond policies in China, Hong-Kong, Japan, Malaysia, and Singapore. These policies amount to a public support to green bond issuance, irrespective of firms' current and future CO2 emissions or of other measures of firms' environmental performance. Firm-level data for companies in these countries are limited so we would not be able to systematically control for firms' characteristics that might affect green bond issuance. We, therefore, use a country-level aggregated version of the sample presented in Section IV.

Data.—There are two basic differences between the firm-level sample presented in Section IV and the sample that we use here. First, we construct the latter by aggregating volumes of green bonds at the country level, which we divide by firms' bond net issuance in each country. Second, for each country and year, we indicate whether public policies supporting the use of green bonds are implemented. In recent years, China, Hong-Kong, Japan, Malaysia, and Singapore have implemented programs to support the issuance of green bonds, helping issuers face various difficulties related to the certification process, disclosure requirements, and monitoring of the financed projects—see the Climate Bonds Initiative's (2018) report. In the baseline model of Section III, the additional benefit from green projects and certified bonds may be interpreted as net of issuance, certification and monitoring costs, that are alleviated by green bond supporting policies. These policies all amount to a form of green bond subsidy. There is no available information on the intensity of these policies. Therefore, we include a dummy variable, which we call "*Policy*," taking value one if and when a country has a green bond policy: i.e., for China post-2016, Malaysia and Singapore post-2017, and Hong Kong and Japan post-2018. This variable will be used as an instrument.

Instrumental variable analysis.—In a first stage, we examine the relation green bonds and green bond policy supports. Formally, we estimate the following model:

$$\textit{Green bonds}_{c,t} = \beta_0 + \beta_1 \textit{Policy}_{c,t-1} + \beta_2 \textit{Controls}_{c,t-1} + \textit{Fixed effects} + \epsilon_{c,t}. \tag{D.6}$$

In this model, the index c refers to countries. The dependent variable is the proportion of green bonds issued in year t by firms based in country c. The independent variable of interest is the *Policy* variable evaluated in country c and year $t-1$. Moreover, controls consist of Gross Domestic Product (GDP), GDP per capita, total volume of bonds, and the effective carbon price in country c and year $t-1$.

We estimate all coefficients by the method of least squares with standard errors clustered at the country level. The results are presented in column (1) of Table VII. They show that the estimated coefficient β_1 is positive and significantly different from zero at the 5% level. The implementation of green bond policy supports was associated with an increase in green bonds in the next year.

Moreover, we reject the null hypothesis of weak instrument. The first-stage F-statistic is 123.01, significantly higher than Stock and Yogo's (2005) critical value of 16.38 for a 10% maximal bias of the instrumental variable estimator relative to the bias of ordinary least squares.

We now take a two-stage-least-squares estimation approach to show how the instrumented values of *Green bonds* for country c and year t, denoted by $\widehat{\textit{Green bonds}}$, are linked to CO2 emissions. The model that we now estimate is:

$$\textit{CO2}_{c,t+1} = \beta_0 + \beta_1 \widehat{\textit{Green bonds}}_{c,t} + \beta_2 \textit{Controls}_{c,t} + \textit{Fixed effects} + \epsilon_{c,t}. \tag{D.7}$$

Our dependent variable is total CO2 emissions of all firms in country c in year t. Besides the main independent variable of interest $\widehat{\textit{Green bonds}}$ for country c and year $t-1$, we include GDP, GDP per capita, total debt, and the effective carbon price as controls, as well as year fixed effects, like in the first stage. We cluster standard errors at the country level.

The results are presented in columns (2) and (3) of Table VII, showing that the coefficient of the predicted proportion of green bonds is negative and significantly different from zero at the 5% level. Obtained estimates suggest that, on average, firms reduce their CO2 emissions by approximately 15% following an increase in green bonds issuance by 1 percentage point.

Table VII: Green bond policy and country-level CO2 emissions

This table presents estimates from panel regressions of countries' CO2 emissions on the proportion of green bonds issued by countries, instrumented by whether policies supporting green bonds have been implemented. We control for GDP, GDP per capita, the total volume of bonds issued by each country in each year, as well as the carbon price. Standard errors are clustered by country. *, **, and *** denote significance at the 10%, 5%, and 1%, respectively.

	1st stage *Green bonds*	2nd stage *CO2*	
	(1)	(2)	(3)
Policy (1 year), instrument	0.120**		
	(0.049)		
Instrumented *Green bonds*, (1 year)		-0.606**	-0.623**
		(0.272)	(0.260)
Controls	Yes	Yes	Yes
Year FE	Yes	No	Yes
Observations	211	211	211
R^2		0.703	0.701

Contact.

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MIT Center for Energy and
Environmental Policy Research

MIT Center for Energy and
Environmental Policy Research
Massachusetts Institute of Technology
77 Massachusetts Avenue, E19-411
Cambridge, MA 02139-4307
USA

ceepr.mit.edu

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