Credit and climate sentiments: the decarbonization frontier of risk pricing

Régis Gourdel

Vienna University of Economics and Business

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Abstract

The role of banks in supporting the low-carbon transition has proved controversial as they seem to price climate transition risk but also maintain investments in polluting industries. To investigate the reasons and implications of this situation, this paper provides first a theoretical benchmark for the carbon premium, based on a formalization of the concept of climate sentiments, the policy-dependent present value of firms' capital, and the Merton model. I find that the current empirical evidence for carbon premia matches a reasonable calibration of investment dynamics in productive capital, with a limited space for higher premia even when banks strongly expect future climate-mitigation policies. Second, I consider discrepancies in climate sentiments between lenders and borrowers, to determine when banks could push reticent borrowers to green their operations, or prevent them from doing so. I find that variations in the cost of debt due to the carbon premium are generally a second-order factor, and not enough of a decarbonization incentive alone. Macro-prudential measures that complement climate risk pricing and policies that limit the volume of high-carbon loans would then be necessary to decarbonize the economy further through the financial system.

Keywords: credit markets; low-carbon transition; climate sentiments; climate scenarios.
JEL: D21, D25, D84, G21, Q58.

1 Introduction

The contribution of the financial system to climate targets is constantly questioned due to the inertia it exhibits in financing industries that have brought about the climate crisis. Meanwhile, financing conditions should be such that high-carbon industries should not be given the financial means to develop in their traditional form. I approach this issue by providing a framework that justifies and operationalizes the concept of *climate sentiments* previously used in the literature. While the mechanism often lacks a complete financial rationale, I show that it can be derived from a setting where banks and real economy firms act in a profit-driven manner and react to given policy signals.

The consideration of country-specific propensities for decarbonization already creates a discrepancy between a risk-based approach and one based on decarbonization scenarios alignment (Gourdel, 2023), i.e. transition risk emerges where the regulators are willing to commit to climate targets, and firms being emission-intensive is not a sufficient condition. However, even where the policy conditions seem favourable, it is unclear whether a risk-based approach could steer the financial system to a sufficient extent. In line with this, the European Banking Authority argued that the prudential framework should not be stretched for other policy purposes, where other policy instruments have a role to play (EBA, 2022). It further argues that undesirable consequences may follow from a dedicated prudential treatment of environmental risk that aims to redirect lending.

The observation of carbon premia in several segments of the financial system (see Figure 1) has given rise to rather optimistic messages with regard to the role of finance. Their authors often describe results with regard to carbon premia as "economically significant". This can be understood as generating non-negligible added profits for the banks that apply such premia, which brings benefits in terms of financial stability, i.e. financial institutions appear to be pricing climate risk. However, it does not mean that the micro-level incentive for firms to decarbonize is itself significant, which is first needed to green the economy.

Thus, loan pricing practices would effectively constitute a form of *financial green paradox*. The traditional green paradox concept is that, under the threat of forthcoming environmental regulations, one possible response by high-carbon industries is to maximize the extraction of resources and profits in the short term in view of the longer-term stranding of assets. For instance, Barnett (2019) finds that the uncertain prospect of climate policies precipitates oil extraction and causes a decrease in the market value of extractive companies. In so far as banks increase the profits made in these industries by increasing the interest rates applied, without significantly reducing the nominal amount of loans and other forms of financing allocated to them, they allow it to continue while increasing their share of profit from these industries. However, this shift in the allocation of profit is not in itself enough to push the economy in a greener direction.

I develop a model where banks and non-financial firms have a climate policy anticipation in the form of a distribution of carbon prices at future points in time. This is defined as *climate sentiment*, and it encompasses most previous uses of the term in the literature. I show that, when these expectations are used to compute the value of companies' assets, the choice of investment by firms between green and brown capital becomes dependent on it. Moreover, when

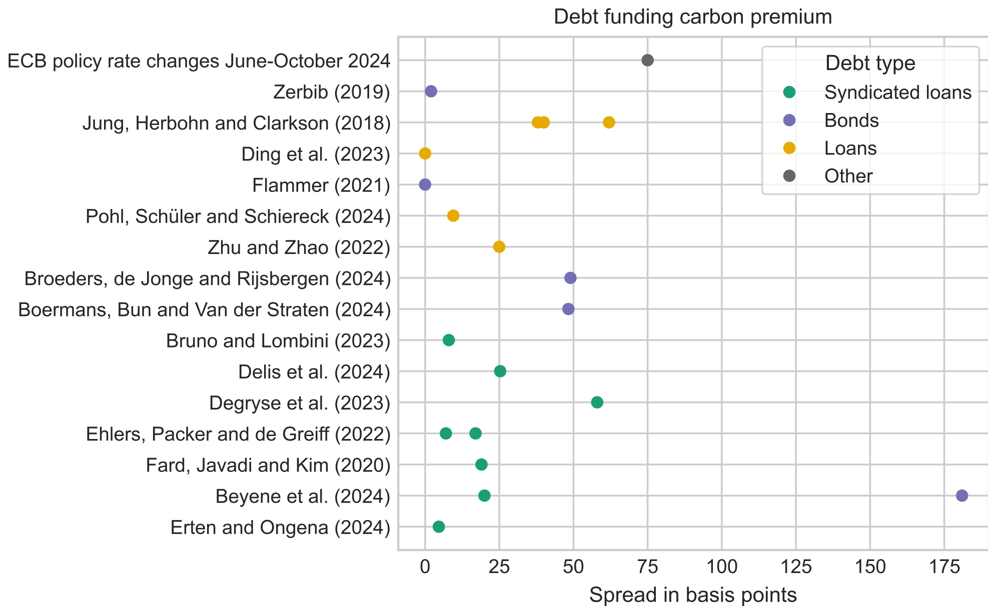

Figure 1: Carbon premium observed on different categories of debt in the literature. The numbers presented describe somewhat different concepts, on top of sample and methodological differences, so that differences between them are expected. For instance, the outlying value on bonds from Beyene et al. (2024) comes from considering fossil fuel firms specifically, compared to the rest. Details on the construction of this figure are provided in appendix A.4. The first point with monetary policy changes is given to provide a reference for the magnitude of changes that can be expected from external factors. Sources: papers cited in the figure and ECB website.

a bank creates a loan to realize that investment, the interest rate that it charges would also be dependent on its own climate sentiment. Thus, the model encompasses micro-level dynamics involving lenders and borrowers that are key to assessing the efficiency of sustainable finance.

The first question that I tackle is that of the motivation of banks to support the climate transition. That is, based on a profit-maximization framework, I define a plausible way for banks to act based on climate sentiments. I find that a reasonable calibration allows me to derive values of the carbon premium that are in line with those provided by the empirical literature (based on the range in Figure 1). Thus, while this does not allow for a definitive conclusion, it suggests that markets already price reasonably well climate risk. However, this is subject to the "tragedy of the horizon" (Carney, 2015), i.e. debt maturities are short relative to even midterm transition plans, so that risk-based pricing remains modest relative to a longer-term view of economic changes.

A sudden change in policy direction can have a more significant impact on the perception that banks have, in line with the literature on the financial effect of the Paris Agreement. However, such occurrences are relatively rare, and if banks were to suddenly change the interest rate they charge to their least climate-friendly borrowers, this would have financial stability downsides that are not desirable.

Second, I investigate the interplay of climate sentiments with credit risk consideration in order to quantify the potential effect of banks in steering the economy toward decarbonization. Thus, while in general, the financial sector should not conflate climate risk mitigation with climate action (Gourdel, 2023; Sachs et al., 2023), I seek to understand how much help the former could possibly be for the latter. I find that the effect of climate sentiments reflected as a carbon premium is generally little when seeking to influence firms that invest in new productive capital. That is, in the best-case scenario of banks with confidence in climate policies, or banks that are forced by regulation and supervision to price climate risk, they can influence firms into choosing greener forms of capital,[1] but this influence is quantitatively marginal. Therefore, the risk channel of finance does not substitute for the climate sentiments of non-financial corporations themselves when they invest, which remains the determinant of their investment when the greening of their activity is an option.

The rest of this paper is organized as follows: section 2 provides a review of the related literature; section 3 introduces the set of policy paths and the formalization of climate sentiments; section 4 exposes the model for firm valuation and lending; section 5 presents the simulation findings, and 6 concludes.

2 Literature review

The investment in carbon-intensive activities is the object of a heated debate, with policy recommendations varying in part due to the absence of consensus on the current state. Some strike a rather positive note, noting that climate policies lead to *some* reduction in fossil fuel companies. However, both developed and emerging economies still invest massively in new fossil fuel extraction projects (SEI, 2023), which runs counter to the recommendation that none should be developed in order to reach climate targets (IEA, 2021; Teske et al., 2022). Their investment is also excessive in the livestock industry (Mikhail et al., 2024). Such failures interrogate not only the ambition and transmission of climate policies but also the role of the financial sector as an enabler.

2.1 Financing importance and policy risk

To better understand how the financial system could transition, we should first recall what financial flows are currently creating a drag on climate targets. Giuzio and Lenoci (2023) shows that bank loans tend to be a better form of financing, as they offer lower rates than the bond market, but that large and well-rated firms may crowd out the loan market. This suggests that the extensive dimension of bank lending is limited and dependent on firms' financial health. In general, despite the rise of non-bank financial intermediaries (Crouzet, 2021), bank lending has a major role in the financing of the economy, and its accessibility to greener firms is important to lower the threshold of green investments.

The negative implications for climate can be found in Beyene et al. (2024), showing the banks price climate risk less than bond markets, hence its importance in maintaining afloat the fossil fuel industry. This is also consistent with the findings from De Haas and Popov (2023) that market-based economies (as opposed to bank-centered ones) are more efficient at driving

[1] Conversely, a bank with little confidence in the implementation of climate policies can create a disincentive for firms to transition.

the low-carbon transition. T. De Angelis et al. (2023) model these market dynamics, showing that green investors can wield some influence, contingent on policy certainty. However, such work in the case of bank-financed economies is still missing.

We focus in this paper on the so-called "risk channel", which is that banks are expected to adapt their lending practices because high-carbon firms would become less profitable and more risky as gradually more stringent climate-transition policies are implemented. Empirically, Liu et al. (2024) show that the implementation of climate transition policies can lead to an increased default risk of high-carbon companies through debt and profitability channels. This may elicit changes in lending policies along two dimensions: the extensive (volume of credit granted) and intensive (interest rates) ones.

2.2 The continued financing of high-carbon projects

So far though, in spite of much public engagement, the shift in financing by banks toward greener firms and projects seems to have been limited. For instance, Mésonnier (2019) shows that, in the case of France, banks' commitments to decarbonization translate into less lending to large corporate firms, but that no effect was observed for small- and medium-size enterprises (SME). The author explains it by the lack of carbon emission reporting requirements for the latter category. Worse, Sastry et al. (2024) find that initiatives such as the Net Zero Banking Alliance have failed to lead to divestment or borrower engagement by the banks.

Also on the volume of credit granted, Kacperczyk and Peydró (2021) study how firm-level carbon emissions affect bank lending. They infer banks' green preferences from their carbon neutrality commitments and find that banks affect carbon emissions through their lending to green firms rather than by supporting brown firms in their decarbonization. This suggests that firms that change their investment because of banks are likely to be a minor group. Similarly, Reghezza et al. (2022) finds that following the Paris Agreement, euro-area banks reallocated credit away from polluting firms in relative terms. Specifically, their loan share to more polluting firms decreased by about 3% compared to less polluting firms. Furthermore, Benincasa et al. (2022) documents how banks shift their lending to other countries as a reaction to domestic climate policies.

Overall, the volume of credit going to brown companies remains at a high level in absolute terms, including the so-called "carbon bombs" (Kühne et al., 2022). Thus, Passaro et al. (2024) find that "the average implied temperature rise of banks' (non-SME) corporate loan portfolios ranges between 3.7°C and 4.1°C" from a sample of selected European banks.

Because lending information is generally data that is confidential and accessible by regulators only, there is little accountability of banks with regard to their loan portfolio. Thus, Giannetti et al. (2023) documents the greenwashing of banks in their lending activity, which is more consistent with the logic of the green paradox, i.e. extracting revenues from brown assets now before they get stranded (Sinn et al., 2008). This means that changes in lending are likely to be driven by genuine policy anticipation held by the banks, and not by marketing incentives. Indeed, the banks are already marketing themselves as green without the need to act accordingly, and there is no short-term prospect of increased transparency and disclosure with regard to their loan portfolio. Therefore, additional marketing benefits to reap from climate action are likely too marginal to be a major driver of their strategy.

Understanding the motives of banks is important in so far as their behavior has an effect on decarbonization. Green and Vallee (2022) found that bans on coal investments were functioning in so far as coal companies had limited financing replacement and the increased cost of operations that ensued could push them to retire from some of their operations. While coal is generally considered a "sunset" industry, i.e. the technology lost its competitive edge, the case of other fossil fuels is less clear yet, and banks would not strongly commit to divesting from oil yet. Thus, since divestment has a role to play, it is important to understand under which conditions banks could be pushed into divesting from these other polluting industries.

2.3 Carbon premium and lending reaction to climate policies

On the intensive margin, several studies document the existence of a carbon premium for syndicated loans (Fard et al., 2020), especially after the Paris Agreement (Ehlers et al., 2022; Degryse et al., 2023; Bruno and Lombini, 2023). Moreover, banks seem to react to climate policies and the perceived greenness of firms and provide easier financing to the low-carbon ones. Still, Rickman et al. (2024) find that phasing out fossil fuel from syndicated loans would require tailored capital requirements that cross a certain threshold for banks to act.[2] Carbone et al. (2021) find that higher emissions seem to harm creditworthiness, both from the ratings of firms provided by agencies and from their market-implied distance-to-default.

Typically, one would hope that the carbon premium, presented across more markets in Figure 1, reflects the pricing of transition risk. Ideally, sufficient pricing would guarantee that banks are not significantly stressed when more climate mitigation policies materialize, and they could continue to finance greener firms that require it.

The present paper provides a theoretical framework for climate risk pricing. This is still rare in the existing literature, with one example being Le Guenedal and Tankov (2022), which tackles bond pricing, with more focus on its time dynamics as new information is integrated, and less on the associated investment choices.

One mechanism that would add to this in the case of bonds is that traded securities issued by brown firms lose market depth as an increasing number of investors commit to decarbonizing their portfolios. In a setting such as that of Pástor et al. (2021), a possible snowballing effect exists, whereby some investors not investing in brown firms will make these firms lose value and decrease the liquidity of their assets. In the case of bank loans, securitization may become more difficult for the same reasons, and it is also possible that a high carbon premium on bonds simply increases the price-setting capacity of banks, resulting in a premium for loans higher than by considering risks only.

2.4 Empirical grounding of climate sentiments

Most scenarios come without an attached probability, which is an exercise more political and difficult in that it relies on assessing the likelihood of societal evolutions along many dimensions. This leaves financial analysts to make assessments of their own to inform market participants (e.g. Berardi and Usardi, 2024).

Empirically, in Bessec and Fouquau (2022), an analysis of textual media concludes in an

[2]The role of equity is more controversial, as Hambel and Sanden (2024) finds that the carbon premium can be negative under certain measurement specifications.

impact of environmental variables, which can be associated with a climate sentiment. Using surveys, Ceccarelli and Ramelli (2024) document a strong heterogeneity in the climate transition beliefs of a sample of over a thousand U.S. retail investors. Moreover, investors with more optimistic climate transition beliefs tend to expect higher green financial performance. Although the source of funding considered is different, the model developed below would provide a rationale for the latter findings.

When it comes to banks, the importance of climate sentiments has been documented at a granular level by Bu et al. (2024). The authors show that bankers and bank managers who are more sceptical of climate change were more hostile toward green firms, and would be more likely to downgrade them. This approach is precisely something we aim to model, by showing in theory the importance of climate sentiment on the side of banks for the credit market to play a role in decarbonizing the economy. Erten and Ongena (2023) show that the sensitivity of the carbon premium in syndicated loans in the U.S. is higher in states with a lesser degree of climate denial. This can be interpreted as a manifestation of climate sentiment, where the climate sentiment as an expectation of future climate policies is seen as dependent on the current local support for such policies.

2.5 Effect of climate sentiments

At the macro level, Gourdel et al. (2022) conducted an exercise using the EIRIN model showing that, in a scenario compatible with net-zero targets, when firms anticipate the carbon tax early the economy decarbonizes faster. That is to say, a stronger belief of entrepreneurs in future carbon tax hikes can steer them to invest in greening their production. Thus, climate sentiments are simplified there as a foresight of future policies. Dunz et al. (2021) consider similarly climate sentiments as an anticipation of future fiscal and macro-prudential policies, but from the point of view of the bank.

Also relying on the EIRIN model, Monasterolo, Mazzocchetti, et al. (2022) demonstrates the effect of climate sentiment on the financial side. They find that, when banks take into account the current GHG emissions or the carbon intensity of new investments, changes in credit allocation can ease decarbonization at the national level. In particular, the coefficients used to define the targets and magnitude are what constitute the climate sentiment in Monasterolo, Mazzocchetti, et al. (2022). However, this approach is not strictly anchored to a profit-maximizing behavior of the bank, and it could also reflect the non-pecuniary incentives of the banker.

When incorporating expectations beliefs over transition policies (similar to what I define below as climate sentiment) of investors in a general equilibrium model, Fried et al. (2022) obtain results counter to the green paradox hypothesis, i.e. investment does become cleaner. This seems to be confirmed by recent empirical evidence pointing to a reduction in the investment in oil and gas companies (Bogmans et al., 2023). However, this strand of work based on a neoclassical approach does not consider the potential endogeneity of investment choices and policy implementation.

Remediating this shortcoming, Campiglio et al. (2024) develop a model where entrepreneurs have beliefs with regard to future climate policies, and the policymakers react to the behaviour of firms. In their model, different equilibria coexist, including low-achieving ones where the policymaker has low credibility, firms do not transition, and the ambition of policies is subsequently reduced because of fears related to the transition risk exposure. This work also considers a choice between two technologies (green and brown productive capital) but does not address the financing dimension.

In particular, we notice that climate sentiments have been approached from different angles, with either entrepreneurs or financial institutions endowed with them. Yet, no framework has considered the joint integration of both yet, and in particular the consequences that may arise from the discrepancies between the climate sentiments of borrowers and lenders. This is what is done in this paper, notably considering firms that have some agency over the type of technology that they use, and thus on their eventual environmental impacts. Therefore, the model considered here is complementary to studies where "green" and "dirty" firms are fixed and only the allocation by markets change between them (e.g. Khalil and Strobel, 2023).

3 Carbon price paths and sentiments

The range of carbon paths considered is a set $(\Phi_u)_{u\in\mathbb{U}}$ of increasing functions from $\mathbb{N}$ (taking time as discrete with yearly accounting[3]) to $\mathbb{R}$, and indexed by a set $\mathbb{U}$. Note that this framework remains general and allows for the consideration of a finite number of paths as well as a continuous multidimensional indexation. While the former is restrictive, few papers have offered a framework to deal with a large or infinite number of possible paths (e.g. Desnos et al., 2023).

I base the carbon prices used in the paper on the actual trajectories considered by the Network for Greening the Financial System (NGFS), as depicted in Figure 2 for the region of the OECD and EU. The scenario Net Zero 2050 is the most ambitious of all those considered, and we will consider it as an upper bound for potential carbon price trajectories in the simulations below. Formally, denote as $\Phi_{\mathrm{NZ}}(t)$ the path of carbon prices from this scenario, minus the starting point which I take as 2022 in that instance.[4]

I assume that the Net Zero 2050 prices remain constant after 2100. For tractability, I also assume that all carbon price paths stop evolving by time T in the model, which is taken after 2100 and sufficiently far not to be quantitatively significant. I base the rest of the paper on carbon price paths defined by $\mathbb{U}=\mathbb{R}$ and

$$\forall t \leq T, \forall u \in \mathbb{U}, \quad \Phi_u(t) = \Phi_{\mathrm{NZ}}(t) \times \frac{\exp(e^{u^-/4}(t/v-u)) - \exp(-e^{u^-/4}u)}{\exp(e^{u^-/4}(t/v-u))+1}, \tag{1}$$

where is a v a positive constant and u^- denotes the negative part of u. It is fit for the modelling of both slow carbon tax increase (for negative values of u) and sudden delayed transitions

[3] In particular, with a direct carbon tax policy, the carbon price would typically be set yearly. By contrast, with a cap-and-trade policy, it is endogenously determined from trade at a higher frequency. In the latter case, the model can be extended to use continuous-time processes. However, when taking a longer-term view as generally done with climate scenarios, one would generally assume that for any volume of emissions allowed by the cap-and-trade program in a period, equilibrium conditions would determine a unique carbon price.

[4] While the scenarios of the NGFS start in 2020, pushing the starting point does not create any comparability issue in so far as the scenarios other than Net Zero 2050 are not used in the following. Moreover, empirically, the actual development of carbon prices in the Emissions Trading Scheme (ETS) operated by the European Union follows reasonably well the interpolated path from the NGFS until 2022.

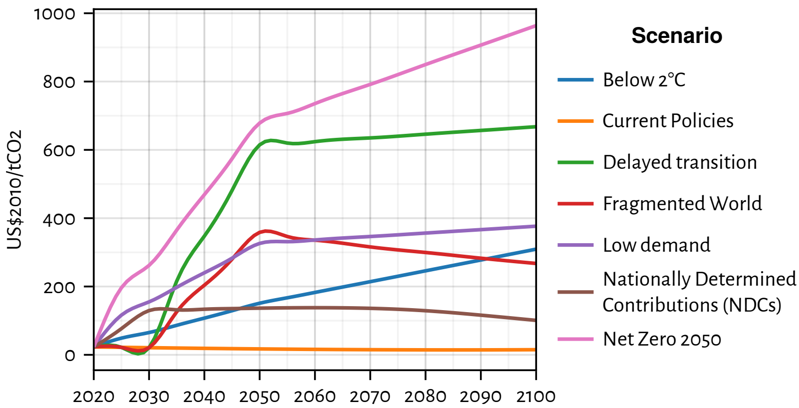

Figure 2: Interpolated carbon price trajectories from the Network for Greening the Financial System, for the region "OECD & EU (R5)". The original trajectories are produced by REMIND-MAgPIE 3.2-4.6 for the version 4.2 of the scenarios. The trajectories are interpolated to a yearly frequency.

(when $u \gg 0$), i.e. with an increase from 0 to Φ over a short period. The interpretation of v is that smaller values will lead to steeper increases in the carbon tax, and in particular the most ambitious policy available would reach Φ faster. Samples generated with this function are represented in Figure 3. The default setting used in the Figure and the rest of the paper is $v = 4$.

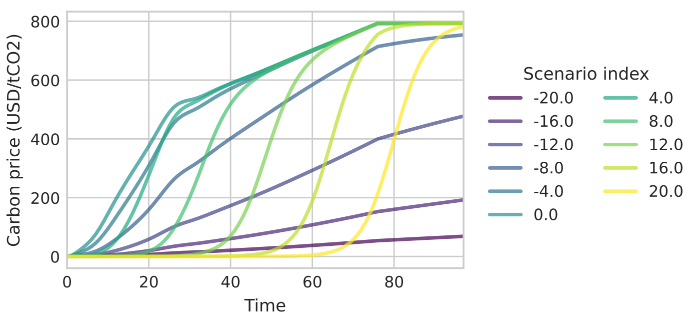

Figure 3: Sample of twelve paths from the family of carbon price policies defined by equation (1).

The range of possible carbon prices presented provides us with a tool to model the uncertainty of future policies. More specifically, we now seek to model the perception of agents about the policy paths, which have a one-to-one relationship with the index set $\mathbb{U}$. To do so, we formalize the concept of climate sentiment as follows.

Definition 1 *We call* climate sentiment *a probability distribution $\mathcal{D}$ over $\mathbb{U}$.*

This definition extends to the case where Φ_u is a random process instead of deterministic functions like the ones defined above. In that case, $\mathbb{U}$ shall denote the parameter space used in the definition of this random process.

4 Firm valuation model

I consider the case of firms seeking credit from the bank. Given an initial level of environmental restrictions and carbon tax, they all have the same profit p on each output unit, that is, the sale price minus costs for input material, energy, and salaries. The firms seek to expand by buying productive capital of type k, accounted such that one unit of capital costs P_k and leads to one unit of additional output.

We suppose that these firms interact with a single bank so that they seek to roll over their loans and contract new loans to make new investments.

Moreover, a capital of type k has a GHG-emission intensity denoted θ_k. Thus, given an additional carbon price of $\Phi(t)$ at t, an additional unit of output produced using k would cost $\theta_k \Phi(t)$ in carbon taxes. There is no abatement possible in the sense of decreasing the carbon intensity of all the firm's operations at a cost. Instead, reducing emissions at the firm level is done by shifting investments towards greener capital. That is, we assume that it is difficult to modify the functioning of capital already in operation, and, given the natural rate of depreciation, buying new greener capital is the preferred decarbonization option.

In the numerical applications below, we consider two technologies:

- *green capital* G, expensive with low GHG emissions: $P_G = 1,000$ and $\theta_G = 0.1$; and
- *brown capital* B, cheaper with higher GHG emissions: $P_B = 850$ and $\theta_B = 0.4$.

The reliance on two different types of capital differs from the more standard approach of abatement costs, but it provides a more explicit explanation as to how decarbonization takes place. Moreover, as buying capital generates sunk cost, this represents more realistic frictions in decarbonization, with changes in the supply chain and inter-temporal effects of decarbonization decisions, relative to the abatement level being set at wish in every period.

4.1 Capital value for given policy paths

We suppose that the assessment of investments' worth is done through the calculation of their present value (PV). The first step that we conduct now, in the case of a given policy, is similar to what is developed in Reinders et al. (2023). The time discount that I use is the cost of capital $\kappa \times (1 - \tau)$, where κ is the interest rate on the debt, and τ is the marginal corporate tax rate. This derives from the weighted average cost of capital (WACC) method, with the assumption of financing through debt only.

For this exercise, we assume that all types of capital available for investment have the same depreciation rate δ. This means that the quantity produced at time t is $q(t) = (1 - \delta)^t$. We assume that the investment is conducted at $t = 0$ and that the capital is immediately used for production. For simplicity, we denote

$$\rho = \frac{1 - \delta}{1 + \kappa(1 - \tau)} \tag{2}$$

such that $\rho < 1$, and it embeds both the capital depreciation and the time discount. We assume that τ is constant, and the granularity and dynamics of the interest rate will be discussed in the following sections. The baseline configuration used is $\delta = 0.04$ and $\tau = 21\%$.

I assume that everything is given in real terms, including the carbon price, so that the sale price from the production given the assets remains constant. The use of a constant value p also assumes that the inflation applies homogeneously to the output, the wages, the energy, and the other input material. In the numeric applications provided below, I set $p = 100$.

We further assume that the capital owned stops being used when the carbon taxes exceed the profits. That is, the capital gets *stranded* at the first time t such that $\theta_k \Phi(t) \geq p$.[5] Thus, the valuation of additional capital of type k is given by

$$\mathcal{V}(\Phi) = \sum_{t=0}^{\infty} \rho^i (p - \theta_k \Phi(t))^+, \tag{3}$$

where $(x)^+ = \max(x, 0)$ denotes the positive part of x. We only consider Φ as variable in this step to keep the notation simple, but the capital k and the interest rate κ are variables that $\mathcal{V}$ depend on and will be used explicitly later.

This specification does not explicitly allow for a pass-through of the carbon tax to clients. In so far as we examine the lending relationship between a bank and a borrower — with no consideration of further supply chain dynamics — most standard pass-through specifications would be mathematically equivalent to lowering the carbon price values or the firm's carbon intensity. Given the maximum Φ achieved, we get:

$$\mathcal{V}(\Phi) = \sum_{t=0}^{T-1} \rho^i (p - \theta_k \Phi(t))^+ + \frac{\rho^T}{1-\rho}(p - \theta_k \Phi(T))^+,$$

and in the case where the capital does not get stranded, the valuation simplifies into an expression linear in θ_k.

$$\mathcal{V}_{\mathrm{NS}}(\Phi) = \frac{p}{1-\rho} - \theta_k \left(\sum_{t=0}^{T-1} \rho^i \Phi(t) - \frac{\rho^T}{1-\rho} \Phi(T) \right) . \tag{4}$$

An example of brown capital valuation for different carbon price paths is given in Figure 4. We can see that the valuation can be very different depending on the carbon price path that is used for the calculations, which highlights the general sensitivity of the economy to climate policy uncertainty. For the most ambitious trajectories, this valuation even becomes negative, signalling that the investment would not be profitable because assets would become stranded before the capital pays for itself.

In the last panel of Figure 4, a dashed line shows the valuation of green capital for comparison. Given the calibration chosen, we can see that the present value of green capital is always positive, even with the most ambitious climate policies. Moreover, when the policy is ambitious enough, the present value of green capital becomes higher than that of the brown one, which is the policy space where buying green capital is more interesting. Note that the valuation adopts here a static view of the issue with no pass-through of the carbon taxes to consumers. In practice, the increase of the carbon price is likely to be transmitted as inflation

[5]This definition of stranded assets has the advantage of being explicit as to why these assets stop being used, in contrast for instance to works such as Grüning and Kantur (2023) where brown capital becomes under-utilized without any profit motivation.

such that p would increase in a way that mitigates the fall in profits, or even increases them for green capital.

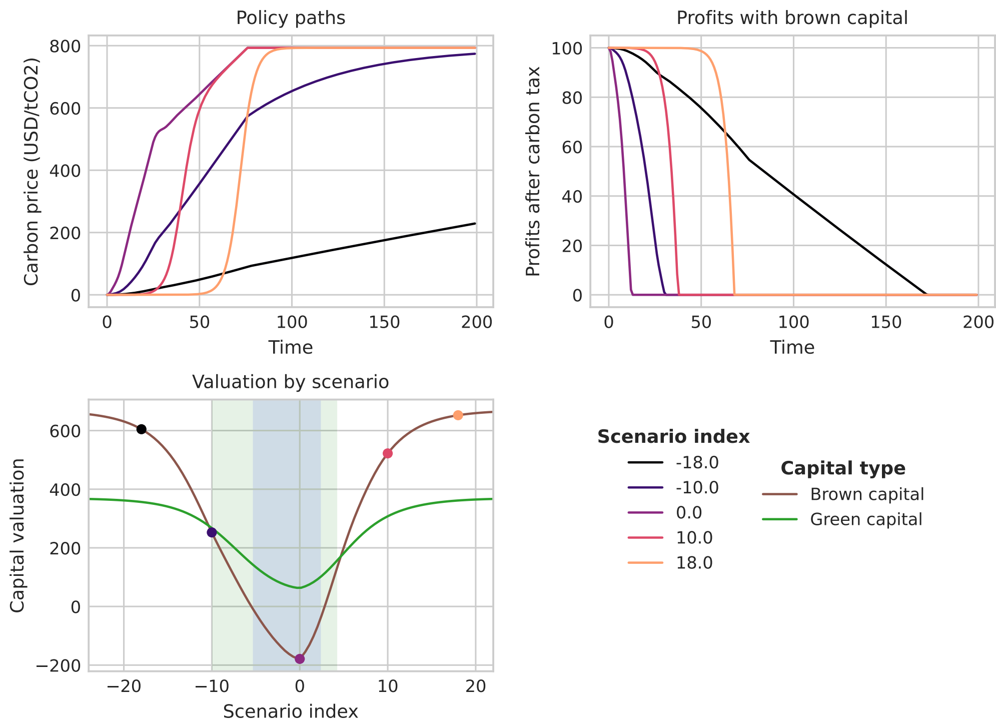

Figure 4: Calculation of capital valuation for different carbon price paths.
The panel on the left presents several carbon price trajectories belonging to the family defined in section 3. The central panel shows the corresponding profit paths for a unit of brown capital submitted to a carbon tax. In the panel on the right, the dots show the present valuation of brown capital under the different trajectories presented. The solid line presents the full view of capital valuation as a function of the carbon price path index. The dashed line fulfils the same function but for green capital.

4.2 Beliefs and expected NPV

In the equations above, because Φ is a random variable, the valuation of assets is also a random variable. Therefore, the final number considered as the present value of a firm's investments is the expected value given a distribution of beliefs on the carbon price paths.

Considering an agent involved (a firm or a bank) with a climate sentiment $\mathcal{D}$ that describes its belief with regard to the probability of different paths to materialize. In the application below I typically model $\mathcal{D}$ using Gaussian distributions over the path family defined in section 3. In Figure 5, the left-hand panel shows the probability density of two such distributions, and the central panel represents a sample of twenty carbon price paths for each of these two distributions.

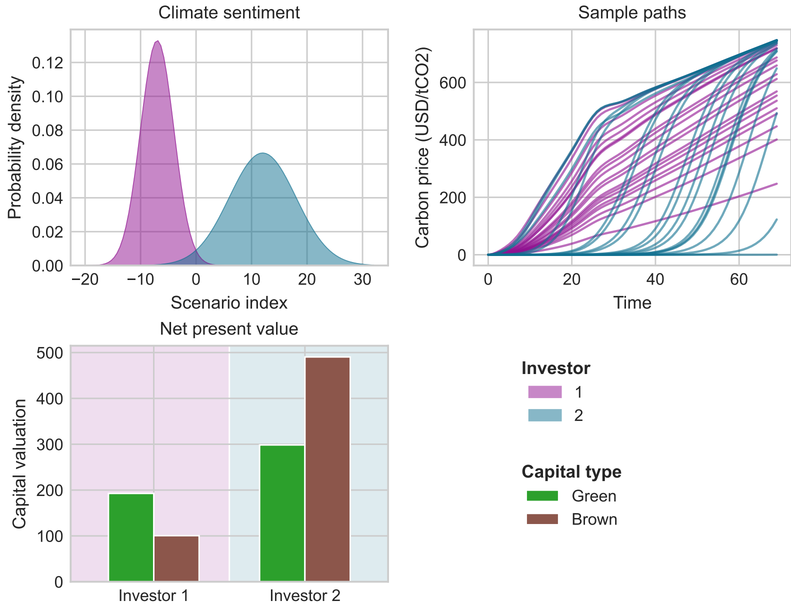

Figure 5: Examples of distributional beliefs about carbon price paths and the resulting net present value of capital. The belief distribution of each investor is a Gaussian, with its parameters indicated in the legend.

The final present value (PV) *per currency unit invested*, given this distribution, is then:

$$\begin{aligned} \mathrm{PV}(\mathcal{D}) &= \frac{1}{P_k}\mathbb{E}_{\mathcal{D}}[\mathcal{V}(k,\Phi)] \\ &= \frac{1}{P_k}\left(\sum_{t=0}^{T-1}\rho^i\mathbb{E}_{\mathcal{D}}\left[(p-\theta_k\Phi(t))^+\right] + \frac{\rho^T}{1-\rho}\mathbb{E}_{\mathcal{D}}\left[(p-\theta_k\Phi(T))^+\right]\right) . \end{aligned} \tag{5}$$

so that the *net* present value is provided by

$$\mathrm{NPV}(\mathcal{D}) = \mathrm{PV}(\mathcal{D}) - 1 . \tag{6}$$

In the right-hand panel of Figure 5, we can see how the beliefs translate into NPV for the two types of capital, green and brown. In this configuration, the first investor would prefer the green capital on the basis of its NPV, while the second investor would prefer the brown capital. NPV calculations are performed via numerical integration as they do not generally admit an analytical solution. This approach can also be adapted for the concept of climate value-at-risk (Battiston and Monasterolo, 2020).

4.3 Policy confidence

We further simplify this first setting by assuming that the most ambitious policy of the family (Φ_u) corresponds to the one that the policymaker should follow if it were to meet its climate mitigation target. The bank identifies this path as being the most plausible, but there is uncertainty around the policy: it could be applied more slowly or too late. We denote the index of this path as $\hat{u}$, which we formally define such that $\Phi_{\hat{u}}$ minimizes the valuation of all capital that does not get stranded, based on equation (4). Thus,

$$\hat{u} = \text{argmax}_{u \in \mathbb{U}} \left(\sum_{t=0}^{T-1} \rho^t \Phi_u(t) - \frac{\rho^T}{1-\rho} \Phi_u(T) \right) \simeq 0 \,. \tag{7}$$

We restrict the model to Gaussian mixture distributions of belief that admit $\hat{u}$ as a mean (and as a median). More precisely, we index belief distributions based on the degree of *policy confidence* that they exhibit, given by a parameter $x \in \mathbb{R}_+$, such that $\mathcal{D}_x$ is the distribution of a variable $Y = \frac{1}{2}Y_1 + \frac{1}{2}Y_2$ where

$$Y_1 \sim \mathcal{N}\left(\hat{u} - \frac{1}{x}, \frac{1}{\sqrt{x}}\right) \quad \text{and} \quad Y_2 \sim \mathcal{N}\left(\hat{u} + \frac{1}{x}, \frac{1}{\sqrt{x}}\right) \,. \tag{8}$$

The underlying distributions and effect of the policy confidence can be visualized in Figure 6. The NPV for both types of capital is a decreasing function of the policy confidence since they both have a positive carbon intensity. The higher carbon intensity of the brown capital translates into a steeper downward curve, such that the green capital becomes more profitable at higher levels of policy confidence.

4.4 Interest rates

The basic model used here is that banks set a firm-level interest rate, based on the probability of default, which is itself dependent on the assessed profitability of the firm. The loan pricing equation used is the same as Gross (2022), whereby the effective interest rate equates a loan's expected interest income, net of funding costs, and adds a profit margin μ. With the additional assumption of a uniform loss given default LGD, the interest rate for a firm i is given by:

$$\kappa_i = r + \mu + \frac{\text{LGD} \times \text{EDF}_i}{1 - \text{EDF}_i}, \tag{9}$$

where r is the risk-free rate, and EDF_i is the expected default frequency of i.

The uniformity of the LGD, which is the complement of the expected recovery rate, is equivalent to assuming that the illiquidity of the assets is already accounted for by how the companies' assets are priced in the first place. I assume that the loan is not collateralized, which is the case for most of them in the EU.[6] The EDF is derived from the probability of default to maturity PD, such that $\text{EDF}_i = \text{PD}_i/\mathcal{T}$ where $\mathcal{T}$ is the time to maturity of the loan. This means that default is equally probable in each period. A consequence is that the conditional probability of default is increasing, i.e. denoting as t_D the time of default we have

$$\forall t, \mathbb{P}\left(t_D \in [t, t+1] | t_D \geq t\right) = \frac{\text{EDF}_i}{1 - t \times \text{EDF}_i} \,.$$

This is consistent with the fact that later periods bear a higher uncertainty. The PD is calculated

[6]Based on data from the European Central Bank, between 17% and 18.5% of loans from EU banks to non-financial corporations had collateral.

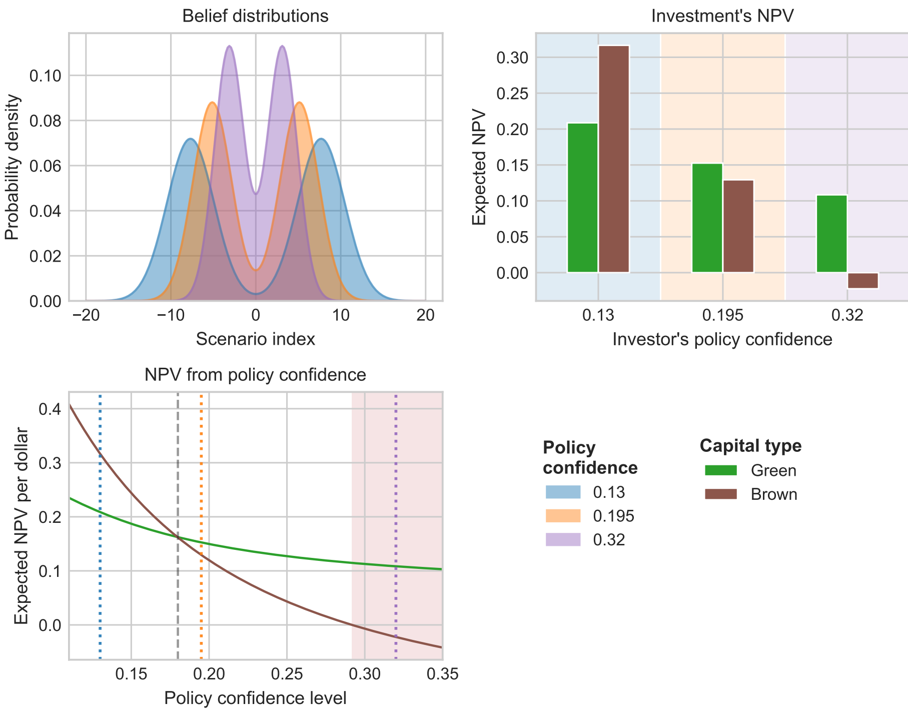

Figure 6: Climate beliefs and capital valuations for banks with different policy confidence profiles. The two dashed vertical lines in the bottom-left panel correspond respectively to the points where both NPVs are equal, and where the brown NPV becomes negative. The dotted vertical lines correspond to the three levels of policy confidence that are used in the top panels.

using the Merton formula with a $\mathcal{T}$-year time horizon. It is a function of total asset value A and debt D, such that

$$\mathrm{PD}(A,D) = F_{\mathcal{N}}\left(\frac{-\ln(A/D) - \left(r - \sigma^2/2\right)\mathcal{T}}{\sigma\sqrt{\mathcal{T}}}\right), \tag{10}$$

where $F_{\mathcal{N}}$ is the standard normal cumulative distribution function, and σ is the implied volatility of the enterprise value. Note that I adopt here a framework similar to that of Wolfson (1996), whereby the terms at which a loan is made are based on a judgment of the firm's overall capacity to repay this loan. That is, I differ from the New Keynesian literature which mostly models the rate as dependent on the return of the specific project funded through new loans. The latter would presumably tend to overestimate the carbon premium in the subsequent application that I conduct, hence the importance of considering the starting point for cash flows and balance-sheet variables. However, the decision whether to grant or not the credit is assumed to still depend on the creditworthiness of the new loans specifically, i.e. the loan for an investment that is not profitable will not be granted even if there is an interest rate that would theoretically allow the bank to make a profit given the overall cash flows of the firm.

Part of the climate stress testing literature is concerned with the calculation of climate-stressed probabilities of default (e.g. Grundmann et al., 2023). However, these are most often taken as end results, and not considered intermediary variables with an influence on real dynamics, which is the object of the present exercise.

The implied volatility is calibrated to $\sigma = 0.2$, which corresponds for the S&P 500 to a regular market environment with a moderate to medium risk level. The baseline value used for the risk-free rate is $r = 3\%$, which is between the long-term government bond yield values for Germany and the United States in April 2023, both being usual proxies. Further details on the calibration are provided in appendix A.

In line with Reinders et al. (2023), we suppose that the NPV calculation of investments informs the value of the assets as priced by the market. The change takes the form of a shift in the leverage of the firm. To clarify the influence of the leverage on the EDF a sensitivity exercise is provided in Appendix B for different values of the implied volatility σ.

4.5 Equilibrium from the feedback of valuation and interest rates

From the definitions presented so far, it emerges that there is a mutual dependency between the valuation of assets and the interest rate charged by the bank.[7] Thus, we ensure that the interest rate due to new investments and the updated NPV of a firm are consistent at a given time. Importantly, we will make the assumption that the new interest rate applies to the whole stock of debt. In practice, companies are likely to use fixed rates for a significant part of their debt, but shifts would still come from the rollover of such debt.

On one hand, we have the asset valuation that is implied by the interest rate, i.e. A as a function of κ when all other variables are known. From equations (9) and (10), we have a loan pricing function $\mathcal{R}$ such that $\kappa = \mathcal{R}(A, D)$, from which we derive the implied capital function

[7] This relies on the assumption that the bank assesses the total value of the firm. In practice, the market value could be employed instead for publicly traded firms. However, equity prices are known to embed climate information as well (see e.g. Loyson et al., 2023), such that dynamics would be observed again in the same direction.

given the debt level:

$$A^{\dagger}\colon \kappa \mapsto D \times \exp\left[-\sigma\sqrt{\mathcal{T}} \times F_{\mathcal{N}}^{-1}\left(\frac{s \times \mathcal{T}}{\mathrm{LGD} + s}\right) - \left(r - \sigma^2/2\right)\mathcal{T}\right], \tag{11}$$

where $F_{\mathcal{N}}^{-1}$ is the quantile function of the standard normal distribution, and $s = \kappa - r - \mu$ is the spread. This function is represented in dark blue in Figure 7.

On the other hand, the valuation of assets from the discounted cash flow approach is the one developed in Section 4. In a situation without any additional carbon tax, this gives the function for capital valuation caused by the interest rate:

$$A^{\diamond}\colon (\mathcal{D}, \kappa, k) \mapsto K \times P_k \times \mathrm{PV}(\mathcal{D}, \kappa, k), \tag{12}$$

making explicit the dependence of the PV on the interest rate and the capital type.

Notice that, when both A and D are fixed, the value of κ is determined through $\mathcal{R}$. Thus, taking A and D as an input will uniquely determine the number of units of capital held by the firm, which satisfies the constraint that A and κ are initially consistent:

$$K = \frac{A}{P_k \times \mathrm{PV}(\mathcal{D}_B, \mathcal{R}(A, D), k)} \tag{13}$$

where $\mathcal{D}_B$ is the climate sentiment of the bank.

In Figure 7, both the dark green and light green lines represent paths of $A^{\diamond}$ for two different climate sentiments $\mathcal{D}_x$ and $\mathcal{D}_y$ respectively (where x and y are the policy confidence levels). For each of the green lines, their intersections with the value implied function correspond to the point of valuation equilibrium, i.e. where interest rate and asset valuation are consistent based on both the NPV and the EDF functional forms. Moreover, the dark line is used to initialize the system. That is, the stock of capital K is determined in order for these two lines to intersect at the calibrated interest rate.

Given this setup, we denote as A_0 and κ_0 the consistent valuation and interest rates of the initial point.[8] Let us then consider the case where the policy confidence shifts from x to y (quantitative results for such a situation are provided in the next section). If the bank used the previous interest rate to reevaluate assets, we would get a new valuation $A_1 = K \times P_k \times \mathrm{PV}(k, \mathcal{D}_y, \kappa_0)$, and the new interest rate κ_1 is calculated based on A_1. We see in Figure 7 that the point (A_1, κ_1) lies on the curve of $A^{\dagger}$, because of the last step described, ensuring that both dimensions are consistent in the interest rate calculation. However, it does not lie on the curve of $x \mapsto A^{\diamond}(x, \mathcal{D}_y)$, because $A^{\diamond}(\kappa_1, \mathcal{D}_y)$ would be generally different from $A^{\diamond}(\kappa_0, \mathcal{D}_y)$.

Therefore, while (A_1, κ_1) can be valid from the financial perspective, depending on the assumptions made on financial dynamics, we want to consider the point where the bank will reassess valuation and interest rate in ways that are consistent within our model. This results in the point (A_2, κ_2), which is then found by taking the intersection of the new curve of $A^{\diamond}$ with that of $A^{\dagger}$. Note that there is generally no close-form solution available for the point

[8]The process to work out a consistent initial point is to first set A_0 and D_0, the initial assets and debt. The interest rate κ_0 is determined from it, which allows the computation of the NPV, and the quantity of capital K_0 is then computed from 13, providing consistency with both A_0 and κ_0.

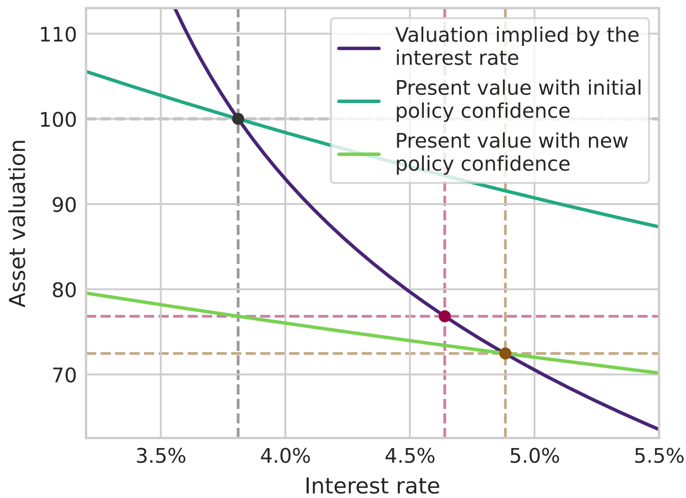

Figure 7: Example of the difference in interest rate and valuation due to the integration of feedback effect in the case of a shift in climate sentiment.
Source: author's computations.

(A_2, κ_2), so it is found numerically by solving $A^{\dagger}(\kappa) = A^{\diamond}(\kappa, \mathcal{D})$.

5 Results

5.1 Application to the case of the interest rate determination with feedback

It is generally important to consider that profits from green investments are more likely to exceed those from conventional investments when more ambitious carbon pricing is implemented, and this policy change is likely to happen further in the future. Therefore, the comparative of investments is sensitive to the modalities of time discounting that are used.

Elaborating on the mechanism presented in the previous section, we can see how, in fact, a green firm would be encumbered by its pre-existing assets at the point of investing in more capital. Indeed, taking more credit leads to an increase in the interest rate in our framework. Then, given the feedback mechanism with the present value and the higher sensitivity of the green capital's present value to the interest rate, higher rates are reached faster.

This mechanism is represented in Figure 8, where we compare the carbon premium on new investments given a low level of policy confidence (solid green lines) to that with higher policy confidence (dashed green lines). On the one hand, the level of the brown capital valuation is more sensitive to the policy confidence than the green capital, due to its higher carbon emissions. We see this from the fact that the gap between the two brown lines is larger than between the two green lines. This is what explains why carbon premium becomes positive given an increase in policy confidence.

On the other hand, for any policy confidence level that is not 0, the green capital realises a larger share of its revenue in the future than the brown capital. Thus, it is more sensitive to the time discount used, and in particular to the interest rate. This explains that the slope of the green PV decreases faster than that of the brown PV. In turn, this stronger slope causes the point of intersection with the rate-implied value to be lower than if it had the same slope as the brown PV. This effect mitigates the previous and tends to make the carbon premium smaller.

Another consequence of the last point is that green capital is also at a disadvantage in a setting with a high policy rate. Indeed, such a movement in the direction of higher rates could also be triggered by external factors, and in particular monetary policy. This points in particular to an interaction of climate and monetary policies, which may run counter to one another in times of inflation overshoot. Moreover, such dynamics highlight the importance of using realistic multi-period models, as this would not be effectively captured by a reduction to two periods.

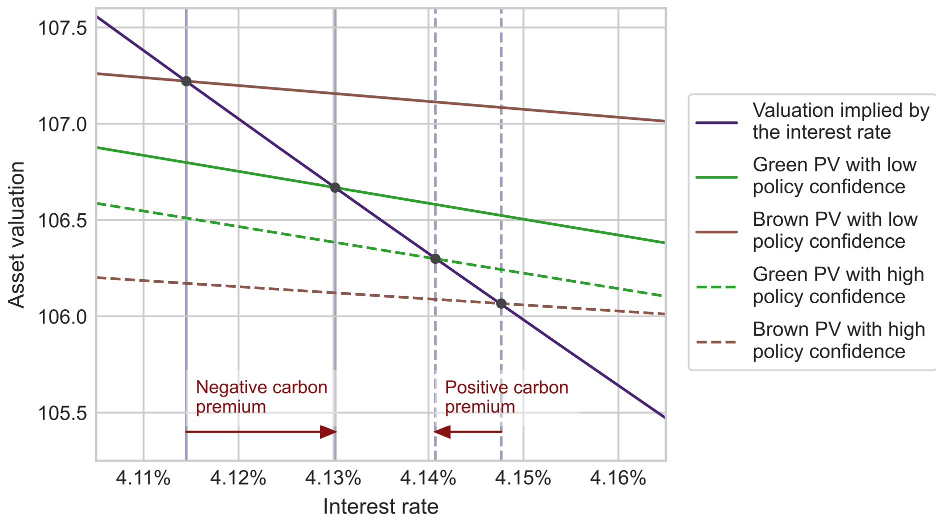

Figure 8: Determination of interest rates when buying new capital for a green and a brown firm.

5.2 Induced carbon premium from new investment

To better quantify the effect of climate sentiment, I apply the framework built in the previous section considering a configuration where a firm takes a loan to buy capital of type k and the rate on this loan depends on the bank's valuation of the project. That is, we assume the interest rates imposed will move from κ_0 to κ_{+k}, where the latter depends on the updated balance sheet of the borrower. While the model does not incorporate decarbonization commitments of firms, the evidence of forward-looking components in the carbon premium (Carbone et al., 2021; Altavilla et al., 2023) indicates that the carbon intensity of the ex-post capital mix is what should matter to determine the interest rate (instead of just applying the previous one).

Importantly, to the difference of 5.1, I assume here that the firm's initial capital is fully brown, and it has an opportunity to green its capital mix when it conducts a new investment. That is, we do not want to capture here a difference due to the value change of the initial capital following a change in interest rates, and we focus on the term that is due to the new investment.

I denote A^0, K^0, and D^0 the initial levels of assets, capital quantity, and debt respectively. The new level of debt is $D = D^0 + \delta D$, such that δD is the credit received from the bank. Then, $K = K^0 + \delta K$, with $\delta K = \delta D / P_k$ the quantity of capital purchased. Following the theoretical setup of section 4.5, we determine the new asset valuation A_{+k} and interest rate κ_{+k} by solving

$$\begin{cases} \kappa_{+k} = \mathcal{R}(A_{+k}, D) \\ A_{+k} = A^{\diamond}(\kappa_{+k}, \mathcal{D}) \end{cases} . \tag{14}$$

The change in leverage induced by new capital depends on the pre-existing leverage level, the price of capital, and its present value. More specifically, we find analytically that, if $\mathrm{PV}(k_i, \mathcal{D}) > 1/\mathcal{L}$, then the PD decreases. Conversely, if $\mathrm{PV}(k_i, \mathcal{D}) < 1/\mathcal{L}$ the PD decreases. In the case of two firms with similar characteristics except the environmental impact, we can designate the induced difference in interest rates as a carbon premium induced by lending:

$$\Pi^L = \kappa_{+B} - \kappa_{+G} . \tag{15}$$

I present in Figure 9 the values of the carbon premium as a function of the policy confidence, given different levels of investment, measured as the ratio $\delta D / D^0$. We observe that the carbon premium induced remains contained in the range of policy confidence where the brown capital is still profitable. Even with relatively large investments implying a 30% increase in the total debt, the increase in interest rates remains of the order of 4 basis points in the brown capital profitability window. This is in line with the observation of Ehlers et al. (2022), which they base on the syndicated loan market. This suggests that banks' adaptive interest rate is limited in isolation as a tool to prevent polluting firms from expanding.

The spread created by the investment appears small here compared to the values from the literature, but considering that the "base" of initial capital is the same and that this premium is only induced by new investments, we should expect a smaller magnitude. The next subsection shows that, when the whole capital stock is different, the premium becomes larger.

A key driver of this relative absence of effect is the "tragedy of the horizon", as coined by Carney (2015). That is, the time discount used is high, reflecting the fact that the horizon of the debt is generally a few years only. Because most of the stranding risk and very high values of carbon price are located further in the future, the carbon premium can be low without being due to an underestimation of risk. In fact, while the precise numbers observed in Figure 9 depend on the calibration of capital, this suggests that significantly higher carbon premia are rather the effect of the banks' market power and a form of financial green paradox, as introduced in Section 1.

5.3 Effect of a policy change

In a second exercise, I consider a situation where banks change their belief following a signal from the regulator. This does not include any change in terms of actually increasing the carbon price, but solely a change in the credibility of future policies. The model event for this is the signature of the Paris Agreement (prepared in 2015 and effectively signed in 2016). We assume that such events cause banks to change their belief, meaning that they will shift from a belief distribution $\mathcal{D}_u$ to $\mathcal{D}_v$ where $v > u$. We then examine how this can lead banks to reassess the

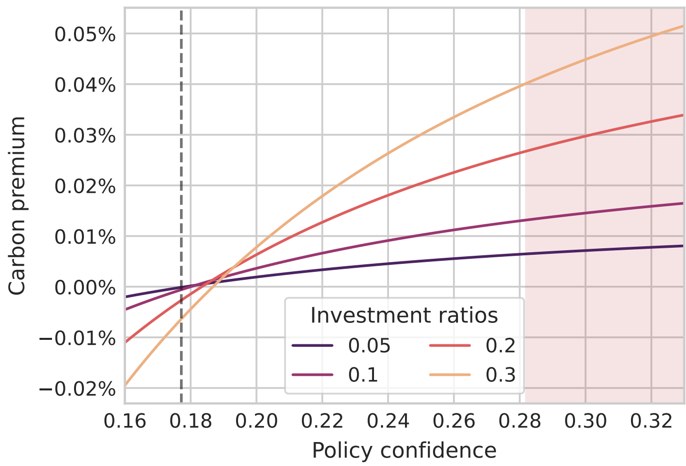

Figure 9: Carbon premium induced by new loans to a firm initially brown that can buy green or brown new capital.

value of pre-existing assets, and the eventual impact on the estimated PD of firms.

We consider here a brown and a green firm with initial capital levels K_B^0 and K_G^0 respectively. Given this setting, we denote as $\ddot{\kappa}_G(x)$ the root of $\kappa \mapsto A^\dagger(\kappa) - A^\diamond(\kappa, \mathcal{D}_x)$ with green capital, and similarly $\ddot{\kappa}_B(x)$ for brown capital. Note that, as the value of assets is reassessed, the initial valuation with starting policy confidence u would generally be different between green and brown, so that $\ddot{\kappa}_G(u) \neq \ddot{\kappa}_B(u)$, except for one point.

In that case, what we are interested in is the evolution of the spread between green and brown, i.e. we identify the added carbon premium from the shift between policy confidence levels u and v. More specifically, the carbon premium from the policy commitment is given by

$$\Pi^P_{u \to v} = \left(\ddot{\kappa}_B(v) - \ddot{\kappa}_G(v)\right) - \left(\ddot{\kappa}_B(u) - \ddot{\kappa}_G(u)\right) . \tag{16}$$

The results for this exercise are presented in Figure 10 for a range of values of the initial policy confidence, and some values of the shift $y - x$. The most extreme shifts (0.2 means going from very low to very high policy confidence) lead to significant changes in interest rates. Their range would reflect some in the higher tier of what is found in the empirical literature (see Figure 1), i.e. with a magnitude in the order of 50 basis points after the cumulative effect of the Paris Agreement, and the European policy packages of the Green Deal and Fit-for-55. Additional results for a specification where all levels of policy confidence start with the same premium are presented in the appendix C.2, so that capital stocks are variable, which leads to higher premia for shifts from low initial policy confidence levels.

Although these results are more quantitatively significant than in 5.2, they have to be interpreted as one-off shocks. That is, in this framework, a succession of policy shifts would lead to the same premium as the immediate cumulation of these shifts. As the added carbon premium decreases with higher initial levels, so would the marginal incentive created by the risk channel.

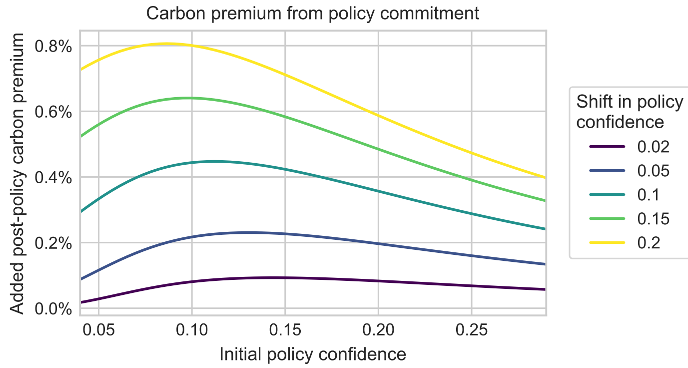

Figure 10: Carbon premium from a reevaluation of existing assets caused by a change in policy confidence. The x-axis represents the value u of the initial policy confidence before policy signal. The different lines corresponds to values of $v - u$, and the y-axis shows the resulting values $\Pi^P_{u \to v}$ in percentages.

5.4 The present value incentivization

The new rate set by the bank is anticipated by the firm, which takes it into account in its choice of capital. The firm, given its level of policy confidence, will choose the capital that maximizes the present value of the investment from its point of view.[9] In turn, this present value depends on the interest rate, which depends on the policy confidence of the bank. Therefore, by giving lower interest rates to each "preferred" kind of capital (which would still depend on the amount invested), the bank could shift the investing behaviour of a firm.

We examine here this effect in the case of a firm with an initial endowment of brown capital. The outcome is presented in Figure 11 for different levels of policy confidence of the firm and the bank. We can see that the presence of a dynamic rate setting can shift the point at which firms will choose to invest in green capital instead of brown, as evidenced by the fact that the area of green investment increases with the policy confidence of the bank. That is, given the feedback between interest rate and valuation, this threshold shifts to a lower value of policy confidence identified by the golden line.

However, the main conclusion of this exercise is that the influence of the bank is very limited: the scale of the y-axis presented is negligible compared to the range of the bank's policy confidence. In fact, the red band represented along the x-axis corresponds to the limits of the y-axis. Therefore, when motivated solely by financial risk consideration, the segment of the real economy that can be incentivized into abating its emissions simply with the bank internalizing climate risk is unlikely to be significant. In particular, the influence of the bank through the interest rate channel appears secondary relative to the structural feature of investment (i.e. capital price, expected profit, and emission intensity).

[9] The first important fact is that, for each level of the firm policy confidence, the investment return of capital is a convex function of the capital mix parameter z. This implies that the firm's preference will always be to invest fully in green capital or fully in brown capital.

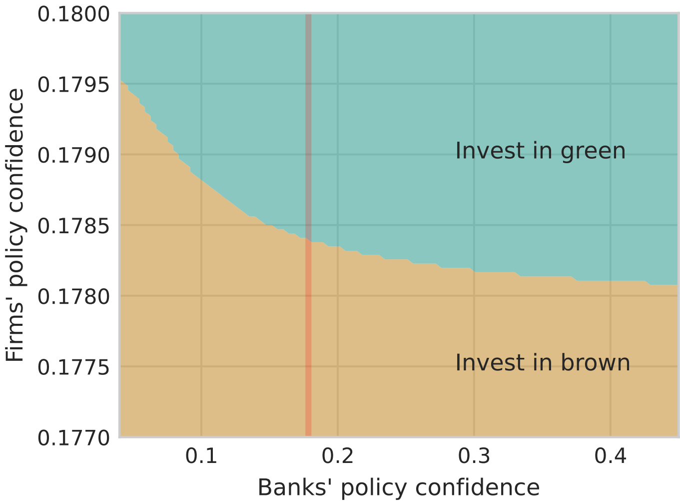

Figure 11: Investment choice of the firm depending on the bank's policy confidence and its own.

6 Conclusion

The results of this paper suggest that an optimistic materialization of the risk channel may still fall short of effectively supporting decarbonization policies. Indeed, both intensive and extensive changes in firm financing are limited relative to the macro-level economic swings that legacy industries have gone through previously. This implies that policy signals must be sufficient to motivate the firms themselves into making radical changes, as the banks may not be enough when following a profit-maximizing rationale. These findings come in complement to the empirical evidence such as that of Matzner and Steininger (2024), showing that actual increases in carbon price (which are distinct from shifts in expectations) do not lead to significant decarbonization efforts by carbon-intensive firms either.

There is still some room for green finance to play a role though, as it can create some level of incentive and screening. Nevertheless, we shall emphasize that the changes achieved through the credit markets are not enough if higher interest rates only induce polluting firms in noncompetitive markets to pass on more of the costs to their customers, or if the shift in credit allocation is only as a proportion of the portfolio and the nominal value of loans provided to brown firms does not decrease. A further complication is that banks are linked to non-bank financial institutions (both on their assets and liabilities) whose portfolios are browner (see e.g. Franceschi et al., 2023, on the links between both).

A more thorough examination of the interaction with the equity market could be provided in future research, and better explain the results of De Haas and Popov (2023). The existing literature has shown that such an interaction could be relevant (Hellmann and Stiglitz, 2000). Indeed, stock market reactions to policy announcements are a documented effect (see e.g. Monasterolo and L. De Angelis, 2020; Birindelli et al., 2023).

One avenue for the regulator to force banks into more virtuous investments would be to crack down on greenwashing, i.e. forcing them to internalize some consequences of their investments on a reputational basis. This is the solution preferred for non-banks so far. Preventing banks from using sustainable marketing could be achieved while the regulator remains the only third party with access to lending data. Therefore, this would require little change in the confidential treatment of the information.

Thus, the results of this paper speak to a core tension of climate finance: polluting activities are still legal, and climate policies are not yet at a point where they can force firms to internalize these externalities. In this context, going through the financial system, and in particular the cost of debt, is at most a second-best option to achieve this internalization. The above findings imply that there is no "free lunch" in that the usual risk-mitigating functions driven by the expectation of future policies, would achieve policy targets before the regulator needs to enact them.

In view of the limitations of the risk-based approach, alternatives emerge such as a green credit policy regime in Kedward et al. (2022). Another proposal is that of Regulatory and Tools (2023), for sustainability-linked debt where the cost of debt is contingent on the issuer's carbon emissions. Note that, more optimistically, investment in innovative green companies could be self-reinforcing as banks would gain expertise (Gao et al., 2023) on greener technologies and offer loans with better terms to these companies.

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A Baseline calibration

A.1 Time to maturity

With regard to $\mathcal{T}$, in the absence of access to complete statistics of bank loan maturities, one can compare it to the following sources. First, discontinued series from the Board of Governors of the Federal Reserve System show that the average maturity of commercial and industry loans from large domestic banks was around three years, in the last years with data from 2014-2017.[10] Second, statistics on syndicated loans reported in Cortina et al. (2016) show that, in this category, 10 years would approximately correspond to the 75th percentile of the maturity distribution in developing countries, and higher for developed countries. Lastly, I represent in figure 12 a decomposition of loan maturities in the euro area, where we can see that loans with an original maturity of over five years are a majority.

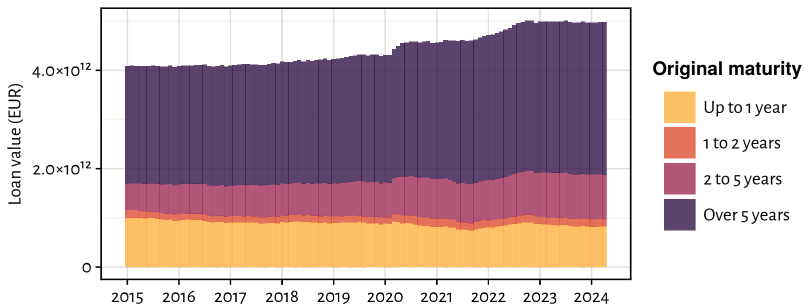

Figure 12: Maturity decomposition of loans provided by banks in the euro area to non-financial corporations also domiciled in the euro area. Source: ECB Statistical Data Warehouse, from the dataset BSI (Balance Sheet Items).

A.2 Leverage

As for the leverage, I provide in figure 13 a representation of aggregate liabilities for non-financial firms in a range of European countries and for the European Union and the euro area overall. The leverage values inferred are generally lower than those used in Reinders et al. (2023), which computes leverage by sector in the Netherlands. The sectoral leverage values they find range from 48% to 74%. In the data obtained and represented in 13, the average for the whole EU is 33%.

A.3 Interest rate components

The calibration with regard to determinants of the interest rates is also informed by values observed in the EU or the euro area over the past decade. First, most of the period was that of a low interest rate environment, as exemplified by the rate on main refinancing operations represented in figure 14. Moreover, as the recent data points are in a context of relatively rapid changes, I do not pick the most recent values to avoid inconsistencies between variables that could be explained by transitory effects. Thus, I set r to 0%.

[10]See `https://fred.stlouisfed.org/series/EDAXSLNQ`.

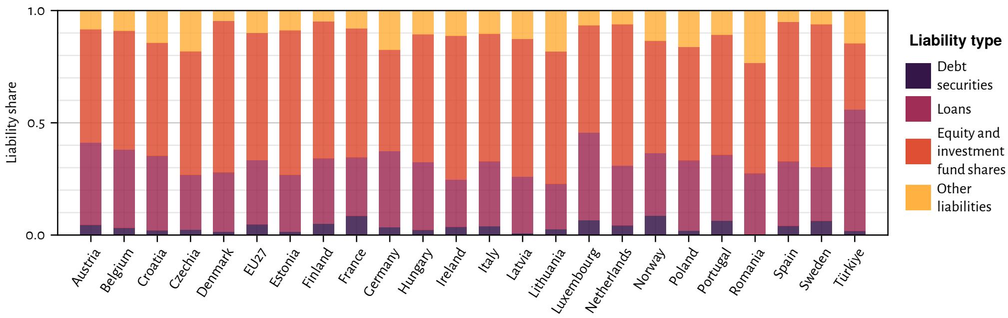

Figure 13: Share of type of assets of non-financial corporations in 2022. Source: eurostat.

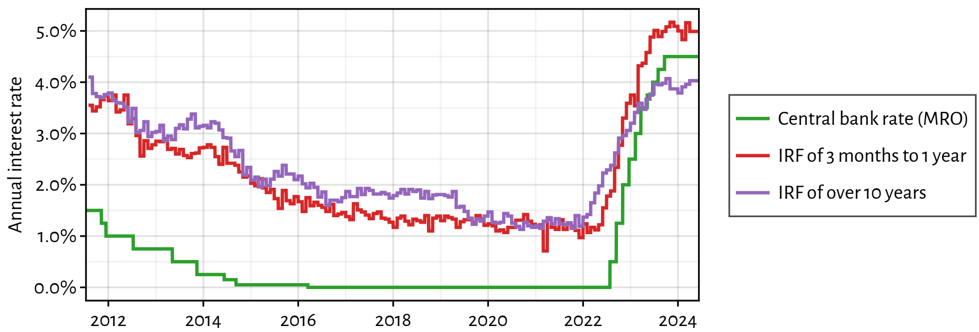

Figure 14: Evolution of interest rates in the euro area.
A series in green is the policy rate set by the European Central Bank on main refinancing operations (MRO). The other series are the interest rates set for NFCs for two different categories of initial rate fixation (IRF) on loans of over EUR 1 million and given in percent per annum.
Source: ECB Statistical Data Warehouse, from the datasets financial market data (FM) and MIR (MFI Interest Rate Statistics).

Second, the choice for the net interest margin (NIM) is motivated by the data on EU banks presented in figure 15. While the NIM for all banks is mostly between 1.2% and 1.5% in the period covered, this includes all loans and not only the ones for NFCs. When restricting the sample of banks to those categorized as “corporate and wholesale lenders”, the NIM observed is mostly between 0.85% and 1% in the same period. This suggests that corporate loans may drive down the average NIM of banks in general due to the specificities of the lending conditions and business model relative to retail loans. Only the most recent data point reflects an exception in the case of banks categorized as less significant. To approximate this, I choose a NIM of $\mu = 1\%$.

A.4 Carbon premia figure

The list below provides information with regard to what the points represented in Figure 1 represent, according to their respective papers.

- In Erten and Ongena (2023), the value is a result of a regression on the variable “total impact of the environment”. It represents the inferred spread for a one-standard-deviation higher level of the dependent variable, for the same lender in the same year, after con-

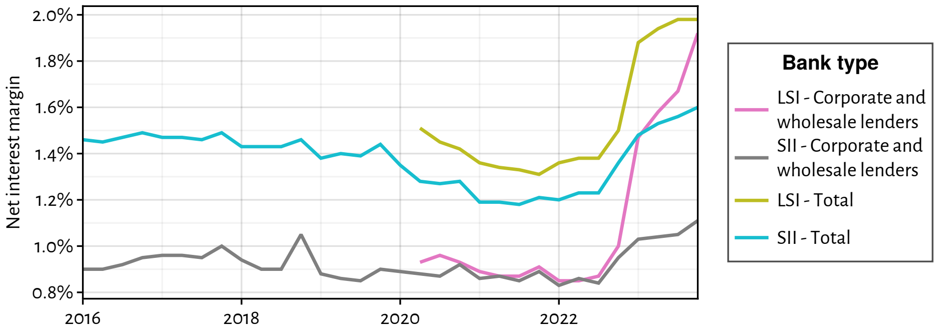

Figure 15: Evolution of the net interest margin of EU banks.
The sample comprises banks from EU countries participating in the Single Supervisory Mechanism (changing composition). The subsample of corporate and wholesale lenders comes from a classification of banks by business models. SI stands for Significant Institution, and LSI for Less Significant Institution. Source: ECB Statistical Data Warehouse, from the datasets SUP (Supervisory Banking Statistics) for the middle panel.

trolling for borrower, and non-price deal characteristics.

- For Beyene et al. (2024) the values used are the differences between the mean all-in spread for all firms, and that for fossil fuel firms only.
- For Fard et al. (2020) the value is the result of a regression. It is the typical spread for an average firm given one standard deviation in the EPS (environmental policy stringency) country-level indicator.
- For Ehlers et al. (2022) the values are the result of a regression setting. They represent the added spread of high emitters (1 CO_2 tonnes per USD thousand) compared to the mean, and of firms one standard deviation above the mean (2.5 CO_2 tonnes per USD thousand).
- For Degryse et al. (2023) the value retained comes from a regression setup and corresponds to the reduction in the cost of debt granted by green banks to green firms.
- For Bruno and Lombini (2023) the value presented is inferred from regression results and corresponds to the change in loan margin induced by one standard deviation change in borrower's CO_2 emissions.
- For Boermans et al. (2024) the value presented is inferred from regression results and corresponds to the change in the bond yield spread induced by one standard deviation change in the issuer's emission intensity.
- For Broeders et al. (2024) the value presented is inferred from rolling regression results. It corresponds to the change in the bond yield spread induced by one standard deviation change in the issuer's log-carbon emission at the end of the sample period (2022). It is larger than the values observed in previous periods.
- For Zhu and Zhao (2022) the value presented is inferred from regression results and corresponds to the change in the cost of loans induced by one standard deviation change in borrower's carbon risk.
- For Pohl et al. (2023) the value presented is inferred from regression results and corresponds to the difference between a conventional loan and a sustainability-linked loan.
- For Flammer (2021) the value presented is the difference in yields between green and

nongreen bonds after matching on their characteristics.

- For Ding et al. (2023) the value comes from an additional regression exercise that the authors conduct on loan cost, showing that "there is no significant correlation between carbon emission and loan cost".
- For Jung et al. (2018) the values presented are inferred from regression results, whereby "a one standard deviation increase in carbon risk mapping into between a 38 and 62 basis point increase in the cost of debt". The different values correspond to alternative measures of the carbon risk.
- For Zerbib (2019) the value is inferred from regression results and corresponds to the opposite of the premium observed for green bonds relative to conventional bonds.

B Sensitivity analysis

The discounting of future events in general is at the core of some of the most important debates at the nexus of climate change and economics, with enormous implications when used for policy purposes. The short-sightedness of financial institutions is a core consideration of climate finance, famously one of the pillars of the "tragedy of the horizon" (Carney, 2015). This aspect is captured in my setting by the time discount factor that is considered.

Therefore, I examine in figure 16 the sensitivity of asset valuation to the interest rate r, which is the variable component of the WACC used as time discount. The general effect observed is that a higher value of r leads to a lesser asset valuation, because future profits are more heavily discounted. In particular, when r increases, there is a broader interval of transition policies in which assets are not profitable any more. However, the valuation difference is more compressed for ambitious climate policies (values of u close to 0) than on the rest of the policy spectrum. This tells us that asset valuation becomes generally less sensitive to the policy choice when the time discount is higher.

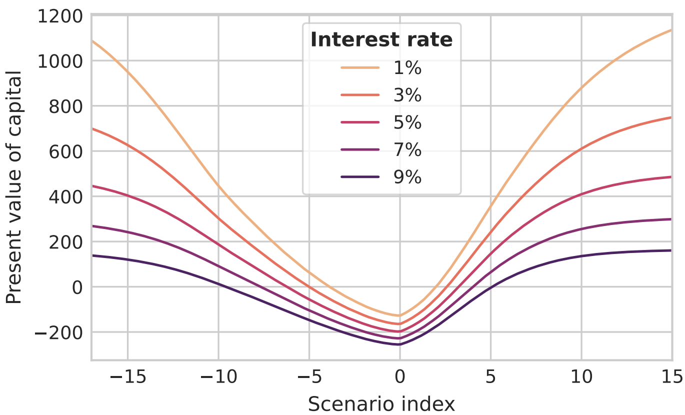

Figure 16: Sensitivity of brown asset prices to the time discount: value of the brown asset for a range of central carbon price paths, given different values of the interest rate r and thus of ρ.
As ρ is an affine function of δ, note that an examination of the figure is also informative as to the changes that would result from modifying δ.

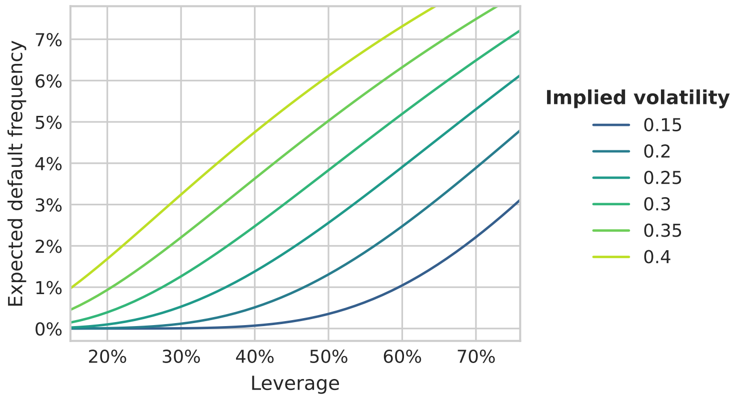

Figure 17: Expected default frequency as a function of the leverage, before any purchase of new capital. The figure is truncated for visualization purposes.

To visualize the effect of the leverage in our setting, I represent in figure 17 the EDF without any capital purchase or policy change, for a range of initial leverage values, denoted as $\mathcal{L}$. The paths for alternative values of σ are represented as a sensitivity analysis. We see that the EDF is an increasing and convex function of the leverage. The value in the baseline configuration is 0.025, which translates into one chance out of forty to default in the next year.

C Additional results

C.1 Implication of policy confidence for expected carbon prices

The policy confidence variable is built so that a higher policy confidence gives more weight to more ambitious decarbonization paths. This subsection purports to illustrate how this translates into different expectations as to how high the carbon price would be at different points in the future.

Figure 18 shows the expected carbon price at the horizon of 5, 10, 15 and 20 years, as a function of the policy confidence. That is, the value represented are $\mathbb{E}_{\mathcal{D}_x}[\Phi(t)]$, where x is the policy confidence and t the time horizon.

As expected, we see that the expected carbon price is an increasing function of the policy confidence. However, the increase in expected carbon price is most pronounced over the first segment of the policy confidence, as it then gets closer to its boundary, which is the Net Zero path.

C.2 Policy premium with equal initial valuation

The results presented here share the same premise as in section 5.3, i.e. a signal changes the policy confidence of economic agents. However, instead of taking a fixed value of the capital stock (one fixed amount for the green firm and another for the brown one), I assume that banks are initially at the point where green and brown PVs are equal. To do so, we consider, for each initial policy sentiment, values of the capital stocks that would given the same valuation of the green and brown firms.

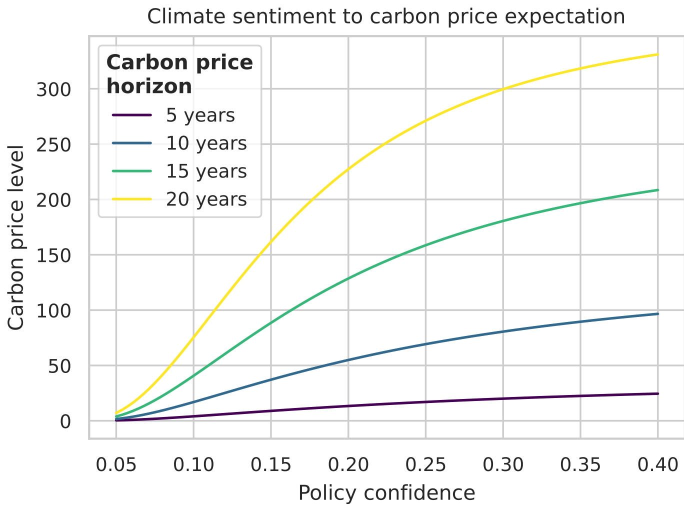

Figure 18: Expectation of the carbon price at different periods in the future, as a function of the policy confidence.

We start from a situation where two firms, one with green capital and one with brown capital, have the same initial valuation A^0 of their assets, prior to the policy change. Thus, the initial capital stocks K_G^0 and K_B^0 are now functions of κ_0. Therefore, they have the same initial cost of debt and zero spread between them.

Their initial quantities of capital are given by equation (13), such that the value of their assets after the policy change is

$$\forall i \in \{G, B\}, \quad A_i = A^0 \times \frac{\text{NPV}(i, \mathcal{D}_y, \kappa_{i,y}) + 1}{\text{NPV}(i, \mathcal{D}_x, \kappa_0) + 1} \, .$$

Thus, the carbon premium from the policy commitment is given by

$$\Pi^S = \kappa_{B,y} - \kappa_{G,y} \, . \tag{17}$$

Thus, it is different from what is done in section 5.3, where values for policy confidence 0.1 assume that both firms have underlying capital of similar value at this point.

The results for this exercise are represented in Figure 19. They appear notably stronger than those of section 5.3 in the segment of low initial policy confidence. Therefore, we can see that the high carbon premium found in Beyene et al. (2024) for fossil fuel firms is plausible in the case of markets that have a low initial policy confidence and with a high emission intensity. However, they are also unlikely to reach much higher values.

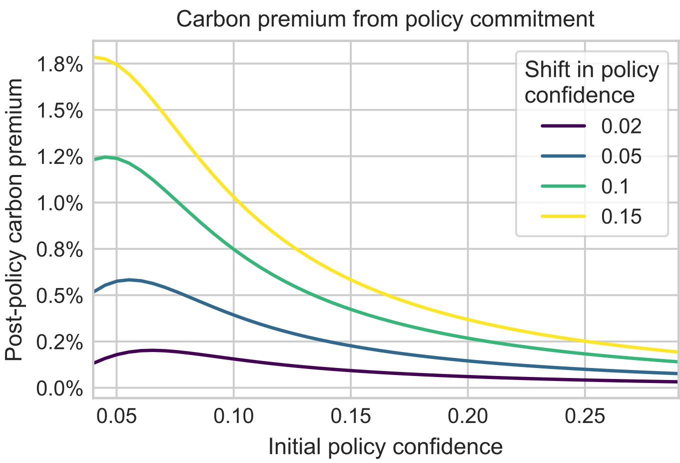

Figure 19: Carbon premium from a reevaluation of existing assets caused by a change in policy confidence when both green and brown firms have the same initial valuation.