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Asset Overhang and Technological Change

Abstract

Investors face reduced incentives to finance projects that devalue their legacy investments. We formalize this “asset overhang” and study its drivers. We apply our framework to the climate-banking nexus, where the net-zero transition effectively poses a dilemma for banks: while environmental innovation can be profitable, its widespread dissemination risks disrupting the value of legacy positions. Using granular firm-level data on innovation and diffusion of environmental goods & services, we document the presence of asset overhang as innovators (diffusors) of disruptive environmental technologies are approximately 4.4 p.p. (1.0 p.p) less likely to receive bank credit compared to non-disruptive counterparts. Individual investors with less legacy positions at risk mitigate the economywide asset overhang problem, thereby facilitating technological transition.

JEL Classification: G21, G32, Q54, Q55

Keywords: Financial Intermediation, Technological change, Innovation, Diffusion, Credit rationing, climate change

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Asset Overhang and Technological Change[§]

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Investors face reduced incentives to finance projects that devalue their legacy investments. We formalize this "asset overhang" and study its drivers. We apply our framework to the climate-banking nexus, where the net-zero transition effectively poses a dilemma for banks: while environmental innovation can be profitable, its widespread dissemination risks disrupting the value of legacy positions. Using granular firm-level data on innovation and diffusion of environmental goods & services, we document the presence of asset overhang as innovators (diffusors) of disruptive environmental technologies are approximately 4.4 p.p. (1.0 p.p) less likely to receive bank credit compared to non-disruptive counterparts. Individual investors with less legacy positions at risk mitigate the economywide asset overhang problem, thereby facilitating technological transition.

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1 Introduction

Technological change is not always in an investor's best interest.[1] In this paper we study the presence and impact of an "asset overhang" problem, i.e., a financier's reduced incentive to fund a firm's profitable – yet disruptive – technology due to externalities imposed by the project on the financier's legacy investments (e.g., through business stealing, devaluation of pledged collateral, etc.).[2,3]

We proceed by first extending the corporate finance model of Holmstrom and Tirole (1997) to study the effect of an investor's legacy portfolio on her decision to fund new projects when these projects may adversely affect the value of the investor's original portfolio. Second, we develop the model's main result that the market structure of the financial system plays a crucial role in determining the extent of aggregate funding supply to disruptive technologies. In particular, we demonstrate that the presence of investors with limited or no exposures to the negative spillovers triggers liquidity supply by the *entire* system. Finally, we discuss how the various moving parts in the model – e.g., information structure, fungibility of the legacy exposures, nature of technological disruption – affect rationing outcomes and levels of technological conservatism.

Our theory posits that asset overhang dampens technological change when the full pool of eligible investors are exposed to the disruptions associated with a new technology. In order to empirically test our predictions, we consider the case of the transition towards environmentally friendly (green) technologies. Importantly, we take on board two stages of technological change: innovation – i.e., the development of new green products and processes – and diffusion – i.e, their widespread dissemination in the economy (Hall, 2004). While the application is appealing in view of the important funding efforts required to win the race against runaway climate change (Giglio et al., 2021; Hong et al., 2020), the climate-finance nexus also constitutes a tight conceptual match with our overhang framework. In particular, climate change uniquely combines large threats of disruptive environmental technologies *and* strong exposures across the population of investors towards brown industries (European Central Bank, 2019).

Our empirical application studies, in the setting of a heavily bank–based economy, whether green technologies suffer from an asset overhang problem in the market for corporate bank credit.

[1] E.g., in 2015 the New York Department of Financial Services placed *Montauk Credit Union* under conservatorship. At the time, one-third of its outstanding loans were to taxicab operators that had been struggling to reimburse their credit lines since the entry of the disruptive matching platform *Uber* in New York City (Farmer, 2015).

[2] Examples where financiers aim to protect legacy stakes from novel technologies are abundant. For example, in 2020, *Olive* – a start-up developping artificial intelligence to automate repetitive tasks for healthcare workers – approached multiple venture capitalists (VC) for seed funding (Berber, 2021). While acknowledging *Olive*'s business potential, the VCs rejected the funding request on the basis that the proposed business model did not align with their vested interests (portfolio firms pursuing a rivaling technology). Similarly, *Instagram* had its funding cut off once the app's underlying technology pivoted to that of a firm already in the VC's portfolio (New York Times, 2012). Relatedly, *Ford* investors opposed to finance a spin-off that would develop Ford's nascent electric vehicle technology. Such a move was argued to carve out their legacy investments in the internal combustion engine business entity (Bloomberg, 2022).

[3] Asset overhang differs from traditional "debt overhang" of Myers (1977) as the latter refers to how outstanding debt of a firm may distort her investment incentives downward.

The analysis reveals that banks have jointly delayed the transition to a greener economy by rationing environmental innovation and its diffusion in both product and technology spaces where the banking system holds large stakes.

Data, identification & results. The empirical strategy proceeds in two steps: (i) identification of adverse spillovers and (ii) estimation of legacy risk and rationing barriers.

In the first step, we pin down the externalities to which firms are exposed when other firms unfold their environmental activities. The linchpin of our identification strategy has two main features. First, in the spirit of Hall and Helmers (2013), we take a two-tiered view on environmental activities. Green activities either take the form of green innovations (i.e., development of new environmentally friendly products and production processes) or green diffusion (i.e., procurement or selling of environmental products and services that embody an incumbent green technology). Drawing on a unique large–scale dataset, we directly observe both components of technological change at the firm level. This bifurcated view is warranted as the two activities differ in their financing and disruptive capacity (Utterback, 1974) – and therefore might trigger different levels of overhang problems – while both are instrumental in the net-zero transition (Aghion et al., 2009; Veugelers et al., 2009). Second, following Bloom et al. (2013), we empirically distinguish each firm's position in the technology space and product market using granular information on the distribution of firms' input and output markets (inferred from detailed B2B transactions). This allows us to construct distinct measures of economic distance between "firms with environmental activities" and "other firms" in the technology (input) and product (output) market dimensions.

We leverage both ingredients to trace out externalities of green activities on neighboring firms. We focus on two types of externalities that were previously documented to weigh heavily on banks' lending decisions (Berger and Udell, 1990): firm performance (as proxied by, i.a., firm household sales, corporate sales, market shares, etc.) and pledgeable asset values (measured by, i.a., losses incurred on secondary markets upon liquidation of tangible assets). The former are taken from granular VAT declarations. The latter are taken from a widespread business survey.

We apply this framework to a panel of Belgian firms over the period $2008-2018$,[4] and document that firms with green innovation and/or green diffusion generate negative spillovers on brown firms through deteriorated firm performance and asset devaluations.[5] We provide further corroborating evidence that these induced firm-level externalities stemming from green technology effectively feed into the banks' assessments of their incumbent borrowers. First, we find that green innovation and diffusion is associated with elevated probabilities of default and additional

[4]As we motivate below, the Belgian economy presents itself as an appropriate case study because of its combination of deep bank-funding dependence and significant exposures to green transition shocks.

[5]For ease of exposition, we abuse language when referring to *green* and *brown* firms. In our framework, this labelling is relative rather than absolute: a firm will be labelled brown because it will be identified as not taking part in green activities, therefore being *less* green than firms identified as green. Appendix A provides evidence that our green identification indeed correlates with better energy consumption and wastage management.

provisioning reported by banks on their incumbent borrowers. Second, we observe – leveraging granular data on market values of pledged collateral – downward adjustments in market values of firms' capital in the face of (particular types of) environmental innovation & adoption by technology peers. Taken together, these findings underpin spillover channels which are at the core of our asset overhang mechanism.

Armed with the established externalities, the second step in our analysis proceeds to quantify individual bank's legacy positions at risk that an individual green firm generates using bank-firm credit exposures as reported in corporate credit registry. This allows us to study the impact of the magnitude and structure of banks' asset overhang on credit allocation to environmental firms. We estimate that, at the extensive margin, an environmental innovator (diffusor) which generates a one standard deviation (s.d.) negative impact on each bank in the credit market is around 4.4 p.p. (1.0 p.p.) less likely to receive bank credit compared to an environmental innovator (diffusor) that does not have an impact on banks' legacy positions.

The rationing effect is largely muted by the presence of intermediaries with low asset overhang. This empirical finding is rationalized by our theoretical result which posits that the investor market structure is an important determinant for systemwide credit supply. More precisely, irrespective of the identity of the investor which effectively funds the project, the negative spillovers bite all investors' legacy portfolios. The population of investors realize this and align their rationing barrier with the investor with the lowest asset overhang in order to potentially recover part of the losses.

We further study, conditional on lending, which bank in the asset overhang spectrum matches up with the green firm. We find that the bank with the smallest asset overhang is 8.4 p.p. more likely to grant a loan to the green firm relative to any other bank in the system. That is, investors with less asset overhang are more likely to "break the barrier" to technological disruptions. Subsequently, at the intensive margin, we document that changes in the asset overhang of the incumbent lender do not play a role in credit supply to the environmental firm. Instead, a 1 s.d. decrease in the lowest asset overhang position (potentially, but not necessarily, that of the incumbent lender) drives up credit supply by the incumbent lender to the disruptive innovator (diffusor) by 0.11 s.d. (0.05 s.d.). Taken together, these result highlight that the distribution of asset overhang across investors determine credit supply to disruptive firms both at the extensive and – once the rationing barrier is broken – at the intensive margin.

Policy implications. The results from this paper talk to a number of ongoing policy debates. First is the promoting of financial intermediaries with no legacy exposures that would suffer from technological disruption. Since these legacy-free investors do not face an overhang problem, they are able to stimulate entry of profitable firms despite the possibility of negative spillovers on other intermediaries' legacy positions. In the context of climate change and to the extent that these intermediaries have sufficient industry expertise, public 'green banks' initiatives such as the UK Green Investment Bank or the New York Green Bank could therefore be key to reduce barriers to entry for more energy-efficient firms. In addition, our results indicate that the entry of such a single legacy-free green bank in the economy breaks the system-wide rationing barrier to disruptive green firms. As a result, the total capacity of credit supply to the green economy gets compounded beyond the individual capacities of the novel green bank, ultimately including all banks in the system.

Second, our results suggest that macro prudential policies concerned with technological disruption could introduce costs related to legacy exposures. In the climate change context, such a penalty could take the form of risk-weight reductions (additions) in the prudential framework for banks' exposures to green (brown) assets. Another example would be the promoting of collateral policies that penalize the use of assets exposed to the type of green externalities documented in our paper.

Finally, our theory posits that an asset overhang materializes when new technologies have a large potential for adverse spillovers to which the full pool of eligible investors is exposed. While the climate-banking application satisfies these criteria, there exist alternative candidate applications which meet similar conditions, thereby warranting an overhang analysis as well. For instance, the pool of candidate investors in advanced niche technologies (e.g., AI, cloud computing, biotech etc.) is typically restricted due to the intimate knowledge required to screen candidate projects (Gompers et al., 2009). This screening-ability is typically acquired through experience in funding projects embodying similar or adjacent technologies which may potentially suffer from the entry of disruptive rivalling projects. If the latter legacy projects still feature on the investors' balance sheet, they have incentives to ringfence their legacy from competing technologies. Similarly, vested interests of investors in shallow financial markets, such as found in developing and emerging economies, or monopoly settings such as found in public infrastructure projects could be plagued by an asset overhang problem.

Contribution to the literature. Our work connects to several research agendas. First, this paper speaks to a broad research agenda on the role of finance in fostering technological change and the associated economic growth (e.g., Beck and Levine (2002); Levine (1997); Levine et al. (2000); Laeven et al. (2015)). A substantial body of research has offered causal evidence that financially developed environments lead to higher economic growth through technological innovation (see Levine (2005) and (Kerr and Nanda, 2015) for reviews) and adoption (see e.g., Bircan and De Haas (2020); Comin and Nanda (2019)). While this research agenda typically treats the level of financial frictions as exogenous, our work offers a novel perspective by studying how the disruptive nature of technological change endogenously raises the financial barriers for innovation & diffusion related to the asset overhang under specific conditions for the structure of the financial market.

Our empirical application zooms in on the role of banks in supporting technological change.

Several mechanisms have been put forward to establish why banks may be ill-suited to finance advanced (high-tech) innovation. First, banks may be less capable of screening early stage technologies. Ueda (2004) argues that this may explain why innovative technology firms with little collateral are financed by venture capital. Second, banks may find it costly to promote new technology when they have already acquired expertise on mature technology. Minetti (2011) shows in this context that banks may exhibit technological conservatism: when acquiring information is costly, banks favor firms with mature technology in order to preserve the value of their acquired expertise. Third, the intangible nature of advanced technology innovation makes such project harder to collateralize (Carpenter and Petersen, 2002; Hall and Lerner, 2010). Finally, the structure of the banking system may also direct banks' decisions to finance innovation (Cestone and White, 2003; Cetorelli and Strahan, 2006; Cornaggia et al., 2015).[6] While some of the above listed mechanisms might only apply to the innovation stage of technological change where non-bank financing may in turn dominate, we show that the overhang mechanism proposed in this paper is also present at the diffusion stage where banks play a key role. More in general, our paper shows that the capacity to promote technological change is also affected by the distribution of legacy exposures to the externalities of innovation and their related intensities which is a form of market structure that is different from standard measures such as market shares.

The third strand of the literature relates to the relationship between climate change and financial markets and, in particular, the role of finance in accommodating the transition away from carbon emissions. In a cross-country, cross-industry panel analysis, de Haas and Popov (2022) find that equity-based economies transit faster towards low-carbon emissions and innovate more in terms of energy efficiency as measured by the number of green patents filed when compared to credit-based economies. Dasgupta et al. (2002) review early works showing environmental news sensitivity of stock markets with gains from good news and losses from bad news. The authors further suggest that banks may prevent loans to firms exposed to adverse environmental liability. In more recent work, Bolton and Kacperczyk (2021) show the existence of a carbon-risk premium from investors in the US stock market. Focusing on syndicated loans, Delis et al. (2019) find that banks started to impose higher costs on credit for fossil fuel firms exposed to climate policies, after 2015. Kacperczyk and Peydró (2021) document that banks affect carbon emissions via credit reallocation (from brown to green firms) rather than via providing loans to brown firms for the investment necessary to reduce carbon emissions. Our paper contributes to this corpus of research by highlighting the role of the banking system structure and the effect of legacy assets subject to negative green externalities: by preventing the financing of green innovation and green diffusion, the banking system effectively slows the necessary transition to a low-carbon economy.

[6] In a model that combines a financial market and a product market, Cestone and White (2003) find that financial entry deterrence is most important when competition in financial markets is most limited. In the same vein, Cetorelli and Strahan (2006) combine theoretical predictions and empirical tests to show that concentrated banking markets increase barriers to potential entrants in local US markets. Exploiting the effect of interstate branching deregulation in the US, Cornaggia et al. (2015) finds that banking competition increases the financing of private innovation, also preventing private firms from being acquired by large public ones.

In general, the asset overhang problem also shares features with a nascent literature on common ownership.[7] This literature studies whether partially overlapping ownership patterns induce coordinated firm decisions (e.g., prices, quantities, product entry, etc.) that imply a deadweight loss for the economy (Azar et al., 2018). While our asset overhang framework does not feature common ownership or tacit/explicit firm coordination, it shares the investors' objective of safeguarding vested interests and the potential adverse impact on technology development and diffusion (Anton et al., 2021).

Outline of the paper. The remainder of the paper is organized as follows. Section 2 describes our theoretical model which studies investor's asset overhang. Section 3 introduces the climate change application and the data sources/variables leveraged in the analysis. Section 4 empirically identifies the externalities environmental firms generate on brown firms' performance and collateral values. In Section 5 we study the impact of banks' legacy positions on credit rationing of green firms. Section 6 offers policy implications while Section 7 concludes.

2 Theoretical framework

We base our model on Holmstrom and Tirole (1997) and formulate our theoretical analysis for general "external financiers" or "investors" in the presence of technology-driven negative spillovers. First, we consider a monopoly investor setting, to introduce the asset-side overhang mechanism, or asset overhang for short (Subsection 2.1). We then proceed to analyze how the rationing of firms' projects interacts with the structure of the financial market (Subsection 2.2). We close the Section by discussing some of the implications and assumptions of our model and results (Subsection 2.3).

2.1 Asset overhang with a monopoly investor

Consider a monopoly investor who is the only source of external finance in the economy. We investigate how legacy positions stemming from previous investments by this monopoly investor affect her decisions towards the funding application submitted by a new firm. To capture this, we first replicate the standard investment problem of the monopoly investor in the presence of moral hazard on part of the firm. We then turn to decisions on a new investment in the presence of externalities on legacy positions.[8]

[7] While this literature dates back to Rubinstein and Yaari (1983) and Rotemberg (1984), a burgeoning literature has recently emerged on this topic. See e.g., Ederer and Pellegrino (2022); Shekita (2022); Schmalz (2018) and references therein for an overview. In parallel to our empirical application, Azar et al. (2021) investigate the impact of common ownership on carbon emissions.

[8] In our analysis, we focus on negative externalities as they are the most relevant to our setting. However, this does not imply that we exclude the possibility of positive externalities, i.e., cases where new projects would decrease default probabilities of the investors' legacy positions or increase their pledged collateral values.

2.1.1 Investment decision in the absence of externalities

Firm's project. Consider a firm applying for external financing to the monopoly investor for a project with the following characteristics. The firm has no cash at hand, but has collateral (i.e., machines or buildings) with value C, that it brings to the project. Next to this collateral, the firm needs an investment of amount I to undertake an indivisible project. If successful, the project yields R whereas it yields zero if unsuccessful. Regardless of failure, the project further always gives back the collateral C.[9] The investor's capacity for rent extraction is limited by the following moral hazard problem. If the entrepreneur (i.e., firm) works, its success probability is P_H. It is P_L if the entrepreneur shirks. The entrepreneur enjoys private benefits from shirking B. We assume that the project has a positive net present value (NPV) if the entrepreneur behaves. In contrast, the NPV is negative in case the entrepreneur shirks. That is

$$P_H R - I > 0 > P_L R + B - I.$$

Investor's decision and profits. The investor makes sure that the following two constraints are fulfilled. The first is the *incentive compatibility* constraint (IC). It implies that the entrepreneur should at least expect to receive as much by working as by shirking:

$$(IC) : P_H R_E \geq P_L R_E + B, \text{ or } \; R_E \geq B/(\Delta P),$$

where R_E is the payment received by the firm when successful (this encompasses a compensation for the collateral being brought to the project by the firm), and $\Delta P = (P_H - P_L)$. In case the IC constraint is not fulfilled, the investor knows the firm will shirk such that the investor would realize losses by granting the loan.

The second constraint is the firm's *individual rationality* (IR) constraint. This implies that the entrepreneur should be willing to bring her collateral to the project, i.e.,

$$(IR) : P_H R_E \geq C, \text{ or } \; R_E \geq C/P_H.$$

In other words, the firm should not expect to make losses when bringing its collateral to the project. This holds whenever $R_E \geq C/P_H$.

Since the monopoly investor is the only source of external finance, it will extract as much rents as possible subject to the IC and IR constraints faced by the entrepreneur. To determine the investor's profit, we need to compare both constraints and determine which is the most binding. Two cases exist depending on whether C/P_H is larger or smaller than $B/(\Delta P)$. Let $\tilde{C} \equiv (BP_H)/(\Delta P)$. We have:

[9] We discuss and relax these assumptions at the end of the Section.

1. When $C \geq \tilde{C}$, the IR constraint binds. The profit of the monopoly investor then becomes:

$$P_H R - I > 0.$$

   This profit is strictly positive given that the NPV of the project is positive. The firm's profit then equals zero.

2. When $C \leq \tilde{C}$, the IC constraint binds. In this case, the entrepreneur always makes positive profits since the investor needs to leave money on the table to prevent the entrepreneur from shirking. This implies that $R_E = B/(\Delta P)$. The entrepreneur's profits then equals $P_H(B/(\Delta P)) - C$. The monopoly investor's profit then becomes:

$$P_H(R - B/(\Delta P)) - I + C > 0$$

   The latter is positive as long as $C \geq \underline{C} \equiv \; I - P_H(R - B/(\Delta P))$.

As a result, the investor funds the project if the firm has collateral that exceeds $\underline{C}$. Lemma 1 summarizes the standard result for the investment decision of a monopoly investor in absence of externalities.

Lemma 1. *In absence of externality, a monopoly investor enjoys positive rents that depend on the magnitude of collateral pledged as long as $\underline{C} \leq C \leq \tilde{C}$. If $C \geq \tilde{C}$, its profits equal the NPV and are independent of C. For values of $C < \underline{C}$, the investor does not make positive profits and therefore does not provide external financing.*

2.1.2 Asset overhang in presence of a negative externality

We now depart from standard settings by allowing for a negative externality between funding applicants driven by technological disruptions. Consider the following situation: firm 1 is the incumbent company who has already been granted external financing by the monopoly investor under the conditions stated in Subsection 2.1.1 (i.e., collateral pledged by firm 1 is such that: $C_1 \geq \underline{C}$); firm 2 is the firm approaching the monopoly investor in order to externally finance a disruptive project. A characteristic of firm 2's project is that when implemented, it generates a negative externality on the value of the collateral of firm 1.[10] That is, should firm 2 obtain financing, the collateral value of firm 1's project would drop by ΔC.[11] Assuming that the investor cannot pass on this loss by repricing the external financing to firm 1, the expected profits on firm 1 will then drop by ΔC.[12]

[10]We discuss the case of externality on firm 1's probability of default at the end of the Section.

[11]For simplicity and without loss of generality, we assume that the externality on firm 1 occurs independently of the success of firm 2. The simple fact of financing firm 2 already generates the externality on firm 1. We further assume that the success probabilities of the two firms are independent from each other.

[12]Note that this setup implies that the relevant legacy positions of the investor are illiquid. Hence we assume the investor cannot modify the exposure to his or her legacy portfolio in the short run. We discuss this aspect of the model

Firm 2's project. Firm 2 approaches the monopoly investor to obtain funding for a project that requires a total investment of I. For simplicity and without loss of generality, we assume the firm has cash at hand $A < I$, but no collateral. Similar to before, the monopoly investor faces a moral hazard problem regarding the entrepreneur of firm 2. When the entrepreneur of firm 2 behaves diligently (shirks), its success probability is P_H (P_L). When successful, the project yields Z. The entrepreneur enjoys private benefits from shirking B. We assume that the project has a positive (negative) NPV when the entrepreneur behaves (shirks):

$$P_H Z - I > 0 > P_L Z + B - I.$$

Notice that by allowing Z to be different from R, we capture the possibility of different investment opportunities for firm 2 relative to firm 1.[13]

Investor's financing decision and profits. In order to induce the entrepreneur of firm 2 to work and to participate, the investor should make sure that the IC and IR constraints of firm 2 are simultaneously fulfilled. Similar to before, we have:

- The IC constraint is as follows:

$$(IC_2) : P_H Z_E \geq P_L Z_E + B, \text{ or } \; Z_E \geq B/(\Delta P),$$

  where Z_E is the payment received by the entrepreneur of firm 2 when successful.

- The IR constraint is as follows:

$$(IR_2) : P_H Z_E \geq A, \text{ or } \; Z_E \geq A/P_H.$$

In absence of an externality, the monopoly investor's decision follows Lemma 1 with cash A in lieu of collateral. We now analyze the role of the negative externality induced by firm 2 which the investor takes into account when deciding on whether firm 2 should be rationed or not. In particular, the granting of external financing to firm 2 leads to a drop in the collateral value of firm 1 by $\Delta C > 0$. If the investor cannot pass on this loss to firm 1, then profit on firm 1 is reduced by ΔC. Put differently, there is an asset-side overhang for the investor stemming from its legacy positions in firm 1 and the negative externality brought by firm 2.

To see this, recall that the profit of the monopoly investor in the absence of the externality equals $P_H(R + C - C/P_H) + (1 - P_H)C - I$ when $C \geq \tilde{C}$. Keeping C/P_H constant (i.e., no pass-through to firm 1), the profit of the monopoly investor in the presence of the externality drops

at the end of the Section.

[13]Without loss of generality, we assume that both entrepreneurs have the same private benefit B.

to $P_H R - I - \Delta C > 0$.[14] Similarly, when $C \leq \tilde{C}$, the profit in the presence of the externality on firm 1 drops to $P_H(R + C - \Delta C - B/(\Delta P)) + (1 - P_H)(C - \Delta C) - I$ when $C \leq \tilde{C}$. In sum, the monopoly investor's profit on firm 1 drops by ΔC.

This result implies that the individual rationality constraint of the investor now considers the additional profit obtained from financing both firms. Put differently, the monopoly investor only wants to fund firm 2 whenever it makes additional profits which are at least as large as ΔC. Otherwise, the investor prefers to forego the investment opportunity as it would undermine the profits it makes on firm 1 too much, all this despite firm 2's project featuring an originally positive NPV.

As before, the monopoly investor needs to make sure that firm 2's constraints (i.e., IR_2 and IC_2) are fulfilled. Two cases are relevant.

1. $P_H Z - I - \Delta C < 0$. In this event, firm 2 is rationed irrespective of its level of cash at hand A. The reason is that the externality that firm 2 generates on the collateral value of firm 1 (and thus the investor's profits on firm 1) make this a negative NPV project from the investor's point of view. In the absence of this externality, firm 2 would not be rationed. As such, it is because of the investor's legacy position and resulting asset-side overhang brought by the firm's value proposition (e.g. technological innovation) that firm 2 is in turn rationed.

2. $P_H Z - I - \Delta C > 0$. In this case, the project is a positive NPV project even after accounting for the negative externality on firm 1. We then need to analyze which constraint binds to determine the investor's decision and profits. Let $\hat{A} \equiv (BP_H)/(\Delta P)$.

   - When $A \geq \hat{A}$, the IR constraint of firm 2 binds. As a result, the profit of firm 2 then equals zero and the net extra profit the monopoly investor derives from firm 2 then becomes:
   $$P_H Z - I - \Delta C > 0.$$
   - When $A \leq \hat{A}$, firm 2's IC constraint binds. The entrepreneur's profits then equals $(P_H B)/(\Delta P) - A$. The monopoly investor's profit becomes
   $$P_H(Z - B/(\Delta P)) - (I - A) - \Delta C.$$
   The latter is positive whenever $A \geq I - P_H(Z - B/(\Delta P)) + \Delta C \equiv \bar{\bar{A}}$. The implication is that firms with $A \leq \bar{\bar{A}}$ are rationed, while some would have been granted funding in the absence of the asset-side overhang faced by the monopoly investor.

Proposition 1 summarizes the results for a monopoly investor's decision to fund a new project

[14] The assumption of no pass-through to firm 1 is not crucial for our analysis. Even if the investor would have complete pass-through and thus act as a debtholder, the bank would still face the negative externality when firm 1 fails. We elaborate on this later in the Section.

in presence of a negative externality between the new project and the investor's legacy of pledged collateral.

Proposition 1. *In presence of an externality $\Delta C > 0$ on an existing firm's project (firm 1), the monopoly investor faces an asset-side overhang and decides to ration another firm's project (firm 2) if*

- $\Delta C > P_H Z - I$
- *When $\Delta C \leq P_H Z - I$, firm 2 is rationed if $A \leq \bar{\bar{A}}$ where $\bar{\bar{A}}$ increases monotonously with ΔC*

Figure 1 graphically illustrates the investor's profit from funding the firm's new project in presence of negative spillovers. The green line shows the profits of the investor as a function of A. It shows that firms with $A \leq \bar{\bar{A}}$ are constrained since the investor cannot realize positive extra profits. For firms with $\bar{\bar{A}} \leq A \leq \hat{A}$, the investor realizes positive profits which are increasing in A. They are however lower with ΔC compared to the situation without legacy position in firm 1. Finally, when $A \geq \hat{A}$, the investor realizes the entire NPV of the project net of the externality generated on firm 1 (i.e., the investor's net profit is lowered with ΔC – the difference between the blue and green line). Note that when ΔC is larger than the NPV of the project, it rations firm 2 independent of its amount of cash at hand, i.e., the asset-side overhang faced by the monopoly investor leads her to fully ration firm 2.

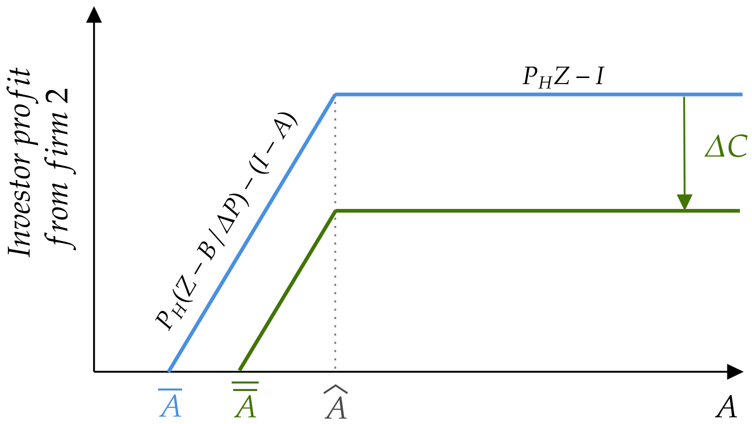

Figure 1: Monopoly investor profits from funding a firm in presence of externality ΔC, as a function of the amount of cash A brought by the firm.

2.2 The role of the intermediary market structure

The previous Subsection assumed that conditional on funding, the investor extracted all remaining rents. We now study a market where intermediaries or investors compete with each other, i.e., all the bargaining power is transferred to the firm.[15] Below, we show that previous results

[15] In a competitive setting, we have to consider the individual rationality constraint (IR_B) faced by the competitive investor on top of the IR and IC constraints on the firm's side. To grant funding, the investor needs to fulfill the

depend on the distribution of the asset-side overhang faced by different investors. The spread in asset-side overhang across investors will be a crucial determinant of rationing. This then allows us to derive empirical predictions that will inform our empirical investigation.

2.2.1 Investors with identical asset-side overhang

Let us recover the setting where firm 2 requests a loan to fund an innovative project which entails a devaluation of incumbent firms' collateral. Investors are so far assumed to be homogeneous in that they have the same legacy of granted loans. This uniformly exposes them to the negative externality such that they face an identical asset-side overhang. Let us further assume for now that investors know about each others' exposures to the externality (i.e, complete information setting). We discuss the role of information structure on our results at the end of this Section.

When there is a negative externality ΔC on the legacy position of investors, the individual rationality constraint of the investor changes: $IR_B = Z_B \geq \frac{I+\Delta C-A}{P_H}$. Intuitively, an investor only wants to engage firm 2 when it is also compensated for the negative impact on its incumbency position (i.e., impact on collateral). This is rational given that each investor knows that all other investors face the same condition. We then obtain the following set of constraints combinations:

- When $A \geq \hat{A}$, the IR of firm 2 binds. We have that $Z \geq Z_2 + Z_B = \frac{A}{P_H} + \frac{I+\Delta C-A}{P_H}$ which yields $Z \geq \frac{I+\Delta C}{P_H}$. Firm 2's profit Z_2 is then determined by $P_H Z - (I + \Delta C)$.
- When $A \leq \hat{A}$, the IC binds. We have that $Z \geq Z_2 + Z_B = \frac{B}{\Delta P} + \frac{I+\Delta C-A}{P_H}$ which yields $A \geq I + \Delta C - P_H(Z - \frac{B}{\Delta P}) \equiv \bar{\bar{A}}$. As a result, if $A \geq \bar{\bar{A}}$, firm 2's profits are determined by $P_H Z - (I + \Delta C)$. If $A < \bar{\bar{A}}$, the firm is rationed. In absence of negative externality, a firm with $\bar{A} \leq A < \bar{\bar{A}}$ would have obtained external financing.

Note that, in this bargaining power setting (i.e., all rent goes to firm), the entering firm endogenizes the negative externality and leaves part of the revenue to the investor to compensate for the loss ΔC. Even when obtaining external finance, profit opportunities are reduced for innovative firms in case of homogeneous asset-side overhang faced by competitive investors. Proposition 2 summarizes the rationing result.

Proposition 2. *In presence of a homogeneous externality $\Delta C > 0$, a competitive investor faces an asset-side overhang and decides to ration the new firm's project if $A < \bar{\bar{A}}$ where $\bar{\bar{A}}$ increases monotonously with ΔC. In absence of a negative externality, a firm with $\bar{A} \leq A < \bar{\bar{A}}$ would have obtained external funding.*

following constraint: $R_B \geq (I - C)/P_H$. Where R_B is the payment made to the investor by the firm on top of the collateral C. When analysing the full set of constraints, we observe that: (i) both individual rationality constraints (IR and IR_B) are satisfied whenever $R_E + R_B \leq R$, or $I \leq P_H R$ - this condition is independent from collateral and is fulfilled given that the project has positive NPV - and (ii) the firm's incentive compatibility constraint and the investor's individual rationality constraint (IC and IR_B) are satisfied whenever $R_E + R_B \leq R$, or $C \geq \underline{C} \equiv I - P_H(R - B/(\Delta P))$. Similar to Lemma 1, investments are made when the firm pledges collateral C larger than $\underline{C}$. However, given the change in bargaining power, the firm now appropriates all profit which accounts for $P_H R - I$.

2.2.2 Investors with heterogeneous asset-side overhang

We now depart from the set-up in which investors feature identical asset-side overhang and allow for investors with different legacy positions at risk. Investors may face heterogeneous legacy positions for various reasons. A direct one may stem from investors having different market shares related to the same externality. Another one occurs because they employ different collateral requirements, or accept collateral with different loadings on the negative externality. In what follows, we are agnostic about the reason behind their different legacy positions and capture it through ΔC_i for each investor i in the intermediary system.

We posit that the extent of rationing faced by firm 2 will be determined by the investor with the lowest externality: $i^* = \arg\min_i\{\Delta C_i\}$. The distance between $\bar{A}$ and $\bar{\bar{A}}_{i^*}$ determines the values of A for which firm 2 is rationed due to the negative externality, while ΔC_{i^*} determines the reduction in the profit of the entering firm. As such, firm 2 now only needs to internalize the externality faced by the investor with the lowest legacy position. Furthermore, in the absence of any other friction (e.g., if information on legacy positions becomes private), investors $i \neq i^*$ are willing to fund firm 2 for $A \geq \bar{\bar{A}}_{i^*}$ even though this hurts their legacy portfolio. The reason is that, while every investor is better off rationing when $A < \bar{\bar{A}}_{i^*}$, they know that firm 2 is able to get a loan from investor i^* once $A \geq \bar{\bar{A}}_{i^*}$. They would therefore face this negative externality and reduction in overall profits independent of whether they or another investor originates firm 2's external financing.

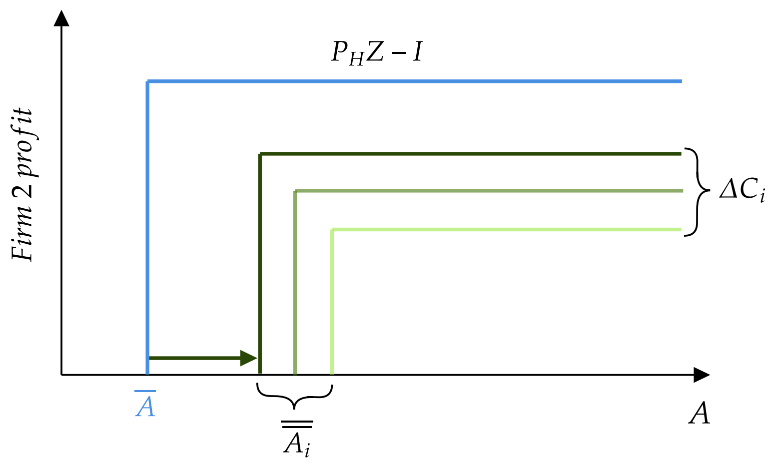

Figure 2: Firm profits with external financing from competitive investor in presence of heterogeneous externalities ΔC_i, as a function of the amount of cash A brought by the firm.

Proposition 3 summarizes the rationing result and Figure 2 illustrates the profit of firm 2 as a function of A and the distribution of shocks $\{\Delta C_i\}$.

Proposition 3. *In presence of heterogeneous externalities ΔC_i, investors with $\Delta C_i > 0$ face an asset-side overhang and firm 2's project is rationed if $A < \bar{\bar{A}}_{i^*}$ where $i^* = \arg\min_i\{\Delta C_i\}$, that is, i^**

is the investor with the lowest exposure to the negative externality. When $A \geq \bar{\bar{A}}_{i^*}$, any investor is willing to fund firm 2's project.

2.3 Discussion and hypothesis development

We close the theoretical part of this paper by discussing the following points: the nature of the collateral and the type of investments our model implies, the impact of information structure, the extension of our results to include negative externalities on the probabilities of default of the incumbent firm (in the absence or jointly with the effects over collateral) and the empirical implications of our results.

Nature of collateral. Our analysis regarding firm 1 and firm 2 makes an important distinction between the nature of the own funds a firm brings into the project. While firm 1 brings inside collateral C (i.e., assets it owns such as machines), firm 2 brings cash A to the project. In the absence of an externality, this inside collateral could be seen as "quasi-cash" as it is risk-free. However, due to the externality, an important distinction between inside collateral and cash or outside collateral (e.g., the entrepreneur's own house or government bonds) can be made. While cash or outside collateral is not subject to the externality and keeps its value independent of the entry of firm 2, inside collateral becomes risky due to its exposure to firm 2's new project. This implies that cash and inside collateral are not perfect substitutes to the extent they have different exposure to shocks.[16]

Type of investments. While our modeling of investors is generic, the asset overhang mechanism we analyse relates to investments of an illiquid nature. In fact, the overhang process results from a negative shock on the asset-side which the investor can only prevent by barring the firm originating the externality from entering the market. Should securitisation of investments be possible and the cost of offloading them from the investors' balance-sheet be negligible, an investor could decide to sell off assets exposed to the negative externality before funding firm 2. As such, the types of investment our model relates to would cover primarily issued funds with no or highly illiquid secondary markets such as long term corporate debt held by banks or private equity held by venture capital investors.

Information structure. According to our results, when multiple investors compete, the rationing barrier is determined by the investor with the lowest exposure to the negative externality. This result relies on other investors knowing about this exposure and adjusting their offer accordingly. So far, we have assumed that investors had complete and reliable information about the underlying market structure.

[16] The literature on collateral often considers that collateral has a lower value to the lender than to the borrower. Our approach assumes that collateral has equal value to both lenders and borrowers.

First, note that, in practice, a complete information scenario could be obtained through mandatory disclosure frameworks such as the publication of annual accounts/reports which would contain the needed information for competitors to infer exposures. Depending on the necessary level of granularity to infer exposures, other channels could include market-sourced information through analysts, or repeated interactions among competitors. In the context of green externalities which we discuss in the next Section, transparency exercises related to climate stress tests could obtain the exposure information required for our assumption to hold.

Next, consider the case where information is asymmetric (i.e., exposure information is private at the moment of the funding request). Our results obtain as long as information on the lowest exposure in the system ($\min\{\Delta C_i\}$) is revealed. Let us illustrate with the following procedure. Assume the firm sequentially and repeatedly applies for the same funding request to all investors while informing them on the best quote received so far. The firm stops when no new offer is made and chooses the best offer received. This multiple round request-for-quote process would produce the information required to sustain our theoretical results. That is, when a competing investor i decides to make an offer or ration the firm, it can either choose to act as if no competing investor were active (i.e., set the rationing barrier to $\bar{A}_i$) or align with the lowest offer made so far (i.e., $\min\{\bar{A}_k\}$ where $k \in K$ is the set of investors so far visited by the firm). This process converges towards $\min\{\bar{A}_i\}$.

We conjecture that, as long as all participants are truthful and communication channels are error-proof, any such mechanism should support our results. However, once we allow for communication errors (e.g., trembling hand) or strategic behavior from the borrower (e.g., cheap talk), the market may unravel and a spiraling down of offers could eventually eliminate the asset overhang problem.[17] The following empirical Section of the paper will therefore also be used as a test to support the information structure assumptions underpinning our model. A falsification test would be that, should unraveling dominate, we would not observe an effect of market structure on rationing.

Externality on probability of default. Our model considers externalities on collateral values. Other externalities are possible that lead to qualitatively similar insights and conclusions. For example, the financing of firm 2's project could increase the probability of default of firm 1, say by q. This could, for example, stem from direct competition between the two firms. Taking the same setup as in Subsection 2.1, the implication would then be that that a monopoly investor would face a reduction in profits on firm 1 of qR_B. Put differently, qR_B plays a similar role

[17] The reason for this can be formalized as follows. Let ϵ be a noise factor in the information set, either on the side of the borrower (i.e., $A + \epsilon$) or the side of the market structure (i.e., $\min\{\bar{A}_i\} - \epsilon$). If $\epsilon \geq |A - \min\{\bar{A}_i\}|$, the investor might fear that the firm gets an offer below her expected $\min\{\bar{A}_i\}$. In order to recover from the potential loss ΔC, the investor may instead chose to add a discount λ to obtain the investment: $\bar{A}_i = I + (\min\{\Delta C_i\} - \lambda) - P_H(Z - B/\Delta P)$. Note that $\lambda \leq \min\{\Delta C_i\}$, that is, the investor will not go below $\bar{A}(\Delta C = 0)$ which corresponds to the original rationing barrier in absence of the externality, similar to the set up of Lemma 1. As a result, in presence of perturbations such as trembling hands, the market may unravel and the effect of the externality on the funding of firm 2 disappears.

as ΔC in our main analysis. Similar conclusions hold for a homogeneous intermediary market when the financing of firm 2's project leads to an identical impact on the probability of default of the portfolio held by each investor. When considering competitive heterogeneous investors, the extent of rationing faced by firm 2 is again determined by the investor with the lowest externality, i.e., $i^* = \arg\min_i\{q_i R_B\}$.

Externality on collateral and **probability of default.** The discussion above modelled each externality separately. When both externalities occur simultaneously, the externalities reinforce each other. Intuitively, an increase in default probability together with a drop in collateral value gives the monopoly investor a bigger shock as it makes it more likely to receive the lower valued collateral.

Empirical predictions. Armed with our theoretical results and the above discussion, we can formulate the following testable predictions.

1. "Legacy effect": An increase in exposures to the negative externality should lead to more rationing. This implication derives from Propositions 1 and 2.

2. "Market structure effect": An decrease in the lowest exposures to the negative externality should lead to less rationing. This implication derives from Proposition 3.

3 Empirical application: data and measurement

Our application studies the financing of environmental technological change through the lens of an asset overhang problem. In particular, we investigate whether Belgian banks ration firms engaged in developing and/or diffusing environmental technologies because of the adverse effects on their legacy borrowers.

The case of green banking barriers. An assessment of banking barriers to the green economy is an appealing application of our theory for multiple reasons. First, the banking-climate nexus constitutes a tight conceptual match with respect to our theoretical framework. Green technologies can be disruptive to the economy both in terms of underperformance of "brown" firms (e.g., business stealing) and via significant repricing of capital embodying non-environmental technologies (e.g., stranded assets).[18] Furthermore, banks are a type of investors relevant to our theory, that is, they are highly exposed to green transition risks[19] and typically hold illiquid legacy positions exposed to such externality. The Belgian economy presents itself as an appropriate case

[18]See for instance European Central Bank (2020), which flags both dimensions as key transition risks faced by the financial sector.

[19]In 2016, more than two-thirds of EU financed fossil-fuel activities came from debt, of which 55% was originated by banks which in total contributed to 43% of total EU funding to fossil-fuel firms (Gros et al., 2016).

study because (a) it is highly bank-based with limited alternative financing opportunities, (b) the banking market structure is heterogeneous[20] and (c) (part of) the economy is exposed to green transition shocks.[21]

Empirical strategy roadmap. We develop our evidence in three steps. First, the remainder of this Section elaborates on the data sources, concepts and variables that shape our identification strategy. In particular, we discuss various measures of environmental activities, notions of product and technology market spaces where externalities materialize and their measurement. Table 1 collects and summarizes all variables/concepts discussed hereafter. Summary statistics are included in Table 2.

Second, Section 4 develops an empirical framework to test for both the existence and nature of spillovers driven by a firm's environmental activity. The setting allows us to connect to the theory by identifying which activity channels trigger externalities in terms of both performance (i.e., qR_B) and asset devaluation (i.e., ΔC). Importantly, it allows us to distill for each environmental firm, a list of brown firms that are exposed to potential externalities of the green firm.

Finally, drawing on these findings, Section 5 constructs a measure of an individual green firm's impact on banks' corporate credit portfolios. Leveraging this metric, we investigate whether banks decide to ration green firms in order to protect their incumbent borrowers.

3.1 Environmental activities

We differentiate forms of green activities by separating innovation from diffusion according to the following definitions:

Definition 3.1 (Green activity)**.** *Green activities are of two types:*

- ***Green innovation*** *relates to the development of new green technology*
- ***Green diffusion*** *relates to the dissemination of incumbent green technology*

Below we delineate the datasources leveraged to measure both forms of green activities and how they enter our empirical framework.

Green innovation. In order to identify firms that engage in green innovation, we rely on the Patent Statistical database (PATSTAT) of the European Patent Office (EPO). PATSTAT classifies each patent application according to the International Patent Classification (IPC). Based on this IPC, the EPO has developed a dedicated taxonomy to flag patents that embody a climate change

[20] Four major banks dominate the economy along with smaller and more specialized banks. Market shares vary across time and sectors.

[21] For instance, a report by the National Bank of Belgium on the real estate credit market states that energy efficiency is a determining factor for both collateral value and probability of defaults of mortgage loans (NBB, 2020).

mitigation technology (CCMT).[22] These patented CCMTs take on two types of environmental innovations: process innovations or product innovations (Cohen and Klepper, 1996).

Definition 3.2 (Green innovation)**.** *Green innovation is of two types:*

- ***Green process innovation*** *embodies a novel, more environmentally friendly way to produce an existing good.*[23]

- ***Green product innovation*** *delivers novel marketable goods/services that either reduce environmental pressures or are designed to be cleaner and more resource efficient when operated than conventional products.*

Sorting between both types of innovation is instrumental as both activities can impose different externalities on the performance and collateral value of neighboring firms. On the one hand, by offering a novel green alternative, product innovation can radically disrupt performance of incumbent brown product market rivals thereby driving up their probabilities of default. On the other hand, by greening current production facilities, process innovation can lower the marketability of environmentally unfriendly assets owned by other firms thereby driving down the value of the collateral pledged to banks.

From the PATSTAT database we extract individual CCMT patent applications. In order to distinguish between process and product innovation, we apply text analytic procedures on the the patent title, abstract and list of patent claims. The latter is an exhaustive list which defines exactly what is claimed by the invention and what is sought to be protected.[24] In practice, we rely on a validated dictionary prepared by Banholzer et al. (2019) to text-mine each individual claim, abstract and title for keywords known to be associated with either process or product innovations and subsequently aggregate the incidence up to the patent level. Relevant details are provided in Appendix A.[25] In our baseline estimates, a firm is tagged as a green process innovator (Green process innovation$_i$=1) if it has patented at least one green process innovation. A firm is tagged as a green product innovator (Green product innovation$_i$=1) if it has patented at least one green product innovation.[26]

Green diffusion. In order to identify firms that engage in green diffusion, we rely on the annual Belgian Structure of Business Survey (SBS). This survey is an unbalanced panel from 2008 –

[22]CCMTs include a wide array of technologies related to, e.g., (a) real estate efficiency (e.g., thermal performance, integration of renewable materials, etc.), (b) waste and wastewater treatment (e.g., bio-packaging, etc.), (c) energy generation (e.g., efficient combustion, renewable energy sources, etc.), etc. See OECD (2015) for the development of this taxonomy. Other papers that have relied on the OECD patent taxonomy to infer green innovation include de Haas and Popov (2022); Popp (2019).

[23]In particular, green process innovation targets, i.a. a reduction in air or water emissions, lessening water consumption, using pollution-control equipment, improving resource and energy efficiency, and switching from fossil fuels to bio-energy (Xie et al., 2019).

[24]For instance, an individual claim could read "*[1] A device for treating wastewater...*".

[25]Our textual analysis is similar in spirit to Bena et al. (2021), Bena and Simintzi (2019) and Banholzer et al. (2019).

[26]Appendix A revisits the time dimension underlying CCMT patenting at the firm level.

2018. Firms with a turnover larger than €5 mil. or more than 20 employees are automatically included in the survey. For firms below both thresholds, the sampling strategy is set up so as to to achieve maximum representativeness while aiming to minimize the administrative burden on small firms. The sample covers 80% of aggregate sales and 60% of aggregate employment. Participation is mandatory and administrative sanctions for inaccurate or incomplete reporting safeguard the high quality of the data. Particularly relevant to our analysis is the fact that the SBS systematically surveys firms on their share of (a) environmental sales & (b) environmental investments. Consequently – and consistent with the survey definitions – we distinguish between two types of green technology diffusion.

Definition 3.3 (Green diffusion)**.** *Green diffusion is of two types*[27]*:*

- ***Green adoption*** *entails investment in environmental capital goods that embody clean technologies and/or end-of-pipe technologies.*[28]
- ***Green provision*** *entails the selling of goods and/or services that either reduce environmental pressures or are designed to be cleaner and more resource-efficient when operated than conventional products.*

Distinguishing between provider and adopter types is warranted as both activities can impose different externalities on the performance and collateral value of neighboring firms. On the one hand, a green provider offering green substitutes potentially distorts the performance of incumbent brown firms operating in the same product market, thereby driving up their probabilities of default. On the other hand, by greening the capital stock, the firm potentially drives down the marketability of capital embodying brown technologies.

Leveraging the SBS data, we tag a firm as a green provider ($\text{Green provision}_i = 1$) if it sells green goods/services. Note that we further condition the selection on the firm not being a green product innovator as we focus on firms that sell incumbent technologies rather than firms that develop green technologies. Similarly, we tag a firm as a green adopter ($\text{Green adoption}_i = 1$) if it reports a non-zero fraction of its investment in green capital goods, conditional on the firm not being a green process innovator. If a firm engages in at least one these two activities, it is labelled as a green diffusor ($\text{Green diffusion}_i = 1$).

Taking stock. Our framework distinguishes between four forms of green activities: process innovation, product innovation, diffusion by provisioning, diffusion by adopting. Figure 3 provides a schematic illustration and documents the number of firms in our estimation sample that engage

[27]These survey definitions align with the glossary put forward by the European Environmental Agency.

[28]*End-of-pipe technologies* encompass (ex-post) pollution control technologies, using equipment that is added as a final process step to capture pollutants and waste prior to their discharge (e.g., NO_x filters). *Clean technologies* embody (ex-ante) pollution prevention technologies, referring to modifications to the manufacturing process that reduce any negative impact on the environment during material acquisition, production, or delivery (e.g., photovoltaic panels, carbon-efficient vehicle routing software).

in each green activities. In the remainder, we define the variable $\text{Green}_i = 1$ if the firm engages in at least one type of green activity. Henceforth, we refer to firms that engage in none of the four green activities as brown firms ($\text{Green}_i = 0$).

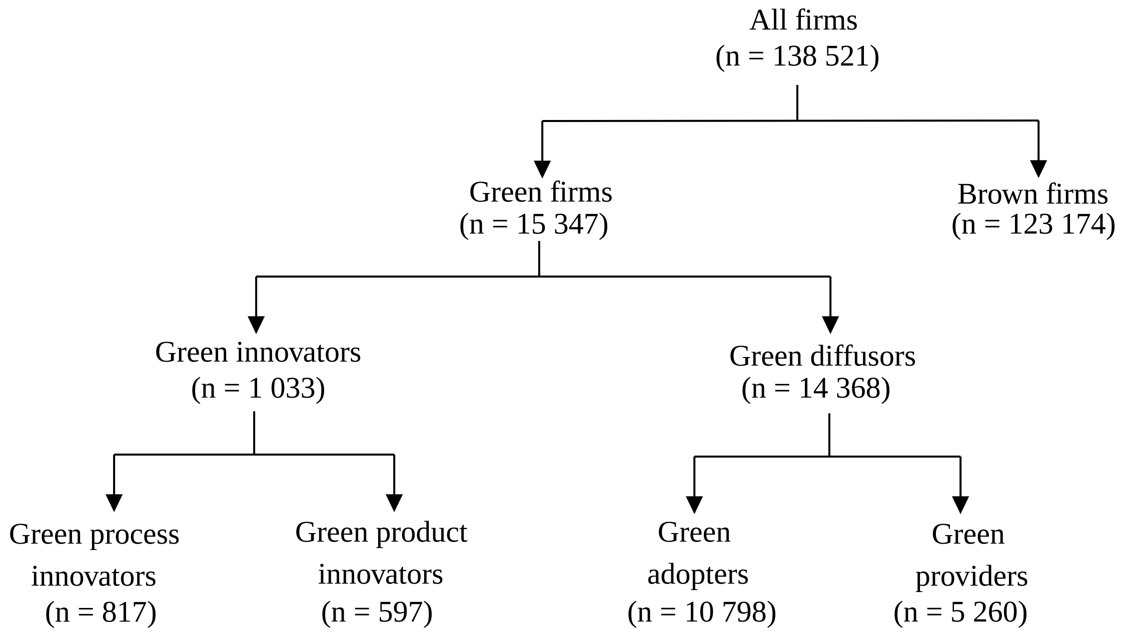

Figure 3: Incidence of various green activities by Belgian non-financial firms.

3.2 Economic spaces: product & technology markets

There can be several forms of interactions between firms where spillovers materialize. Following Jaffe (1988), we distinguish between two economic spaces, namely, the *product space* and the *technology space*. For each space, we consider pairwise proximity measures (i.e., closeness).[29]

Definition 3.4 (Economic spaces). *Green spillovers materialize over two economic spaces.*

- ***The product space*** *is the economic space where firms overlap in output markets. For each pair of firms (i, j), their* ***product space closeness*** *is given by*

$$\Pi_{ijt} = \frac{\boldsymbol{\pi}'_{it}\boldsymbol{\pi}_{jt}}{\sqrt{\boldsymbol{\pi}'_{it}\boldsymbol{\pi}_{it}}\sqrt{\boldsymbol{\pi}'_{jt}\boldsymbol{\pi}_{jt}}},$$

  where $\boldsymbol{\pi}_{it} = (\pi_{i1t}, \pi_{i2t}, ..., \pi_{iKt})'$ is a vector containing the share of firm-level sales to each sector $k = 1, ..., K$.

- ***The technology space*** *is the economic space where firms overlap on input markets. For each pair of firms (i, j) the level of bilateral input similarity is determined by their* ***technology space***

[29] Proximity measures in product and/or technology spaces were previously leveraged by Branstetter and Sakakibara (2002); Bloom et al. (2013); Lucking et al. (2019).

closeness *given by*

$$T_{ijt} = \frac{\boldsymbol{\tau}_{it}'\boldsymbol{\tau}_{jt}}{\sqrt{\boldsymbol{\tau}_{it}'\boldsymbol{\tau}_{it}}\sqrt{\boldsymbol{\tau}_{jt}'\boldsymbol{\tau}_{jt}}},$$

where $\boldsymbol{\tau}_{it} = (\tau_{i1t}, \tau_{i2t}, ..., \tau_{iKt})'$ *is a vector containing the share of firm-level procurements from each sector* $k = 1, ..., K$.

Note that Π_{ijt} is an uncentered correlation and ranges between zero (if firms are active in completely different output markets) and one (if firms operate in exactly the same output space). The measure is symmetric such that $\Pi_{ijt} = \Pi_{jit}$. Year-on-year variation in Π_{ijt} arises because firms move into (out of) similar customer markets.[30] Finally, a high value for T_{ijt} signals that both firms have a very similar capital and intermediate input portfolio.

We calibrate T_{ijt} and Π_{ijt} based on the business–to–business (B2B) transactions dataset. This dataset, based on VAT filings, runs from $2012 - 2018$ and documents all directional domestic sales from firm i to firm j (nominal, aggregated at the annual level). We merge information on the 5-digit sector in which each firm resides. This allows us to calibrate $\boldsymbol{\pi}_{it}$ and $\boldsymbol{\tau}_{it}$ as the vectors containing shares of firm i sales (procurements) to (from) sector k in total sales (procurements) at time t.[31]

An example with three firms. Let us illustrate possible interactions between different firms according to both spaces. Figure 4 portrays stylized product and technology spaces for three real world firms: DHL Aviation (aerospace and aviation freight company), Brussels Airlines (airline company) and Maersk (shipping company). In the technology space, DHL Aviation and Brussels Airlines are related as they require similar inputs (airplanes). However, the two companies serve a different customer base (freight vs. customer transport) and therefore do not overlap in the product space. Similarly, as DHL Aviation and Maersk compete on cross-Atlantic freight transportation services – the former by air and the latter by ocean – they share a similar customer base but are distant in the technology space.

[30] Two firms can be close in the product space because they offer substitutes or complements. Below we will focus exclusively on negative externalities. Since product market rivalry is only relevant if the products in question are substitutes, we put $\Pi_{ijt} = 0$ if firm i and j are in different sectors.

[31] The B2B records sales between two separate VAT identifiers and therefore also records intra–group trade. Consistent with the patenting approach detailed in Appendix A, we correct for group structures by cancelling out all intra–group trade flows prior to computing $\boldsymbol{\pi}_{it}$ and $\boldsymbol{\tau}_{it}$. In addition, we impose $T_{ijt} = \Pi_{ijt} = 0$ if firm i and j reside in the same corporate group in order to rule out negative externalities from one group member to another.

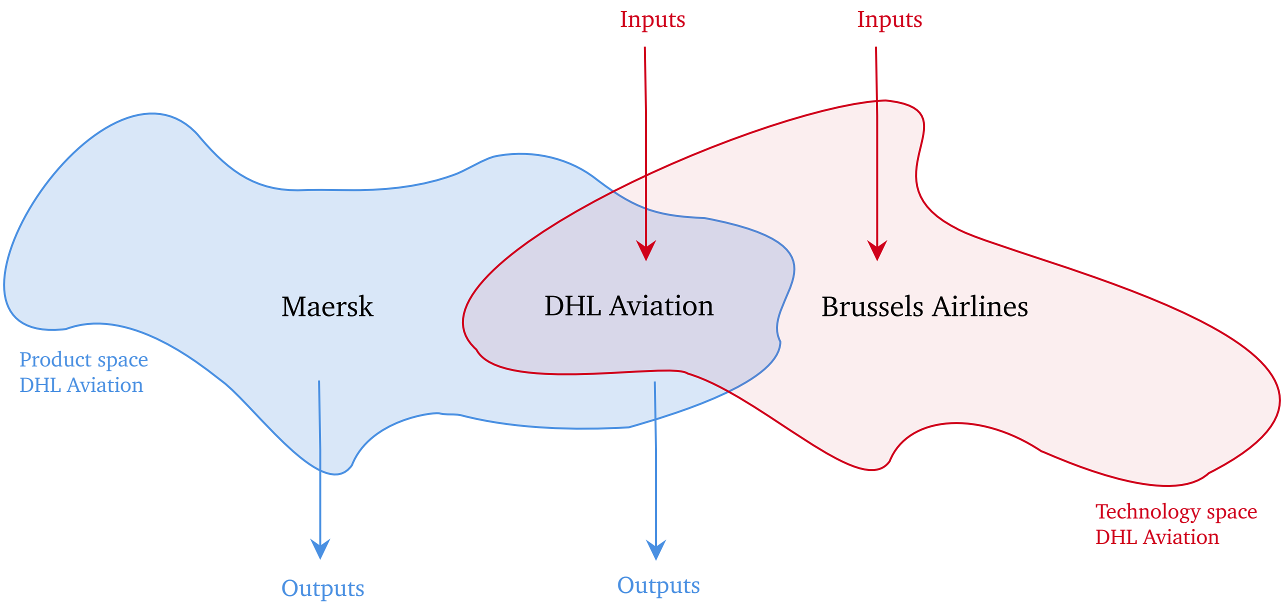

Figure 4: Product & technology spaces (stylized example).

3.3 Two types of externalities

Our theoretical model relies on two ways in which technological innovation/diffusion may affect a bank's incumbent client: (a) an increase in the probability of default (i.e., $qR_B > 0$) and (b) a decrease in the value of the collateral pledged by the client (i.e., $\Delta C > 0$). Our baseline results rely on various firm–level metrics that proxy both dimensions. Complementary results, restricted to bank borrowers, draw on direct measurements of default probabilities and pledged collateral values. The former (latter) set of variables are introduced below (in Section 4).

Performance. A firm's green activity may affect a brown firm's performance by means of competition and business stealing, thereby increasing its probability of default. We measure this firm–level externality via the change in sales to households (Δ ln (HH sales$_{it}$)) and corporate customers (Δ ln (B2B sales$_{it}$)). Appendix B.1 explores alternative performance metrics.

Asset value. Green activities can depress market values of laggard assets that are typically pledged as collateral (i.e., $\Delta C > 0$). We infer a devaluation of pledgeable assets from the annual accounts and the SBS survey. First, Writedown$_{it}$ flags whether the firm has booked exceptional writedowns on tangible fixed assets. Following generally accepted accounting principles, a firm needs to resort to such amortization if there exists a significant (and persistent) discrepancy between the book value and the value at which the asset could be liquidated. Text-book examples explicitly include technological obsolescence through technological progress as a relevant case in point. Second, Liquidation loss$_{it}$ indicates whether the firm has suffered losses when liquidating tangible fixed assets on secondary markets (liquidation value minus book value).[32]

3.4 Taking stock

Table 3 summarizes the four granular green activities (and combinations thereof) that we consider in this paper ($\mathcal{A}$), the two externalities that we explore on adjacent firms ($\mathcal{E}$), and the economic space over which they materialize ($\mathcal{S}$). In the following Section, we set up an econometric framework to tease out whether – and to what extent – a particular green activity by firm j imposes a negative externality on firm i.

4 Identifying green externalities

Leveraging the variables and concepts introduced in Section 3, this Section identifies and quantifies the presence of green externalities. Section 5 subsequently draws on these results to construct granular measures of a banks' exposure to green activity.

4.1 Empirical framework

Green innovation spillovers. In order to verify whether green innovation impacts the performance/asset valuation of neighboring brown firms, we estimate the following dynamic panel model

$$\begin{aligned} y_{it} =& \beta_1 \times \overline{\Delta d(i,t)}^{\mathcal{A}=\text{green product innovation}}_{\mathcal{S}=\text{product space}} + \beta_2 \times \overline{\Delta d(i,t)}^{\mathcal{A}=\text{green process innovation}}_{\mathcal{S}=\text{product space}} + \\ & \beta_3 \times \overline{\Delta d(i,t)}^{\mathcal{A}=\text{green product innovation}}_{\mathcal{S}=\text{technology space}} + \beta_4 \times \overline{\Delta d(i,t)}^{\mathcal{A}=\text{green process innovation}}_{\mathcal{S}=\text{technology space}} + \\ & \boldsymbol{\zeta}' \boldsymbol{z}_{it-1} + \varepsilon_{it} \end{aligned} \tag{1}$$

where y_{it} equals either a performance metric or a tangible asset value (pledgeability) metric.

Covariate $\overline{\Delta d(i,t)}^{\mathcal{A}=\text{green product innovation}}_{\mathcal{S}=\text{product space}} = M^{-1} \sum_{m=1}^{M} \sum_{j=1}^{J} \left(\Delta \Pi_{ijt-m} \times \text{Green product innovation}_j \right)$ captures the average annual entry of green product innovators in the product space of firm i. In particular, a value of $\overline{\Delta d(i,t)}^{\mathcal{A}=\text{green product innovation}}_{\mathcal{S}=\text{product space}} = 1$ implies an average annual entry rate of 1 green product innovator in the exact same product space as firm i throughout $t-1$ and $t-M$. Coefficient β_1 then quantifies the performance/asset markdown due to these increased green product innovation activities of neighboring firms. The other three covariates of interest are defined in a similar vein and detailed in Table 1. Descriptives can be found in Table 2.

[32] Note that both of these measures are imperfect for several reasons: (a) exceptional writedowns are idiosyncratic by definition and only a small part of the variation is relevant to our analysis, (b) book values and market values do not always coincide, and (c) the underlying assets do not necessarily refer to actual collateral pledged to banks. We later address these concerns by leveraging richer collateral data restricted to firms with banking credit.

Control vector $\boldsymbol{z}_{it}$ saturates the model with firm fixed effects (FE), region $\times$ time FE, sector $\times$ time FE and firm–level controls – all defined in Table 1 – from the annual accounts (i.e., total assets (logged), leverage and age of tangible fixed assets (logged)). In order to control for contemporaneous product market competition from brown firms, we include "Brown product space entrants$_{it-1}$", which reflects the additional mass of brown competition in the product space throughout $t-1$ and $t-M$. Similarly, "Brown technology space entrants$_{it-1}$" controls for novel (but non-environmental) capital investments by firms in the shared technology space.

Green diffusion spillovers. In order to verify whether green diffusion impacts the performance/asset valuation of neighboring brown firms, we estimate the following dynamic panel (where y_{it} takes on the same metrics as before):

$$\begin{aligned} y_{it} = &\beta_1 \times \overline{\Delta d(i,t)}^{\mathcal{A}=\text{green provision}}_{\mathcal{S}=\text{product space}} + \beta_2 \times \overline{\Delta d(i,t)}^{\mathcal{A}=\text{green adoption}}_{\mathcal{S}=\text{product space}} + \\ &\beta_3 \times \overline{\Delta d(i,t)}^{\mathcal{A}=\text{green provision}}_{\mathcal{S}=\text{technology space}} + \beta_4 \times \overline{\Delta d(i,t)}^{\mathcal{A}=\text{green adoption}}_{\mathcal{S}=\text{technology space}} + \\ &\boldsymbol{\zeta}' \boldsymbol{z}_{it-1} + \varepsilon_{it} \end{aligned} \tag{2}$$

Covariate $\overline{\Delta d(i,t)}^{\mathcal{A}=\text{green provision}}_{\mathcal{S}=\text{product space}} = M^{-1} \sum_{m=1}^{M} \sum_{j=1}^{J} \left(\Delta\Pi_{ijt-m} \times \text{Green provision}_j \right)$ captures the average annual entry of green goods/services providers in the product space of firm i. A value of $\overline{\Delta d(i,t)}^{\mathcal{A}=\text{green provision}}_{\mathcal{S}=\text{product space}} = 1$ implies an average annual entry rate of 1 green product/service provider in the exact same product space as firm i throughout $t-1$ and $t-M$. Coefficient β_1 quantifies the performance/asset markdown due to the increased presence of green alternatives in the product space. The other three covariates of interest are defined in a similar vein and elaborated in Table 1. The control vector is the same as in Eq. (1).

Estimation details. A few estimation details bear noting. First, Eq. (1) & (2) are estimated on the set of non–green innovators (non– green diffusors), respectively. Second, all standard errors are clustered at the firm level. Third, in our reported results we take $M = 3$ but find our results to be robust to the lag length specification. Fourth, unless stated otherwise, all specifications include a lag of the dependent variable to control for reverse causality: an ongoing trend of deteriorating performance/asset valuation might have triggered the enhanced green presence captured by the covariates.

4.2 Results on externalities: a firms' perspective

Baseline results. Table 4 contains the results for both innovation (Eq. (1) in Panel A) and diffusion (Eq. (2) in Panel B) when y_{it} proxies changes in performance (column (1)–(2)) and asset devaluation (column (3)–(4)).

First, we observe that green product innovation by product market rivals pushes down performance of incumbent brown firms (Panel A). While the incidence of a product innovator entering a product space is rare (see Table 2), when it happens, the effect on incumbents is sizeable; an annual entry rate of 1 environmental product innovator in a firm's product market pushes down household sales of brown firms by 6.7 % and corporate sales by 2.2%. A similar, but milder, result holds for providing incumbent green alternatives to that of brown product market peers (Panel B): green product market rivals push down household sales of brown firms by 0.98% and corporate sales by 0.4%. Green diffusion is found to be less destructive than innovation, yet more common.

Second, Table 4 suggests that both green process innovation and investment in environmental capital by product market rivals has a negative effect on performance of brown incumbents. Both activities are likely to give the environmental firms an edge in the product market, thereby creating a performance wedge. Table A.1 in Appendix A supports this "cost-reducing mechanism" by showing that green adopters and green process innovators exhibit lower average consumption of electricity, gas and smaller wastage expenses (per value added).

Finally, green process innovation and adoption of environmentally friendly capital by technology peers makes it more likely that brown firms liquidate their fixed assets at a loss and radically depreciate their assets in order to align the book value of their tangibles with market values.

Summary and discussion. We observe four sets of firms affected by each environmental activity (summarized in Table 5):

- **Externality 1.** Green product innovators negatively affect brown incumbents in the same product space.
- **Externality 1'.** Green providers negatively affect brown incumbents in the same product space.
- **Externality 2.** Green process innovators negatively affect firms in the same product & technology space.
- **Externality 2'.** Green adopters negatively affect firms in the same product & technology space.

The first externality has antecedents in a more generic innovation literature: performance decline through (generic) product innovation by product market rivals was formalized by Jones and Williams (1998) and Jones (2005) while shown to be empirically operative by Bloom et al. (2013). Our results corroborate these findings in the niche application of environmental innovation. Moreover, we show these performance spillovers to also operate when firms offer green products that embody a green technology they have not invented themselves (externality 1').

By externality 2, process innovation creates advantages over product market rivals through cost efficiencies (in casu environmental costs), as previously documented more generally by Griliches (1987) and Hall et al. (2009). This mechanism also applies to adopters of green capital (externality 2').

Finally, the seminal work of Aghion and Howitt (1992) argues that technological progress imposes losses on others by rendering obsolete their old manufacturing processes. Our application reveal these economic forces to devalue incumbent assets in the context of environmental process innovation (externality 2) and its widespread adoption (externality 2').

Robustness. We close this Subsection with a few points related to the estimation and set–up of Eq. (1) & (2). First, the covariates in our baseline results take a static view on environmental activities. In an ideal empirical set-up, one would observe time variation in each of the green activities. While our datasources would allow us to introduce some form of dynamics in the environmental status of firms, Appendix B.2.1 builds the case that variation through that channel is limited in our time frame under consideration.

Second, increased/decreased economic proximity between firms has multiple origins. E.g., enhanced product market closeness could stem from a brown firm starting to serve the product market on which a green firm was previously active – or vice versa. Appendix B.2.2 teases apart the summands underlying the covariates in Eq. (1) & (2) to drive out the variation less likely to be associated with externalities.

Finally, calibrating the covariates entails setting a level of granularity of the sectors in $\boldsymbol{\pi}_{it}, \boldsymbol{\tau}_{it}$. Our baseline estimates rely on the most granular level of disaggregation (5-digit level). An aggregate sector definition is expected to dilute the concept of proximity and serves as an interesting falsification test (Appendix B.2.3). Furthermore, Appendix B.2.3 studies alternative distance measures put forward by the literature (Mahalobis distance, geo-location distance).

4.3 Sets of firms at risk

We draw on the established externalities (supra) to construct the set $\mathcal{I}_{it}^{\mathcal{A}}$ of brown firms which are negatively exposed to the green activity $\mathcal{A}$ of a given firm i. This measure will allow us to calibrate the exposure of a bank's credit portfolio to the green activity of any given firm by intersecting the bank's borrowers and the set $\mathcal{I}_{it}^{\mathcal{A}}$.[33]

First, following externalities 1 and 1', the sets $\mathcal{I}_{it}^{\mathcal{A}=\text{green product innovation}}$ and $\mathcal{I}_{it}^{\mathcal{A}=\text{green provision}}$ contain all brown firms that are in the same product space of firm i. In our setting, we qualify firms to be in the same product space if their product closeness exceeds a given threshold Π^* (i.e., $\Pi_{ijt} > \Pi^*$). Second, following externalities 2 and 2', the sets $\mathcal{I}_{it}^{\mathcal{A}=\text{green process innovation}}$ and $\mathcal{I}_{it}^{\mathcal{A}=\text{green adoption}}$ contain all brown firms that are in the technology and/or product space of firm i.

[33]A well-established literature has documented the presence of positive "knowledge" spillovers from innovation on technology peers (see Hall et al. (2010) and Jones and Williams (1998) for reviews). In that literature, technology peers are firms that overlap in the patenting space (see e.g., Bloom et al. (2013); Lucking et al. (2019); Lychagin et al. (2016)) whereas our notion of technology similarity draws on (production function) input similarity. Our analysis takes no stand on the presence or absence of benign spillovers. To the extent the firms in $\mathcal{I}_{it}^{\mathcal{A}}$ also enjoy positive externalities that emanate from firm i, this will attenuate our rationing results if banks also take on board such positive spillovers.

As before, firms are said to be in the same technology space if their technology closeness exceeds a given threshold T^* (i.e, $T_{ijt} > T^*$).

Setting Π^*, T^* involves a trade-off; a too low threshold falsely joins firms in the same space while in fact they are not. In addition, a too low threshold leads to unstable sets over time (firms frequently move in and out of each other's technology/product markets over time). Reversely, a too high threshold potentially imposes too strong proximity requirements on two firms (causing two firms that are similar to be qualified as not). Going forward, we take $\Pi^* = T^* = 0.75$ and demonstrate in Appendix C.4, that our results are robust to setting different thresholds.

5 Legacy positions & bank credit rationing

In this Section we consider the perspective of banks. We first provide corroborating evidence that the firm-level externalities established in Section 4 effectively feed into the banks' assessments of their affected incumbent borrowers. We then construct a bank–firm specific measure of bank b's legacy at risk that stems from the green activities unfolded by firm i. Next, following the hypotheses spelled out in Subsection 2.3, we test whether (cross-bank heterogeneity in) this measure is related to a banks' decision to discriminate against firm i in the market for corporate credit (both in the extensive and intensive margin).

5.1 Results on externalities: a banks' perspective

Complementing the results in Subsection 4.2, we investigate whether green externalities are reflected in a bank's measures of client performance and asset pledgeability. To that end, we draw on the central corporate credit register (CCR), which, within the context of established credit relationships between firms and banks, contains information on firm default risk and value of pledged collateral (their value, type, how they are valued, by whom and when).

We measure changes in performance of a client–firm i through changes in the bank b's reported probability of default (PD$_{ibt}$). This measure directly maps to qR_b defined in our theoretical framework. Below, in order to sidestep empirical concerns related to non–linearities in the revisions of banks' PD$_{ibt}$ and heterogeneity in banks internal risk models, we focus on the direction of change (if any) in PD$_{ibt}$ between two consecutive years (increase/decrease). As a direct measure of ΔC, we consider annual changes in the market value of collateral item c pledged by firm i. We classify collateral items into three categories: financials (Financials$_{ict}$), real estate (Real Estate$_{ict}$) and physical assets (Physical Assets$_{ict}$).[34] All variables are formally defined in Table 1.

[34]The CCR tracks the date at which the value of collateral is appraised (without implying that the valuation effectively changes). Some collateral values are never revised (e.g., nominal value of a contract which does not change over time), rarely revised (e.g., some commercial real estate) or are estimated noisily (e.g., by the borrower), etc. We therefore focus on collateral items that reflect market values and are subject to an annual revaluation. As a result, the number of collateral-firm-bank observations analyzed here represents only a small subset of the population of pledged items.

We re-estimate equations (1) & (2), augmented with bank–time fixed effects, on the subset of bank-borrowers, where y_{it} now takes on riskiness and collateral valuation metrics. The results are reported in Table 6 where the structure of the table mimics that of Table 4. Corroborating externality 1 & 1' from before, the results in column (1) and (2) show that an increasing presence in the product space by green product innovators (panel A) or providers (panel B) increases the probability of an upward revision of the default probability.[35] Similarly, green process innovators and adopters render brown product market competitors more risky (externality 2 and 2'). Finally, green process innovation and green capital acquisition by firms with which a client shares the technology space drives down the value of physical assets that are pledged (column (5)). Interestingly, collateral related to real estate and financials appear immune to green activity (column (3)–(4)). This result speaks directly to our discussion in Section 2 on the nature of collateral at stake, as physical assets are more likely to represent inside collateral while outside collateral, such as real estate or financials, is more likely to be driven by other fundamentals.

In sum, these results point to evidence that green activities activate negative spillovers on brown firms which in turn translate into downgrades of credit value by the bank. Table 6 ultimately suggests that banks should care about the green channels: the externalities exist and have ramifications for their legacy portfolio.

5.2 Legacy positions at risk: measurement

Let c_{jbt} denote the percentage share of credit authorized by bank b to firm j in aggregate corporate credit granted by bank b at time t. These shares are taken from the CCR, which records all authorized credit relationships between non–financial firms and credit institutions licensed by the NBB.[36] Drawing on the sets $\mathcal{I}_{it}^{\mathcal{A}}$ defined in Subsection 4.3, we infer the share of bank b's credit portfolio that is subject to negative externalities emanating from firm i. More formally, the share of bank b's corporate credit portfolio that is negatively exposed to green activity $\mathcal{A}$ of firm i is given by:

$$\theta_{ibt}^{\mathcal{A}} = \sum_{j \in \mathcal{I}_{it}^{\mathcal{A}}} c_{jbt} \tag{3}$$

with $\boldsymbol{\theta}_{it}^{\mathcal{A}} = (\theta_{ibt}^{\mathcal{A}})$. Based on $\boldsymbol{\theta}_{it}^{\mathcal{A}}$ we generate two statistics that relate to our theory. First, $f_1(\boldsymbol{\theta}_{it}^{\mathcal{A}})$ captures the size of the externalities that firm i imposes on the aggregate banking system because of its activity $\mathcal{A}$. Our baseline estimates take $f_1(\cdot)$ to be the median across the banking market (i.e. $f_1(\boldsymbol{\theta}_{it}^{\mathcal{A}}) = Med(\boldsymbol{\theta}_{it}^{\mathcal{A}})$). Second, $f_2(\boldsymbol{\theta}_{it}^{\mathcal{A}})$ quantifies the role of differences in banks' legacy

[35] Importantly, but unsurprisingly, banks mimic the previous firm–level results which suggest that environmental innovation (panel A) is more disruptive than diffusion (panel B).

[36] The financial institutions cover both (i) branches incorporated under foreign law established in Belgium as well as (ii) banks incorporated under Belgian law. Other studies that have relied on this data source include Degryse et al. (2019); De Jonghe et al. (2020); Lenzu et al. (2021).

positions. In line with our theoretical predictions, our baseline estimates take $f_2(\cdot)$ to be the minimum across the corporate credit market (i.e. $f_2(\boldsymbol{\theta}^{\mathcal{A}}_{it}) = Min(\boldsymbol{\theta}^{\mathcal{A}}_{it})$).

Discussion. Our measurement of $\theta^{\mathcal{A}}_{ibt}$ warrants two points of discussion. First, evidently, brown firms create no legacy risk (i.e., $\boldsymbol{\theta}^{\mathcal{A}}_{it} = \mathbf{0}$ if Green$_i = 0$) and so $f_1(\boldsymbol{\theta}^{\mathcal{A}}_{it}) = f_2(\boldsymbol{\theta}^{\mathcal{A}}_{it}) = 0$ if Green$_i = 0$. Reversely, note that Green$_i = 1$ does not imply that $\boldsymbol{\theta}^{\mathcal{A}}_{it} \neq \mathbf{0}$. Stated differently, it is possible that a green firm imposes no externality on any bank in the system (i.e., $\boldsymbol{\theta}^{\mathcal{A}}_{it} = \mathbf{0}$ although Green$_i = 1$). This occurs if the firm has developed a particular green activity that does not threaten incumbent brown firms because they all operate in different product and technology spaces (and so $\mathcal{I}^{\mathcal{A}}_{it} = \varnothing$) or because the brown firms at risk are not bank borrowers.

Second, the empirical identification of rationing barriers requires that $\boldsymbol{\theta}^{\mathcal{A}}_{it}$ encompasses the full list of eligible lenders to firm i. $f_1(\cdot)$ and $f_2(\cdot)$ would be corrupted if (a) banks included in $\boldsymbol{\theta}^{\mathcal{A}}_{it}$ are not eligible lenders to firm i or, (b), if relevant eligible non-bank financiers were excluded. Due to their specific lending policy, some banks in the CCR are effectively unlikely candidate lenders to firms whose activities do not align with the banks' specific business model.[37] For this reason, when setting the perimeter of banks in $\boldsymbol{\theta}^{\mathcal{A}}_{it}$, we consider only banks that have more than 100 corporate clients & have at least 50 corporate customers in the sector in which firm i resides.[38] In Appendix C.4, we investigate the sensitivity of our results to these thresholds.

Reversely, calibrating $\boldsymbol{\theta}^{\mathcal{A}}_{it}$ based on the CCR sets the boundary of the Belgian banking sector as the relevant perimeter of eligible financiers. This implies that legacy positions of non-Belgian banks and non-bank financiers are irrelevant in our application. While the exclusion of foreign bank finance should be a concern in general, in the case of Belgium, the high matching rate between bank credit volumes registered in the CCR (which also covers foreign branches and subsidiaries with a banking license in Belgium) and that reported by the firm in their annual accounts reveals that most Belgian firms borrow exclusively from banks included in the CCR. Moreover, while outside non–bank finance, such as venture capital, is quantitatively very small in Belgium[39] (and typically not targeted at diffusors of incumbent technology), it might be an important early–stage source of finance for innovators. Nonetheless, innovators with a maturing business model typically turn to banks later in their life–cycle (e.g., after a proof–of–concept (Florida and Kenney, 1988)), implying that potential bank rationing – to prevent a scale–up/maturing of the disruptive technology – kicks in at a later phase.

[37]E.g., some financial institutions in the CCR are in–house banks that only lend to their group members (e.g. Volkswagen bank as part of the Volkswagen group). Alternatively, various branches/subsidiaries of foreign banks only lend to firms headquartered in the same country of origin as the bank (e.g., Habib Bank Ltd typically only lends to firms that engage in trade with the Pakistan region). In addition, some banks exclusively target niche industries (e.g., Banque Eni focuses exclusively on firms operative in "Oil & natural gas extraction").

[38]A filter based on sectoral expertise is justified by a nascent literature on sector–specialization (De Jonghe et al., 2020).

[39]See e.g. OECD (2015).

Descriptive statistics. Measurements of legacy positions at risk and their distribution functions are reported in Table 7. From the descriptives, we observe that firm-level legacy positions are low on a firm-by-firm basis. This is to be expected: a single firm typically only threatens a very small portion of a bank portfolio. At the same time, Appendix C.1 shows that a significant share of the aggregated bank portfolio appears at risk vis-à-vis the population of environmental firms. Such sizeable exposure makes it rational for banks to integrate their legacy stakes into lending policies. Appendix C.2 provides further insights into the properties of $\boldsymbol{\theta}_{it}^{\mathcal{A}}$, highlighting i.a. that the number of eligible lenders per environmental firm is typically small (cf. the concentrated banking sector in Belgium) and on average larger for green diffusors than for green innovators (consistent with the specific nature of the latter).

5.3 Bank credit rationing: extensive margin

Econometric set–up. In order to investigate the impact of asset overhang on bank credit rationing, we estimate the following linear probability model (LPM[40]):

$$\text{Borrower}_{it} = \beta_1 \times \mathcal{A} + \beta_2 \times Med(\boldsymbol{\theta}_{it-1}^{\mathcal{A}}) + \beta_3 \times Min(\boldsymbol{\theta}_{it-1}^{\mathcal{A}}) + \boldsymbol{\zeta}'\boldsymbol{z}_{it-1} + \varepsilon_{it} \tag{4}$$

where Borrower_{it} equals 100 when firm i has an entry in the credit registry at time t (i.e., is a bank borrower), zero otherwise. Depending on the specification, $\mathcal{A} = \{\text{Green}_i, \text{Green innovation}_i, \text{Green diffusion}_i\}$ is an indicator variable flagging whether the firm engages in a particular activity.

The vector of controls $\boldsymbol{z}_{it}$ includes measures that typically determine access to bank credit. In particular, as young firms typically suffer from informational asymmetries that discourage lending, we control for firm age (logged). We include return on assets for current profitability and a dummy for negative equity to reflect persistency in losses (which potentially stems from high up-front investments by green firms). In the case of green innovation, the intangible nature of advanced technologies makes it harder for these firms to pledge collateral. We therefore include the ratio of intangible fixed assets to total fixed assets. To control for generic rationing vis–a–vis innovators, we include a dummy if the firm has filed a patent (not necessarily a CCMT patent). Moreover, we consider access to alternative sources of financing. Firms that are part of a corporate group could tap into intragroup capital markets (in which case a bank relationship is established with another member in the group). We therefore include a group dummy if the firm is part of an (inter)national group. Two additional dummies control for access to capital and bond markets, respectively. Finally, we add generic controls for firm size (assets), sector $\times$ time FE (4-digit) which may control for specialization effects of banks towards specific sectors, as well as region $\times$ time FE (region).

[40]LPM models have been used in similar set–ups, see e.g. Jiménez et al. (2012, 2014). Alternatively, the results from a logistic specification are reported in Appendix C.3.

The coefficients of interest for our analysis are β_2 and β_3. We lag the covariates $Med(\cdot)$ and $Min(\cdot)$ to make sure that legacy positions are predetermined at t. By virtue of the "*legacy effect*" (Proposition 1), we expect $\beta_2 < 0$: an increase in the banking system's exposures to green activities by firm i should lead to more credit rationing. Moreover, through the "*market structure effect*" (Proposition 3), we hypothesize that $\beta_3 < 0$: a decrease in the lowest asset overhang position in the banking system (i.e., decrease in the minimum exposure to the technological shock) should lead to less credit rationing. Our theory is silent on β_1.[41]

Below, we estimate various versions of Equation (4), starting from a general baseline and subsequently expanding on several dimensions informed by our theoretical framework. Furthermore, Appendix C.3 conducts a series of complementary robustness checks to demonstrate that our results are robust to an alternative estimation routine, the inclusion of firm fixed effects, sample selection and measurement of the covariates. In addition, through a falsification test, Appendix C.4 highlights that input from Section 4 is key to measure the relevant legacy stakes at risk that lead to rationing barriers.

Baseline rationing results. Table 8 presents the baseline results and establishes two important findings.[42] First, from the coefficients on $Med(\cdot)$, the larger the legacy positions in the banking system that are at risk to the disruptive environmental activity of firm i, the less likely the banking sector is willing to lend to this firm. The *Legacy effect*, reported at the bottom of the table, gauges the economic significance of these coefficients. It measures the marginal rationing impact of a 1 s.d. increase in the banking sector's legacy portfolio at risk. In the case of environmental innovation (column (4)), this leads to a 4.4 p.p. reduction in the probability of receiving bank credit. For environmental diffusors, this rationing sizes up to 1.0 p.p. This size differential aligns with the results from the previous Section (e.g., Table 4) where innovators were more detrimental than diffusors, both in terms of both performance and collateral valuation.

Second, from the coefficients on $Min(\cdot)$, the *Market structure effect* reveals that a market structure in which a single bank has a lower asset overhang problem attenuates this rationing. In particular, for innovators, a 1 s.d. drop in the rationing barrier (i.e. the lowest legacy position at

[41] Absent any other friction from the model, our main testable prediction relates to the market structure effect which we measure through $f_2(\boldsymbol{\theta}_{it}^{\mathcal{A}}) = Min(\boldsymbol{\theta}_{it}^{\mathcal{A}})$). In practice however several frictions may impede a proper identification of the minimum exposure among investors across the whole population. In addition to information aggregation frictions discussed above, other sources of friction include costly industry specialization, capacity constraints on the part of investors, and bilateral frictions between investors and entrepreneurs. In such cases, an aggregate measure of the market exposure to the negative externality - captured by the legacy effect (and empirically by $f_1(\boldsymbol{\theta}_{it}^{\mathcal{A}}) = Med(\boldsymbol{\theta}_{it}^{\mathcal{A}})$) - is more robust. Overall, testing for both effects will also allow to us to identify the relative role of frictions not explicitly modelled in our theoretical framework.

[42] In addition to these two results, it is worth highlighting that, in general, green firms get rationed irrespective of their effect on legacy positions. There are various reasons for this. First, perhaps $\boldsymbol{z}_{it}$ imperfectly controls for inherent riskiness of green activities (and the dummy variables pick up this effect). Next, greenness is potentially a dimension of bank–specialization (similar to sector–specialization) that requires intimate knowledge of green activities to lower informational frictions. However the precise purpose of our analysis is not to identify the coefficients on the greenness activity dummies. In this paper we are instead interested in determining the impact of exposed legacy positions associated with green firms that cause rationing.

risk in the banking spectrum) increases the probability of receiving bank credit by 5.3 p.p. Quantitatively, this largely neutralizes the initial rationing impact. Similarly, for diffusors the market structure effect fully undoes the initial legacy effect (1.3 p.p.). In general, this decomposition exercise showcases the quantitative importance of the banking market structure for the overhang problem, prompting important policy implications which we discuss in Section 6.

Decomposition by narrow green activity. In Table 9, we decompose the baseline results into all the forms of green activities present in our framework. More precisely, we re–estimate eq. (4) with $\mathcal{A} = \{\text{Green process innovation}_i, \text{Green product innovation}_i, \text{Green provision}_i, \text{Green adoption}_i\}$. The *legacy effect* suggests that process innovators are rationed the most while product innovators appear next in line (column (3)).[43] Green providers & adopters are rationed more or less equally (and significantly less than innovators).

Do large green firms get rationed more? By construction, there exists no correlation between our measure of the legacy positions threatened by firm i and the actual size of firm i. Nonetheless, rationing might be heterogeneous across the spectrum of firm size. For example, one could expect that larger firms – given the scale of their operations – are more threatening to the banks' legacy portfolio than a small firm engaged in the same environmental activity. In addition, from an informational perspective, it is likely that banks spend more time and resources on screening potential impacts on their legacy portfolio when the credit request involves a large borrower. Table 10 panel A tests for the differential effect of firm size by interacting the two rationing covariates with four indicator variables based on total assets of firm i (bottom 10%, bottom 10% to 50%, top 50% to 10%, top 10%). Corroborating the ex-ante intuition, the results reveal that rationing is insignificant for small firms and turns economically and statistically significant only for larger firms.

Decomposition by legacy maturity. Finally, we investigate the effect of the residual maturity of the exposed legacy positions. To that end, we additively decompose $\boldsymbol{\theta}^{\mathcal{A}}_{it-1}$ in four summands based on the maturity of the exposed legacy credit lines (lower than 1 year, one to two years, two to five years and longer than five years). On each of these four summands, we apply the $Min(\cdot)$ and $Med(\cdot)$ operator and estimate the market structure and legacy effect for each maturity. The results from Table 10 panel B reveal that banks do not take on board their short-term exposures in their lending policies. Instead, long term positions do matter. This result reinforces our theoretical discussion for two reasons. First, it addresses the sunk nature of the investment. Long term exposures are expected to stay on a bank's balance sheet long enough for externalities to materialize. This might not hold for short term positions. Moreover, long term exposures are also

[43] Note that many product innovators are also process innovators. As a result, disentangling the effect for the former group is not straightforward and the related standard errors are relatively large.

a better reflection of banks' general lending strategies, policies, sector specialization, etc. that are expected to remain in place even beyond maturization of the current exposures.

Second, the fact that long-term exposures are the positions that matter also provides some support for our discussion on the information structure of the theoretical model. It would indeed be reasonable to assume that competing banks are more capable of gathering information about their competitors' long-term exposures rather than their short-term ones, the former being generally more stable than the latter.

5.4 Breaking the barrier: who starts lending?

A natural follow–up to our results on the extensive margin is: which bank ends up offering credit? While our theory does not provide predictions on this, it is not unlikely that banks that face the lowest asset overhang will be the ones to "break the barrier" and provide loans to environmental disruptors or diffusors. Furthermore, uncovering of such matching will allow us to investigate the effect of rationing in the intensive margin. To that end, we estimate the following LPM on the subset of firms that receive bank credit for the first time at time t:

$$\text{Borrower}_{ibt} = \beta_1 \times \theta^{\mathcal{A}}_{ibt-1} + \beta_2 \times \iota_t(b = \arg\min_b(\boldsymbol{\theta}^{\mathcal{A}}_{it-1})) + \beta_3 \times \iota_t(b = \arg\max_b(\boldsymbol{\theta}^{\mathcal{A}}_{it-1})) + \varepsilon_{ibt}$$

Where Borrower_{ibt} equals 100 if firm i is matched with bank b at time t. Borrower_{ibt} takes on 0 if firm i is not matched with bank b. We only include firm observations on the first year in which the firm receives bank credit. While firm–bank observations where $\text{Borrower}_{ibt} = 100$ are directly observed in the data, observations where $\text{Borrower}_{ibt} = 0$ are less straightforward. We maintain our previous assumption that not all banks are eligible borrowers and take $\text{Borrower}_{ibt} = 0$ for all banks in $\boldsymbol{\theta}^{\mathcal{A}}_{it-1}$ that did not start up a lending relationship with firm i at time t (implying that the list of eligible borrowers is firm-specific and typically smaller than the population of active banks).

On the right-hand side, $\iota_t(b = \arg\min_b(\boldsymbol{\theta}^{\mathcal{A}}_{it-1}))$ is a dummy indicator function taking on 1 if the bank has the smallest legacy position in the banking sector and zero otherwise; $\iota_t(b = \arg\max_b(\boldsymbol{\theta}^{\mathcal{A}}_{it-1}))$ is a dummy indicator function taking on 1 if the bank has the largest legacy position in the banking sector and zero otherwise; $\theta^{\mathcal{A}}_{ibt-1}$ is a continuous variable with the legacy positions of bank b at risk due to green activity $\mathcal{A}$ of firm i.[44]

Our findings in Table 11 reveal a negative association between the legacy position at risk and the probability that a bank turns out to be the actual lender to the firm. In fact, we find that – conditional on receiving bank credit – the bank with the smallest legacy position at risk is more likely to grant the loan. In particular, a green firm is 8.4 p.p. more likely to receive credit from the bank with the lowest legacy position than from any other bank in the system (column (1)).

[44]Note that, in this setup, concerns about appropriately controlling for demand are muted: observations relate to firms that request & receive credit.

The results are economically larger for innovators than for diffusors.

5.5 Bank credit rationing: intensive margin

In this last round of results we investigate rationing effects in the intensive margin. In particular, we assess whether the market structure of the asset overhang in the banking system remains to affect credit supply after a green firm has become a bank-borrower. More precisely, would changes in the legacy position of the incumbent lender matter? Or, alternatively, does the lowest legacy position of the entire banking market drive the extent of credit rationing when this change originates from a bank other than the incumbent lender? In order to address this question, we run the following regression:

$$\Delta ln(\text{Credit}_{ibt}) = \beta_1 \times \Delta\theta^{\mathcal{A}}_{ibt-1} + \beta_2 \times \Delta Min(\boldsymbol{\theta}^{\mathcal{A}}_{it-1}) + \gamma_{bt} + \gamma_{gt} + \varepsilon_{ibt}$$

Where γ_{bt} captures bank-time fixed effects to control for general bank–level credit supply; γ_{gt} captures location-size-sector fixed effects to control for firm–level credit demand[45]; $\Delta\theta^{\mathcal{A}}_{ibt-1}$ captures the change in the legacy position of the incumbent lender and $\Delta Min(\boldsymbol{\theta}^{\mathcal{A}}_{it-1})$ captures the change in the market structure. Results are presented in Table 12.

First, note that this exercise constitutes a tough test: by virtue of the results in Subsection 5.4 the first two covariates on the r.h.s. are expected to be highly correlated (i.e., often the incumbent lender *is* the lender with the lowest legacy position at risk). Identification follows from cases where the two covariates differ (i.e., the change in the lowest legacy position at risk does not originate from the incumbent lender). The results from Table 12 show that a 1 s.d. decrease in the lowest asset overhang position (potentially, but not necessarily, that of the incumbent lender) drives up credit supply by the incumbent lender to the disruptive innovator (diffusor) by 0.11 s.d. (0.05 s.d.). The legacy positions of the incumbent borrower, β_1, are irrelevant. Taken together, these results highlight that the rationing barrier continues to play a role in determining credit supply to disruptive firms. They further highlight that, once the barrier is broken, a reduction in the lowest overhang generates effects beyond the lending bank's individual willingness to provide loans. The reason is that banks with greater asset overhang also increase their willingness to lend to green firms at the intensive margin following a decrease in the lowest asset overhang.

5.6 Taking stock

In this Section we have shown that the magnitude and distribution of the asset overhang across financial intermediaries determines credit rationing of green firms. First, at the extensive margin, the presence of an average asset overhang compared to no overhang reduces the likelihood of receiving credit for disruptive innovators (diffusors) with 4.4 p.p. (1.0 p.p.). The presence of intermediaries with less legacy positions at risk largely mitigate the economy wide asset overhang

[45] See Degryse et al. (2019) who have leveraged this procedure in the context of Belgian data.

problem. Second, banks with the lowest asset overhang are more likely to "break the barrier" and start lending to disruptive innovators and distributors. Third, at the intensive margin, an increase in the lowest asset overhang reduces lending growth at the intensive margin.

6 Policy implications

We now discuss policy implications that stem from our theoretical and empirical investigation. Our theoretical framework suggests that economies may suffer from technological conservatism when new entrants threaten the legacy position of investors through changes in performance and asset devaluation. Proposition 1 formalizes how legacy positions in a financier's portfolio impede funds from being channeled to otherwise profitable firms. Proposition 3 further highlights the role of the intermediary market structure in setting aggregate financing barriers to innovative firms. In the context of climate finance, Sections 4 and 5 present empirical evidence from the Belgian economy which reveals that bank lending policies effectively aim to protect business models that do not fit into global commitments to transition into a green economy. Various policy measures can help to breach the source of this barrier at the investor level.

Legacy-free financiers. The first measure could be the promoting of financial institutions that do not hold legacy positions exposed to the negative spillovers originating from incoming technologies (i.e., for these institutions, $qR_B = \Delta C = 0$). This outcome can be achieved by several initiatives.

First, it can be by design: promoting financial institutions with explicit intentions of supporting the production and diffusion of specific technologies. This case commands particular business models and expertise to be sustainable. Large scale demand such as the fight against climate change can promote such conditions. Relevant examples include the UK Green Investment Bank, or the Green Credit department of ICBC China. Moreover, to the extent that these initiatives are public (or quasi-public), their mandate potentially does not require them to factor in the impact of ΔC (i.e., their behavior is not governed by our framework) should these externalities appear later on in the financiers' life cycle.

In a more general setting, where the demand and need for technology transitions are not specifically formulated upfront, a generic policy of promoting entry of new – hence legacy-free – financial institutions would achieve a similar result from the perspective of our theoretical and empirical analysis.

Aggregate effects of a single legacy-free intermediary. Perhaps more important to note is that the presence of at least one legacy-free financier has the capacity to produce larger scale effects. From Proposition 3, the presence of investors with less or no exposures to asset devaluations promotes credit provisioning by the entire system. By virtue of this result, the entry of a single sizeable investor with no legacy exposures would effectively mute overhang issues and break rationing barriers since $\min \Delta C_i = \min qR_b = 0$. In other words, the existence of spillovers may positively amplify the effectiveness of limited interventions (i.e., entry of a single legacy-free agent). In fact, the devaluation of legacy assets materializes irrespective of the loan originator. Therefore, once the entry of a disruptive technology is certain, losses will materialize irrespective of the loan originator. Accordingly, all investors in the system become theoretically likely to extend credit to disruptive technologies. This is confirmed in our empirical analysis where a reduction in the lowest asset overhang engages incumbent banks to increase credit supply at the intensive margin.

Macroprudential policies. Focusing on incumbent institutions, policymakers have voiced the possibility of leveraging macro prudential policies to address the green transition (European Central Bank, 2019; European Union, 2018). Such policies work by introducing an additional implicit/explicit cost ΔM, where ΔM either (i) increases if the investor (e.g., bank) persists in lending to laggard firms or (ii) drops when it lends to innovative firms. The investor's behavior can then be steered by driving the sign of $\Delta C - \Delta M$. In the case of climate change, banks would therefore prefer to lend to green firms if $\Delta C < \Delta M$. Examples include (i) a risk-weight reduction (addition) in the prudential framework for banks' exposures to green (brown) assets, (ii) lower (higher) required reserve rates for portfolios skewed toward greener, less carbon-intensive assets (brown, carbon-intensive assets), (iii) dedicated disclosure requirements, (iv) climate-related stress testing, etc. Evidently, the feasibility of such measures hinges on a proper taxonomy (a classification of economic activities and the conditions under which economic activities can be considered sustainable) to sort between green and brown firms. Such work is underway at the European Commission.

Alternative applications. While our empirical analysis focused on the climate-banking nexus, our theory posits that an asset overhang materializes when new technologies have a large potential for adverse spillovers to which the full pool of *eligible* investors is exposed. As such, a number of alternative policy applications might be relevant to the use of our asset overhang framework. For instance, the pool of candidate investors in novel niche technologies (e.g., AI, cloud computing, biotechnology, etc.) is typically restricted due to the intimate knowledge required to screen candidate projects (Gompers et al., 2009). Importantly, this screening cost is typically acquired through experience in funding projects embodying similar or adjacent technologies. If these latter legacy projects remain on an investor's balance sheet during the investment decision, she will have incentives to ringfence incumbents from competition. If the disruption applies to the entire pool of investors, then the disruptive firm seeking funding may theoretically face a rationing barrier due to the asset overhang she generates. Similarly, vested interest in shallow financial markets, such as found in developing and emerging economies where competition between investors may be insufficient and where incumbent legacies may be sufficiently large, could be plagued by an asset overhang problem.

Finally, note that our framework also applies to public monopoly settings. By virtue of Proposition 1, public finance policies for technological investments (e.g., public infrastructures) may hinder technological change when the entry of new technologies generate negative spillovers on legacy public investments. For instance, in the early 1980s, France heavily invested in a videotex technology called the Minitel – a precursor to the World Wide Web – by means of heavy subsidies through the telecommunication public monopoly company France Telecom. With the advent of the internet a decade later, the Minitel became gradually obsolete. Both the government and France Telecom were however reluctant to promote early adoption of internet related technologies as this process would undermine revenues generated by the Minitel industry (Le Monde, 1997) and partly reacted by investing even further into the Minitel ecosystem (Wired, 2001). Towards the end of the 1990s, France was markedly lagging in the penetration of information and communication technologies compared to other countries. In 1997, the French Prime Minister Lionel Jospin famously claimed that "*the Minitel became a limiting factor in the development of novel and promising applications in the field of information technology*".

7 Conclusion

In this paper, we theoretically and empirically study the role of investors' asset overhang in the financing of technological change. We model how legacy positions of financiers generate potential asset overhang, as new technologies may lead to drops in collateral value or increases in probabilities of default of the incumbent firm population. Rationing stemming from asset overhang is more pronounced when financiers' legacy positions at risk are larger and more common across all financiers.

We empirically investigate the role of asset overhang in the context of climate finance. Our empirical analysis combines several unique data sources providing information on green innovation, environmental outputs/inputs at firm level, bank-firm credit exposures, and firm characteristics. This information allows us to quantify (a) the externalities environmental firms generate on incumbent product and technology market peers, and (b) the individual bank and aggregate banking system's legacy positions exposed to individual green firms.

We empirically document that green innovators or diffusors that generate negative spillovers on banks' legacy positions are less likely to receive bank credit. In particular, an environmental innovator which generates an average negative impact on each bank in the credit market is around 4.4 p.p. less likely to receive bank credit compared to an environmental innovator that does not harm banks' legacy positions. This average effect is largely muted when there is an intermediary without asset overhang (i.e., a bank without a legacy position). This empirical finding corroborates our theoretical model which argues that the financier with the lowest asset overhang is an important determinant of credit rationing.

In the context of climate change, our analysis corresponds to banks jointly delaying the transition to a carbon-neutral economy by limiting entry of green innovators or green adopters in product and technology spaces where the banking system holds large stakes. Our work offers policy recommendations on how macroprudential policies and/or the introduction of legacy-free providers of external finance help to promote the technological transition to the green economy. Finally, our asset overhang framework can be applied to other policy relevant applications which feature a risk of disruption to the entire pool of eligible investors such as the developing of niche technologies, the financing of disruptive businesses in emerging economies and technological transition under a public monopoly investor.

Table 1: Variable definitions & data sources

Variable	Description	Type	Source
Firm-level controls			
ROA_{it}	Return on assets at time t.	Continuous	(1)
$Group_{it}$	1 if firm is part of an (inter)national group at time t (0 if firm is standalone at time t).	Binary	(1)
$Assets_{it}$	Balance sheet total at time t.	Continuous	(1)
$Leverage_{it}$	Debt over assets at time t.	Continuous	(1)
Negative $equity_{it}$	1 if firm has negative equity at time t (0 otherwise)	Binary	(1)
$Intangibles_{it}$	Ratio of intangible fixed assets over total fixed assets at time t.	Continuous	(1)
Capital age_{it}	Age of fixed capital (in years) at time t. Derived as the average of the inverse of the firm-level depreciation rate up to time t. The latter is defined as the end of year tangible fixed asset depreciation over the stock of tangible fixed assets.	Continuous	(1)
Firm age_{it}	Age of the firm (in years) at time t.	Continuous	(2)
$Region_i$	Region in which the (headquarters of the) firm resides (Flanders, Wallonia or Brussels capital region).	Dichotomous	(2)
$Sector_i$	5 digit NACE code in which the firm resides.	Dichotomous	(2)
Public $equity_{it}$	1 if the firm is listed on the stock exchange at time t (0 otherwise)	Binary	(3)
Public $debt_{it}$	1 if the firm has issued debt securities at time t (0 otherwise)	Binary	(3)
$Patenter_i$	1 if the firm has filed for at least one patent.	Binary	(4)
Green innovation activities			
Green process $innovation_i$	1 if firm (or group member) has filed at least one green process patent according to Appendix A (0 otherwise).	Binary	(4)
Green product $innovation_i$	1 if firm (or group member) has filed at least one green product patent according to Appendix A (0 otherwise).	Binary	(4)
Green $innovation_i$	1 if firm is a green process and/or product innovator (0 otherwise).	Binary	(4)
Green diffusion activities			
Green $adoption_i$	1 if the firm has a non-zero share of capital investments matching Definition 3.3 and is not a green process innovator (0 otherwise).	Binary	(4), (5)
Green $provision_i$	1 if the firm has a non-zero share of sales matching Definition 3.3 and is not a green product innovator (0 otherwise).	Binary	(4), (5)
Green $diffusion_i$	1 if the firm is a green provider and/or green adopter (0 otherwise).	Binary	(4), (5)
Green activities			
$Green_i$	1 if the firm engages in (at least one) green activity (0 otherwise).	Binary	(4), (5)
Economic spaces			

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Variable	Description	Type	Source
π_{ikt}	The share of firm i sales to firms in sector k in total sales of firm i at time t. Sectors $k = 1, \dots, K-1$ are defined at the granular 5 digit NACE-level and K captures the household sector.	Continuous	(1), (2), (6)
τ_{ikt}	The share of firm i procurements from firms in sector k in total procurements of firm i at time t. $k = 1, \dots, K$ sectors are defined at the granular 5 digit NACE-level.	Continuous	(1), (2), (6)
GREEN PRESENCE MEASURES			
$\overline{\Delta d(i,t)}^{\mathcal{A}=\text{green product innovation}}_{\mathcal{S}=\text{product space}}$	$M^{-1}\sum_{m=1}^{M}\sum_{j=1}^{J}\Delta\big(\Pi_{ijt-m}\times \text{Green product innovation}_j\big)$	Continuous	(1), (2) , (4), (6)
$\overline{\Delta d(i,t)}^{\mathcal{A}=\text{green process innovation}}_{\mathcal{S}=\text{product space}}$	$M^{-1}\sum_{m=1}^{M}\sum_{j=1}^{J}\Delta\big(\Pi_{ijt-m}\times \text{Green process innovation}_j\big)$	Continuous	(1), (2), (4), (6)
$\overline{\Delta d(i,t)}^{\mathcal{A}=\text{green product innovation}}_{\mathcal{S}=\text{technology space}}$	$M^{-1}\sum_{m=1}^{M}\sum_{j=1}^{J}\Delta\big(T_{ijt-m}\times \text{Green product innovation}_j\big)$	Continuous	(1), (2), (4), (6)
$\overline{\Delta d(i,t)}^{\mathcal{A}=\text{green process innovation}}_{\mathcal{S}=\text{technology space}}$	$M^{-1}\sum_{m=1}^{M}\sum_{j=1}^{J}\Delta\big(T_{ijt-m}\times \text{Green process innovation}_j\big)$	Continuous	(1), (2), (4), (6)
$\overline{\Delta d(i,t)}^{\mathcal{A}=\text{green provision}}_{\mathcal{S}=\text{product space}}$	$M^{-1}\sum_{m=1}^{M}\sum_{j=1}^{J}\Delta\big(\Pi_{ijt-m}\times \text{Green provision}_j\big)$	Continuous	(1), (2), (4) – (6)
$\overline{\Delta d(i,t)}^{\mathcal{A}=\text{green adoption}}_{\mathcal{S}=\text{product space}}$	$M^{-1}\sum_{m=1}^{M}\sum_{j=1}^{J}\Delta\big(\Pi_{ijt-m}\times \text{Green adoption}_j\big)$	Continuous	(1), (2), (4) – (6)
$\overline{\Delta d(i,t)}^{\mathcal{A}=\text{green provision}}_{\mathcal{S}=\text{technology space}}$	$M^{-1}\sum_{m=1}^{M}\sum_{j=1}^{J}\Delta\big(T_{ijt-m}\times \text{Green provision}_j\big)$	Continuous	(1), (2), (4) – (6)
$\overline{\Delta d(i,t)}^{\mathcal{A}=\text{green adoption}}_{\mathcal{S}=\text{technology space}}$	$M^{-1}\sum_{m=1}^{M}\sum_{j=1}^{J}\Delta\big(T_{ijt-m}\times \text{Green adoption}_j\big)$	Continuous	(1), (2), (4) – (6)
BROWN PRESENCE MEASURES			
Brown product space entrants$_{it}$	$M^{-1}\sum_{m=1}^{M}\sum_{j=1}^{J}\Delta\big(\Pi_{ijt-m}\times(1-\text{Green}_j)\big)$	Continuous	(1), (2), (4)–(6)
Brown technology space entrants$_{it}$	$M^{-1}\sum_{m=1}^{M}\sum_{j=1}^{J}\Delta\big(T_{ijt-m}\times(\text{Investor}_{jt-m})(1-\text{Green adoption}_j)\big)$ where Investor$_{jt-m}=1$ if the firm has a positive investment flow at time $t-m$ (zero otherwise).	Continuous	(1), (2), (4)–(6)
FIRM–LEVEL PERFORMANCE/TANGIBLE ASSET PLEDGEABILITY VARIABLES			
Δ ln (HH sales$_{it}$)	Y-o-Y percentage change in sales to the household sector.	Continuous	(1), (6)
Δ ln (B2B sales$_{it}$)	Y-o-Y percentage change in sales to the corporate sector (excl. intra-group sales & exports).	Continuous	(6)
Writedowns$_{it}$	100 if firm i has booked an exceptional writedown on tangible assets beyond the pre-determined amortization scheme at time t (0 otherwise). Only available for large firms.†	Binary	(1)
Liquidation loss$_{it}$	100 if firm i has liquidated tangible fixed assets at a value lower than its book value at time t (0 otherwise).	Binary	(5)
BANK–FIRM–LEVEL RISK VARIABLES			
PD$_{ibt}$	Bank b assessed probability of firm i defaulting within the next 12 months.	Continuous	(7)
FIRM–COLLATERAL–LEVEL VARIABLES			
Δ ln (Financials$_{ict}$)	Y-o-Y percentage change in the value of financial collateral item c (e.g., metals, currency, futures, etc.), pledged by firm i in the context of a credit facility. We focus on Financials$_{ict}$ valued at market prices as quoted at an exchange for identical assets and liabilities in an active market.	Continuous	(7)

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Variable	Description	Type	Source
Δ ln (Real estate$_{ict}$)	Y-o-Y percentage change in the value of real estate collateral item c (commercial and residential), pledged by firm i in the context of a credit facility. We focus on Real estate$_{ict}$ valued by the bank or third party appraisers.	Continuous	(7)
Δ ln(Physical assets$_{ict}$)	Y-o-Y percentage change in the value of physical asset item c (e.g., industrial furnaces, robots, etc.), pledged by firm i in the context of a credit facility. We focus on Physical assets$_{ict}$ valued by the bank or third party appraisers.	Continuous	(7)
Rationing measures			
Borrower$_{it}$	100 if firm i has an authorised bank credit facility at time t (0 otherwise).	Binary	(7)
Borrower$_{ibt}$	100 if firm i has an authorised credit facility with bank b at time t (0 otherwise).	Binary	(7)
Δ ln(Credit$_{ibt}$)	Y-o-Y percentage change in the authorised amount of bank b credit to firm i.	Continuous	(7)

Notes: Data sources listed: (1) Annual accounts, (2) Crossroads databank, (3) NBB Securities Settlement System, (4) PATSTAT, (5) SBS survey, (6) Business–to–business transactions dataset, (7) Central corporate credit register. All datasets are at an annual frequency (or lower) and minimally span the period $2008-2018$ (except for the firm-bank risk and collateral indicators in (7), which are available as of 2018). (3), (5)–(7) are confidential. †Large firms are either publicly listed and/or cross at least two of the following size criteria: (a) 50 FTE, (b) turnover 9 mil., asset total 4.5 mil.

Table 2: DESCRIPTIVE STATISTICS

Variable	N	Mean	Std. dev.	p.10	p.50	p.90
GREEN PRESENCE						
$\overline{\Delta d(i,t)}^{\mathcal{A}=\text{green product innovation}}_{\mathcal{S}=\text{product space}}$	534443	0.00	0.42	-0.28	0.00	0.24
$\overline{\Delta d(i,t)}^{\mathcal{A}=\text{green process innovation}}_{\mathcal{S}=\text{product space}}$	534443	-0.03	0.60	-0.50	0.00	0.36
$\overline{\Delta d(i,t)}^{\mathcal{A}=\text{green product innovation}}_{\mathcal{S}=\text{technology space}}$	534443	0.17	0.92	-0.75	0.08	1.26
$\overline{\Delta d(i,t)}^{\mathcal{A}=\text{green process innovation}}_{\mathcal{S}=\text{technology space}}$	534443	0.02	0.84	-0.98	0.02	1.04
$\overline{\Delta d(i,t)}^{\mathcal{A}=\text{green provider}}_{\mathcal{S}=\text{product space}}$	453769	0.28	11.06	-9.43	0.04	11.36
$\overline{\Delta d(i,t)}^{\mathcal{A}=\text{green adopter}}_{\mathcal{S}=\text{product space}}$	453769	-3.10	19.27	-24.35	-0.29	15.98
$\overline{\Delta d(i,t)}^{\mathcal{A}=\text{green provider}}_{\mathcal{S}=\text{technology space}}$	453769	4.66	35.06	-42.86	2.93	54.12
$\overline{\Delta d(i,t)}^{\mathcal{A}=\text{green adopter}}_{\mathcal{S}=\text{technology space}}$	453769	3.82	67.40	-89.07	2.72	98.02
FIRM–LEVEL PERFORMANCE						
Δ ln (HH sales$_{it}$)	440784	-0.01	1.06	-0.69	0.01	0.63
Δ ln (B2B sales$_{it}$)	534117	0.00	0.65	-0.53	-0.02	0.55
FIRM–LEVEL ASSET PLEDGEABILITY						
Writedowns$_{it}$	77134	5.33	22.47	0.00	0.00	0.00
Liquidation loss$_{it}$	33954	16.00	36.66	0.00	0.00	100
BANK–FIRM–LEVEL RISK						
PD up$_{ibt}$	74960	33.83	47.31	0.00	0.00	100
PD down$_{ibt}$	74960	39.50	48.89	0.00	0.00	100
COLLATERAL						
Δ ln (Financials$_{ict}$)	9643	-0.03	0.39	-0.65	0.00	0.16
Δ ln (Real estate$_{ict}$)	1787	0.00	0.27	-0.06	0.00	0.00
Δ ln (Physical assets$_{ict}$)	2982	-0.05	0.40	-0.50	0.00	0.34

Notes: Descriptive statistics for the variables used in Table 4. All variables are defined in Table 1. All continuous variables are winsorized at the 5/95 level.

Table 3: Green activities ($\mathcal{A}$), externalities ($\mathcal{E}$) & economic spaces ($\mathcal{S}$)

Green activity ($\mathcal{A}$)	Externality ($\mathcal{E}$)	Economic space ($\mathcal{S}$)
Green	*Performance*	*Product space*
(Green_i)	(Δ ln (HH sales_{jt}))	(Π_{ijt})
	(Δ ln (B2B sales_{jt}))	
Green innovation		*Technology space*
($\text{Green innovation}_i$)	*Asset pledgeability*	(T_{ijt})
	(Writedowns_{jt})	
Green process innovation	($\text{Liquidation loss}_{jt}$)	
($\text{Green process innovation}_i$)		
Green product innovation		
($\text{Green product innovation}_i$)		
Green diffusion		
(Green diffusion_i)		
Green provision		
(Green provision_i)		
Green adoption		
(Green adoption_i)		

Notes: This table summarizes the four granular green activities (and aggregates thereof) that we consider in this paper ($\mathcal{A}$), the two externalities we explore on adjacent firms ($\mathcal{E}$) and the economic space over which they materialize ($\mathcal{S}$). The associated variable names are between parentheses.

Table 4: GREEN PRESENCE & BROWN FIRM PERFORMANCE/PLEDGEABILITY (FIRM PERSPECTIVE)

	Firm performance		Asset pledgeability	
	Δ ln (HH sales$_{it}$)	Δ ln (B2B sales$_{it}$)	Writedowns$_{it}$	Liquidation loss$_{it}$
	(1)	(2)	(3)	(4)
PANEL A: INNOVATION				
$\overline{\Delta d(i,t)}^{\mathcal{A}=\text{green product innovation}}_{\mathcal{S}=\text{product space}}$	−0.067***	−0.024***	−0.029	0.769
	(0.005)	(0.003)	(0.168)	(2.375)
$\overline{\Delta d(i,t)}^{\mathcal{A}=\text{green process innovation}}_{\mathcal{S}=\text{product space}}$	−0.021***	−0.005**	−0.077	−0.337
	(0.003)	(0.003)	(0.137)	(1.677)
$\overline{\Delta d(i,t)}^{\mathcal{A}=\text{green product innovation}}_{\mathcal{S}=\text{technology space}}$	0.000	0.002	0.000	−0.707
	(0.003)	(0.002)	(0.029)	(0.438)
$\overline{\Delta d(i,t)}^{\mathcal{A}=\text{green process innovation}}_{\mathcal{S}=\text{technology space}}$	0.003	−0.003	0.208**	1.093*
	(0.003)	(0.002)	(0.092)	(0.590)
Controls	Y	Y	Y	Y
Sector × Time FE	4 digit	4 digit	3 digit	3 digit
Location × Time FE	Y	Y	Y	Y
Firm FE	Y	Y	N	N
Cluster-level	Firm	Firm	Firm	Firm
# Observations	428180	533052	76397	33625
Adj. R^2	0.159	0.090	0.024	0.129

	Firm performance		Asset pledeability	
	Δ ln (HH sales$_{it}$)	Δ ln (B2B sales$_{it}$)	Writedowns$_{it}$	Liquidation loss$_{it}$
	(1)	(2)	(3)	(4)
PANEL B: DIFFUSION				
$\overline{\Delta d(i,t)}^{\mathcal{A}=\text{green provision}}_{\mathcal{S}=\text{product space}}$	−0.0098***	−0.0040***	0.0011	−0.0003
	(0.0008)	(0.0006)	(0.0019)	(0.0004)
$\overline{\Delta d(i,t)}^{\mathcal{A}=\text{green adoption}}_{\mathcal{S}=\text{product space}}$	−0.0004***	−0.0003***	0.0000	0.0001
	(0.0001)	(0.0000)	(0.0002)	(0.0001)
$\overline{\Delta d(i,t)}^{\mathcal{A}=\text{green provision}}_{\mathcal{S}=\text{technology space}}$	0.0001	−0.0001	−0.0025	−0.0001
	(0.0001)	(0.0001)	(0.0028)	(0.0001)
$\overline{\Delta d(i,t)}^{\mathcal{A}=\text{green adoption}}_{\mathcal{S}=\text{technology space}}$	0.0000	0.0000	0.0022*	0.0018*
	(0.0001)	(0.0000)	(0.0012)	(0.0010)
Controls	Y	Y	Y	Y
Sector × Time FE	4 digit	4 digit	3 digit	3 digit
Location × Time FE	Y	Y	Y	Y
Firm FE	Y	Y	N	N
Cluster-level	Firm	Firm	Firm	Firm
# Observations	360260	453357	47742	20858
Adj. R^2	0.163	0.093	0.018	0.133

Notes: Panel A summarizes the performance/asset pledgeability impact of green process and product innovation on firms that engage in neither of both activities. Panel B summarizes the performance/asset pledgeability impact of green product provision and green capital investment on firms that engage in neither of both activities. In both panels, the unit of observation is the firm-year-level. The unbalanced sample period runs from $2008 - 2018$. Controls include lags of ln(Assets$_{it}$), Leverage$_{it}$, ln(Capital age$_{it}$), brown product space entrants$_{it}$ and brown technology space entrants$_{it}$ as defined in Table 1. Columns (1)–(2) include a lag of the dependent variable (columns (3)–(4) do not given that, due to the idiosyncratic nature of the dependant variable, the panel is highly unbalanced). Columns (3)–(4) are estimated using linear probability routines. Robust standard errors, reported in parentheses, are clustered at the firm–level. All regressors and regressands are defined in Table 1. *, ** and *** denote significance at the 10%, 5% and 1% level, respectively.

Table 5: ESTABLISHED EXTERNALITIES

	GREEN ACTIVITY ($\mathcal{A}$)			
	INNOVATION		DIFFUSION	
SPACE ($\mathcal{S}$)	Green product innovation	Green process innovation	Green provision	Green adoption
Product space	Performance: ↓ Pledgeability: ∅	Performance: ↓ Pledgeability: ∅	Performance: ↓ Pledgeability: ∅	Performance: ↓ Pledgeability: ∅
Technology space	Performance: ∅ Pledgeability: ∅	Performance: ∅ Pledgeability: ↓	Performance: ∅ Pledgeability: ∅	Performance: ∅ Pledgeability: ↓

Notes: This table summarizes the established impacts of various green activities on neighbouring firms not engaged in said activity. "↓" signifies a negative externality whereas "∅" designates no impact has been established.

Table 6: GREEN PRESENCE & BROWN RISKINESS/COLLATERAL VALUE (BANK PERSPECTIVE)

	Bank assessed firm riskiness		Collateral value		
PANEL A: INNOVATION	PD up_{ibt}	PD $down_{ibt}$	Δ ln(Financials$_{ict}$)	Δ ln(Real estate$_{ict}$)	Δ ln(Physical assets$_{ict}$)
	(1)	(2)	(3)	(4)	(5)
$\overline{\Delta d(i,t)}^{\mathcal{A}=\text{green product innovation}}_{\mathcal{S}=\text{product space}}$	7.4053**	−0.7738***	−0.0173	−0.0074	0.0741
	(3.4658)	(0.2401)	(0.0696)	(0.0061)	(0.0714)
$\overline{\Delta d(i,t)}^{\mathcal{A}=\text{green process innovation}}_{\mathcal{S}=\text{product space}}$	3.6877***	−1.0682***	0.0423	0.0280	0.0256
	(1.3310)	(0.3481)	(0.0627)	(0.1627)	(0.1405)
$\overline{\Delta d(i,t)}^{\mathcal{A}=\text{green product innovation}}_{\mathcal{S}=\text{technology space}}$	0.3977	−0.2320	0.0047	0.0031	0.0220
	(1.0964)	(0.4997)	(0.0051)	(0.0125)	(0.0160)
$\overline{\Delta d(i,t)}^{\mathcal{A}=\text{green process innovation}}_{\mathcal{S}=\text{technology space}}$	−2.5308	0.5108	−0.0045	−0.0144	−0.0404*
	(2.1774)	(0.9383)	(0.0054)	(0.0181)	(0.0219)
Controls	Y	Y	Y	Y	Y
Sector × Time FE	4 digit	4 digit	3 digit	3 digit	3 digit
Bank × Time FE	Y	Y	N	N	N
Location × Time FE	Y	Y	Y	Y	Y
Cluster-level	Firm	Firm	Firm	Firm	Firm
# Observations	74921	74921	9642	1787	2937
Adj. R^2	0.029	0.068	0.011	-0.001	0.040

	Bank assessed firm riskiness		Collateral value		
PANEL B: DIFFUSION	PD up_{ibt}	PD $down_{ibt}$	Δ ln(Financials$_{ict}$)	Δ ln(Real estate$_{ict}$)	Δ ln(Physical assets$_{ict}$)
	(1)	(2)	(3)	(4)	(5)
$\overline{\Delta d(i,t)}^{\mathcal{A}=\text{green provision}}_{\mathcal{S}=\text{product space}}$	0.0226*	−0.0812*	−0.0025	0.0001	0.0001
	(0.0118)	(0.0497)	(0.0034)	(0.0001)	(0.0002)
$\overline{\Delta d(i,t)}^{\mathcal{A}=\text{green adoption}}_{\mathcal{S}=\text{product space}}$	0.0118*	−0.0380	−0.0050	−0.0008	0.0002
	(0.0067)	(0.0241)	(0.0056)	(0.0009)	(0.0004)
$\overline{\Delta d(i,t)}^{\mathcal{A}=\text{green provision}}_{\mathcal{S}=\text{technology space}}$	−0.0230	−0.0133	0.0007	−0.0001	0.0001
	(0.0480)	(0.0122)	(0.0016)	(0.0004)	(0.0002)
$\overline{\Delta d(i,t)}^{\mathcal{A}=\text{green adoption}}_{\mathcal{S}=\text{technology space}}$	0.0134	0.0049	0.0002	0.0000	−0.0002**
	(0.0233)	(0.0069)	(0.0009)	(0.0001)	(0.0001)
Controls	Y	Y	Y	Y	Y
Sector × Time FE	4 digit	4 digit	3 digit	3 digit	3 digit
Bank × Time FE	Y	Y	N	N	N
Location × Time FE	Y	Y	Y	Y	Y
Cluster-level	Firm	Firm	Firm	Firm	Firm
# Observations	62287	62287	7993	1332	2228
Adj. R^2	0.030	0.064	0.001	-0.017	0.001

Notes: Panel A summarizes the impact of green process and product innovation on the bank assessed riskiness/collateral value of firms that engage in neither of both activities. Panel B summarizes the impact of green product provision and green capital investment on the bank assessed riskiness/collateral value of firms that engage in neither of both activities. The sample period runs from $2018-2019$. The unit of observation is the firm-bank-year level (column (1)–(2)) or firm-collateral-year level (column (3)–(5)). Controls include lags of ln(Assets$_{it}$), Leverage$_{it}$, ln(Capital age$_{it}$), brown product space entrants$_{it}$ and brown technology space entrants$_{it}$ as defined in Table 1 or the body of the text. Column (1) and (2) are estimated using linear probability routines. PD up_{ibt} is an indicator variable taking on 100 if PD$_{ibt}$ goes up vis-a-vis last year (0 otherwise). PD $down_{ibt}$ is an indicator variable taking on 100 if PD$_{ibt}$ goes down vis-a-vis last year (0 otherwise). All other regressors and regressands and defined in Table 1. Robust standard errors, reported in parentheses, are clustered at the firm–level. *, ** and *** denote significance at the 10%, 5% and 1% level, respectively.

Table 7: Descriptives legacy positions, market structure & borrowing metrics

Variable	Mean	Std. dev.	p.10	p.50	p.90
Legacy positions and market structure – By broad activities					
$\theta_{ibt}^{\mathcal{A}=\text{Green}}$	1.400	7.235	0.002	0.320	2.262
$Med(\boldsymbol{\theta}_{it}^{\mathcal{A}=\text{Green}})$	0.326	0.721	0.000	0.010	1.130
$Min(\boldsymbol{\theta}_{it}^{\mathcal{A}=\text{Green}})$	0.180	0.415	0.000	0.001	0.588
$\theta_{ibt}^{\mathcal{A}=\text{Green innovation}}$	0.642	3.392	0.000	0.180	1.519
$Med(\boldsymbol{\theta}_{it}^{\mathcal{A}=\text{Green innovation}})$	0.187	0.386	0.000	0.002	0.613
$Min(\boldsymbol{\theta}_{it}^{\mathcal{A}=\text{Green innovation}})$	0.121	0.274	0.000	0.000	0.385
$\theta_{ibt}^{\mathcal{A}=\text{Green diffusion}}$	1.403	7.249	0.002	0.320	2.266
$Med(\boldsymbol{\theta}_{it}^{\mathcal{A}=\text{Green diffusion}})$	0.327	0.722	0.000	0.010	1.132
$Min(\boldsymbol{\theta}_{it}^{\mathcal{A}=\text{Green diffusion}})$	0.180	0.415	0.000	0.001	0.589
Legacy positions and market structure – By narrow activities					
$\theta_{ibt}^{\mathcal{A}=\text{Green process innovation}}$	0.507	3.231	0.000	0.053	1.208
$Med(\boldsymbol{\theta}_{it}^{\mathcal{A}=\text{Green process innovation}})$	0.133	0.334	0.000	0.000	0.401
$Min(\boldsymbol{\theta}_{it}^{\mathcal{A}=\text{Green process innovation}})$	0.085	0.231	0.000	0.000	0.265
$\theta_{ibt}^{\mathcal{A}=\text{Green product innovation}}$	0.285	2.415	0.000	0.001	0.663
$Med(\boldsymbol{\theta}_{it}^{\mathcal{A}=\text{Green product innovation}})$	0.080	0.255	0.000	0.000	0.189
$Min(\boldsymbol{\theta}_{it}^{\mathcal{A}=\text{Green product innovation}})$	0.052	0.180	0.000	0.000	0.111
$\theta_{ibt}^{\mathcal{A}=\text{Green adoption}}$	1.693	8.088	0.010	0.467	2.531
$Med(\boldsymbol{\theta}_{it}^{\mathcal{A}=\text{Green adoption}})$	0.377	0.765	0.000	0.023	1.270
$Min(\boldsymbol{\theta}_{it}^{\mathcal{A}=\text{Green adoption}})$	0.206	0.439	0.000	0.006	0.668
$\theta_{ibt}^{\mathcal{A}=\text{Green provision}}$	0.354	2.289	0.000	0.040	0.865
$Med(\boldsymbol{\theta}_{it}^{\mathcal{A}=\text{Green provision}})$	0.161	0.515	0.000	0.001	0.421
$Min(\boldsymbol{\theta}_{it}^{\mathcal{A}=\text{Green provision}})$	0.096	0.309	0.000	0.000	0.247
Borrowing metrics					
Borrower$_{it}$	73.000	44.259	0.000	100.000	100.000
Δ ln(Credit$_{ibt}$)	-0.029	0.367	-0.479	0.000	0.446

Notes: Descriptive statistics. Legacy positions are bound between 0 and 100 and are not winsorized. Credit growth rates are winsorized at the 5/95 level.

Table 8: RATIONING EXTENSIVE MARGIN: BASELINE RESULTS

	Dependent variable: Borrower_{it}			
	(1)	(2)	(3)	(4)
Green_i	-3.162^{***}	-3.086^{***}		
	(0.337)	(0.351)		
$\text{Green innovation}_i$			-1.130	-1.285
			(2.022)	(1.087)
Green diffusion_i			-3.300^{***}	-3.235^{***}
			(0.337)	(0.221)
$Med(\boldsymbol{\theta}_{it-1}^{\mathcal{A}=\text{Green}})$		-1.381^{*}		
		(0.859)		
$Min(\boldsymbol{\theta}_{it-1}^{\mathcal{A}=\text{Green}})$		-3.120^{**}		
		(1.423)		
$Med(\boldsymbol{\theta}_{it-1}^{\mathcal{A}=\text{Green innovation}})$				-11.342^{**}
				(5.453)
$Min(\boldsymbol{\theta}_{it-1}^{\mathcal{A}=\text{Green innovation}})$				-19.405^{**}
				(8.631)
$Med(\boldsymbol{\theta}_{it-1}^{\mathcal{A}=\text{Green diffusion}})$				-1.377^{*}
				(0.783)
$Min(\boldsymbol{\theta}_{it-1}^{\mathcal{A}=\text{Green diffusion}})$				-3.026^{**}
				(1.273)
$\mathcal{A}$: Green				
Legacy effect		-0.996		
Market structure effect		-1.294		
$\mathcal{A}$: Green innovation				
Legacy effect				-4.380
Market structure effect				-5.309
$\mathcal{A}$: Green diffusion				
Legacy effect				-0.995
Market structure effect				-1.255
Controls	Y	Y	Y	Y
Sector × Time FE	4 digit	4 digit	4 digit	4 digit
Location × Time FE	Y	Y	Y	Y
Cluster-level	Firm	Firm	Firm	Firm
# Observations	654689	654689	654689	654689
Adj. R^2	0.185	0.185	0.185	0.185

Notes: This table quantifies the legacy and market structure effect. The dependent variable is an indicator variable taking on 100 if firm i has an authorised bank credit facility at time t (0 otherwise). The covariates of interest, $Med(\boldsymbol{\theta}_{it-1}^{\mathcal{A}})$ and $Min(\boldsymbol{\theta}_{it-1}^{\mathcal{A}})$, measure the median and minimum of the legacy positions exposed to green activity $\mathcal{A}$ of firm i across all eligible lenders. Controls include lags of ln(Assets_{it}), Leverage_{it}, ln(Firm age_{it}), ln(Capital age_{it}), Group_{it}, Negative equity_{it}, ROA_{it}, Intangibles_{it}, Patenter_i, Public equity_{it} and Public debt_{it} as defined in Table 1. The legacy effect quantifies the impact of a one standard deviation increase in $Med(\boldsymbol{\theta}_{it-1}^{\mathcal{A}})$ on the probability of having bank credit. The market structure effect quantifies the impact of a one standard deviation increase in $Min(\boldsymbol{\theta}_{it-1}^{\mathcal{A}})$ on the probability of having bank credit. All specifications are estimated using linear probability routines. The unit of observation is the firm-year-level. The sample period runs from $2008-2018$ and contains both brown and green firms. Standard errors, reported in parentheses, are clustered at the firm–level. *, ** and *** denote significance at the 10%, 5% and 1% level, respectively.

Table 9: RATIONING EXTENSIVE MARGIN: GRANULAR RESULTS PER NARROW ACTIVITY

	Dependent variable: Borrower_{it}					
	(1)	(2)	(3)	(4)	(5)	(6)
Estimation sample:	Brown Firms + Green process innovators	Brown Firms + Green product innovators	Brown Firms + Green process & product innovators	Brown Firms + Green providers	Brown Firms + Green adopters	Brown Firms + Green providers & adopters
Green process innovation_i	-2.245 (2.179)		0.283 (1.287)			
Green product innovation_i		0.490 (1.090)	3.515** (1.514)			
Green provision_i				-4.310*** (0.276)		-3.124*** (0.267)
Green adoption_i					-3.265*** (0.198)	-2.729*** (0.196)
$Med(\boldsymbol{\theta}_{it-1}^{\mathcal{A}=\text{Green process innovation}})$	-15.225** (7.053)		-16.444** (6.388)			
$Min(\boldsymbol{\theta}_{it-1}^{\mathcal{A}=\text{Green process innovation}})$	-26.075** (11.163)		-23.733** (9.810)			
$Med(\boldsymbol{\theta}_{it-1}^{\mathcal{A}=\text{Green product innovation}})$		-15.055** (7.671)	-8.776 (6.914)			
$Min(\boldsymbol{\theta}_{it-1}^{\mathcal{A}=\text{Green product innovation}})$		-32.237** (13.671)	-22.037* (11.866)			
$Med(\boldsymbol{\theta}_{it-1}^{\mathcal{A}=\text{Green provision}})$				-2.443* (1.399)		-1.868* (1.134)
$Min(\boldsymbol{\theta}_{it-1}^{\mathcal{A}=\text{Green provision}})$				-5.020** (2.295)		-2.477** (1.186)
$Med(\boldsymbol{\theta}_{it-1}^{\mathcal{A}=\text{Green adoption}})$					-1.289** (0.520)	-0.991* (0.520)
$Min(\boldsymbol{\theta}_{it-1}^{\mathcal{A}=\text{Green adoption}})$					-3.001*** (0.901)	-2.547*** (0.904)
$\mathcal{A}$: Green process innovation						
Legacy effect	-5.079		-5.486			
Market structure effect	-6.019		-5.478			
$\mathcal{A}$: Green product innovation						
Legacy effect		-3.831	-2.234			
Market structure effect		-5.808	-3.970			
$\mathcal{A}$: Green provision						
Legacy effect				-1.257		-0.916
Market structure effect				-1.550		-0.765
$\mathcal{A}$: Green adoption						
Legacy effect					-0.987	-0.759
Market structure effect					-1.316	-1.117
Controls	Y	Y	Y	Y	Y	Y
Sector × Time FE	4 digit	4 digit	4 digit	4 digit	4 digit	4 digit
Location × Time FE	Y	Y	Y	Y	Y	Y
Cluster-level	Firm	Firm	Firm	Firm	Firm	Firm
# Observations	569134	568557	569643	598173	632861	654001
Adj. R^2	0.191	0.191	0.191	0.187	0.187	0.185

(Table notes on next page)

Notes: This table quantifies the legacy and market structure effect. The dependent variable is an indicator variable taking on 100 if firm i has an authorised bank credit facility at time t (0 otherwise). The covariates of interest, $Med(\boldsymbol{\theta}^{\mathcal{A}}_{it-1})$ and $Min(\boldsymbol{\theta}^{\mathcal{A}}_{it-1})$, measure the median and minimum of the legacy positions exposed to green activity $\mathcal{A}$ of firm i across all eligible lenders. Controls include lags of ln(Assets$_{it}$), Leverage$_{it}$, ln(Firm age$_{it}$), ln(Capital age$_{it}$), Group$_{it}$, Negative equity$_{it}$, ROA$_{it}$, Intangibles$_{it}$, Patenter$_{i}$, Public equity$_{it}$ and Public debt$_{it}$ as defined in Table 1. The legacy effect quantifies the impact of a one standard deviation increase in $Med(\boldsymbol{\theta}^{\mathcal{A}}_{it-1})$ on the probability of having bank credit. The market structure effect quantifies the impact of a one standard deviation increase in $Min(\boldsymbol{\theta}^{\mathcal{A}}_{it-1})$ on the probability of having bank credit. All specifications are estimated using linear probability routines. The unit of observation is the firm-year-level. The sample period runs from $2008 - 2018$ and contains both brown and green firms. Standard errors, reported in parentheses, are clustered at the firm–level. *, ** and *** denote significance at the 10%, 5% and 1% level, respectively.

Table 10: RATIONING EXTENSIVE MARGIN: FIRM SIZE AND LEGACY MATURITY

	Legacy effect			Market structure effect		
	Green	Green innovation	Green diffusion	Green	Green innovation	Green diffusion
PANEL A: FIRM SIZE						
Bottom 10	−2.551	−4.071	−0.909	2.904	0.000	−1.107
	(3.642)	(5.705)	(0.717)	(3.500)	(3.303)	(1.116)
Bottom 10 to 50	0.128	−2.146	1.075	−0.526	2.237	1.626
	(0.547)	(3.025)	(1.013)	(0.730)	(3.461)	(0.497)
Top 50 to 10	−1.513**	−10.311***	−0.910**	−1.297*	−4.262*	−2.423*
	(0.665)	(2.758)	(0.389)	(0.753)	(6.001)	(0.510)
Top 10	−2.648***	−7.367**	−2.529***	−2.072***	−11.399***	−2.314***
	(0.652)	(3.326)	(0.481)	(0.520)	(3.432)	(0.530)
PANEL B: RESIDUAL MATURITY						
Lower than one year	−0.549	4.437	0.461	1.522	9.620	2.272
	(1.109)	(5.007)	(0.380)	(1.050)	(6.709)	(0.396)
One to two year	0.667	2.485	0.076	−3.300***	−7.037	−0.903***
	(0.788)	(5.114)	(0.454)	(0.755)	(5.487)	(0.327)
Two to five years	−1.324*	−10.805***	−0.958***	−2.786**	−8.404	−3.103**
	(0.765)	(3.296)	(0.341)	(1.085)	(9.151)	(0.540)
Longer than five years	−3.285***	−5.235*	−1.979***	−10.106***	−9.620***	−2.272***
	(1.023)	(3.102)	(0.513)	(1.829)	(2.236)	(0.396)

Notes: This table quantifies the legacy and market structure effect, broken down by firm size (panel A) and maturity of the legacy portfolio (panel B). The estimates in panel A are obtained from a modification of the specifications in Table 8 in which we interact $Med(\boldsymbol{\theta}^{\mathcal{A}}_{it-1})$ and $Min(\boldsymbol{\theta}^{\mathcal{A}}_{it-1})$ with one of four size indicator variables based on total assets of firm i (bottom 10%, bottom 10% to 50%, top 50% to 10%, top 10%). Panel B studies the role of the maturity structure underlying $\boldsymbol{\theta}^{\mathcal{A}}_{it-1}$. It additively decomposes $\boldsymbol{\theta}^{\mathcal{A}}_{it-1}$ in four summands based on the maturity of the exposed credit (lower than 1 year, one to two year, two to five years and longer than five years). Panel B reports the legacy and market structure effects, per maturity category, obtained from a set–up otherwise equal to that of Table 8. In all underlying regressions, controls include lags of ln(Assets$_{it}$), Leverage$_{it}$, ln(Firm age$_{it}$), ln(Capital age$_{it}$), Group$_{it}$, Negative equity$_{it}$, ROA$_{it}$, Intangibles$_{it}$, Patenter$_{i}$, Public equity$_{it}$ and Public debt$_{it}$ as defined in Table 1. In panel A, the legacy effect (market structure effect) quantifies the impact of a one standard deviation increase in $Med(\boldsymbol{\theta}^{\mathcal{A}}_{it-1})$ ($Min(\boldsymbol{\theta}^{\mathcal{A}}_{it-1})$), differentiated by firm size, on the probability of receiving bank credit. In panel B, the legacy effect (market structure effect) quantifies the impact of a one standard deviation increase in $Med(\boldsymbol{\theta}^{\mathcal{A}}_{it-1})$ ($Min(\boldsymbol{\theta}^{\mathcal{A}}_{it-1})$), differentiated by maturity, on the probability of receiving bank credit. All specifications are estimated using linear probability routines. The unit of observation is the firm-year-level and contains both brown and green firms. In panel A, the sample period runs from $2008 - 2018$. In panel B, the sample period runs from $2012 - 2018$ (maturity data is only available as of 2012). Standard errors of the legacy and market structure effects are, reported in parentheses, are based on firm–level clustering. *, ** and *** denote significance at the 10%, 5% and 1% level, respectively.

Table 11: RATIONING EXTENSIVE MARGIN: WHO IS BREAKING THE BARRIER?

	Dependent variable: Borrower_{ibt}		
	(1)	(2)	(3)
Estimation sample:	$\text{Green}_i = 1$	$\text{Green innovation}_i = 1$	$\text{Green diffusion}_i = 1$
$\theta_{ibt-1}^{\mathcal{A}=\text{Green}}$	-49.527^{***}		
	(15.079)		
$\iota_t(b = \arg\min_b(\boldsymbol{\theta}_{it-1}^{\mathcal{A}=\text{Green}}))$	8.362^{***}		
	(1.126)		
$\iota_t(b = \arg\max_b(\boldsymbol{\theta}_{it-1}^{\mathcal{A}=\text{Green}}))$	-7.114^{***}		
	(1.610)		
$\theta_{ibt-1}^{\mathcal{A}=\text{Green innovation}}$		-380.730^{***}	
		(131.150)	
$\iota_t(b = \arg\min_b(\boldsymbol{\theta}_{it-1}^{\mathcal{A}=\text{Green innovation}}))$		21.675^{**}	
		(10.637)	
$\iota_t(b = \arg\max_b(\boldsymbol{\theta}_{it-1}^{\mathcal{A}=\text{Green innovation}}))$		9.438	
		(6.763)	
$\theta_{ibt-1}^{\mathcal{A}=\text{Green diffusion}}$			-48.995^{***}
			(14.955)
$\iota_t(b = \arg\min_b(\boldsymbol{\theta}_{it-1}^{\mathcal{A}=\text{Green diffusion}}))$			8.272^{***}
			(1.071)
$\iota_t(b = \arg\max_b(\boldsymbol{\theta}_{it-1}^{\mathcal{A}=\text{Green diffusion}}))$			-6.969^{***}
			(1.555)
Sector $\times$ Time FE	Y	Y	Y
Location $\times$ Time FE	4-digit	1-digit	4-digit
Cluster	Y	Y	Y
# Observations	6960	175	6825
Adj. R^2	0.105	0.339	0.102

Notes: This table studies the identity of the bank that is acting as the first-time lender to a firm engaged in green activity $\mathcal{A}$. Borrower_{ibt} is an indicator variable taking on value 100 if bank b lends to firms i at time t (zero otherwise). $\iota_t(b = \arg\min_b(\boldsymbol{\theta}_{it-1}^{\mathcal{A}}))$ is an indicator function taking on value 1 if bank b has the smallest legacy position at risk (to firm i's activity) in the banking sector (zero otherwise). $\iota_t(b = \arg\max_b(\boldsymbol{\theta}_{it-1}^{\mathcal{A}}))$ is an indicator function taking on value 1 if bank b has the largest legacy position at risk (to firm i's activity) in the banking sector (zero otherwise). The unit of observation is the firm-bank-year-level and is restricted to the first year in which the firm received a credit line. On top of the actual lending relationship (Borrower_{ibt}=100), the eligible (but non–materialized, Borrower_{ibt}=0) lending relationships are those banks that have at least 50 established relationships to firms in the same sector in which firm i resides (cf. Subsection 5.2). The sample period runs from $2008-2018$. *, ** and *** denote significance at the 10%, 5% and 1% level, respectively.

Table 12: RATIONING INTENSIVE MARGIN

	Dependent variable: Δ ln(Credit$_{ibt}$)		
	(1)	(2)	(3)
Estimation sample:	Green$_i = 1$	Green innovation$_i = 1$	Green diffusion$_i = 1$
$\Delta\theta^{\mathcal{A}=\text{Green}}_{ibt-1}$	2.724		
	(1.816)		
$\Delta Min(\boldsymbol{\theta}^{\mathcal{A}=\text{Green}}_{it-1})$	-5.302^{*}		
	(3.213)		
$\Delta\theta^{\mathcal{A}=\text{Green innovation}}_{ibt-1}$		-7.989	
		(10.129)	
$\Delta Min(\boldsymbol{\theta}^{\mathcal{A}=\text{Green innovation}}_{it-1})$		-28.004	
		(17.181)	
$\Delta\theta^{\mathcal{A}=\text{Green diffusion}}_{ibt-1}$			2.957
			(1.839)
$\Delta Min(\boldsymbol{\theta}^{\mathcal{A}=\text{Green diffusion}}_{it-1})$			-5.894^{*}
			(3.247)
$\mathcal{A}$: Green			
Δ Market structure effect	-0.045		
$\mathcal{A}$: Innovator			
Δ Market structure effect		-0.111	
$\mathcal{A}$: Diffusor			
Δ Market structure effect			-0.050
Controls	Y	Y	Y
Bank $\times$ Time FE	Y	Y	Y
Loc. $\times$Sect. $\times$ Size $\times$ Time FE	Y	Y	Y
Location	Region	Region	Region
Assets	Decile	Decile	Decile
Sector	3 digits	2 digits	3 digits
Cluster	Bank	Bank	Bank
# Observations	108235	978	107618
Adj. R^2	0.037	0.029	0.037

Notes: This table investigates whether the market structure effect drives the intensive margin of bank-borrowing green firms. The unit of observation is the firm-bank-year-level. The sample period runs from $2008 - 2018$. All specifications are saturated with bank–time fixed effects (to control for generic bank–level credit supply at time t) and location–sector–size fixed effects (to control for firm–level credit demand at time t) as in Degryse et al. (2019). Δ Market structure effect measures the impact (measured in standard deviations) on Δ ln(Credit$_{ibt}$) of a one standard deviation increase in $\Delta\theta^{\mathcal{A}}_{ibt-1}$. Standard errors, reported in parentheses, are clustered at the firm–level. The reported regressors and regressand and are defined in Table 1. *, ** and *** denote significance at the 10%, 5% and 1% level, respectively.

Asset Overhang and Technological Change

– Online Appendix –

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A Procedure to distinguish product & process innovations

This Section provides details on our procedure to classify patents as product or process innovations.

A.1 Language processing of patent applications

Alongside a title and abstract, each patent application contains a list of patent claims. This exhaustive list defines exactly what is – and what is not – claimed by the invention and sought to be protected. As an illustration, we provide excerpts from two patent applications in Subsection A.4.

1. **Patent**: EP 2871 227 A1, owned by AB InBev, governs a sustainable technology called "*Simmer & Strip*" that limits the amount of water and heat needed for the beer brewing process, resulting in a reduction of water consumption and carbon emissions.

2. **Patent**: WO 2018/215888 Al, owned by Rietland – a firm offering commercial wastewater treatment solutions – seeks to protect a novel environmentally friendly water purification system.

In both patent excerpts, the title, abstract and list of claims are highlighted in red.

As conveyed by both examples, a key feature of patent applications – and claims in particular – is their legalistic, standardized and pedantic language. Text mining routines therefore serve as an appropriate tool to sort between two types of innovations. For instance, process claims are typically reported in a form starting with "A process for ...", "A method for ..." or variations thereof. Product claims, instead, include statements such as "An apparatus for..." or "A device for ..." (or minor variations). The AB-InBev and Rietland applications are clear examples of process and product innovations, respectively.

Starting from the list of patents associated with Climate Change Mitigation Technologies (CCMT), applied for by firms established in Belgium, we first import claims and associate each patent with a list of specific claims. Note that in contrast to Bena et al. (2021), Bena and Simintzi (2019) and Banholzer et al. (2019) our sample covers patents worldwide and therefore requires us to treat reports with heterogeneous structures.

Because of irregularities in their reporting, not all patents have claims directly associated to them. In order to treat this limitation, our procedure starts by importing all available claims associated with a patent's family in all languages possible.[46] Parsing through the entire family-related patents allows to expand to scope of claims collection.

For each patent, we first treat each claim by filtering off non-alpha terms and tokenizing, lemmatizing and stemming the remaining elements of the text. We then use an adapted version of the "process" dictionary prepared by Banholzer et al. (2019) to classify between process and product claims. More precisely, process claims are identified by the presence of variants of the words 'process', 'method', 'procedure', 'use' and 'utilization' in the first five words of the treated vector of the claim. Claims for which no word related to a process innovation was found are then classified as product claims. We replicate the same approach for text in English, German and French. Both the focus on the first relevant words of the claim and the identification-by-rejection of product innovation follow from the approach of Bena et al. (2021).

We subsequently qualify a patent as a process (product) innovation if the majority of claims are process (product) claims. When claims cannot be recovered, we resort to the patent title and abstract for which we compute the overlap with the list of process-related words. Similar to claims, we qualify the patent in function of the presence of process related words in the abstract's treated vector. Figure A.1 provides a full account of the dimensions of this sorting process.

[46] In theory, patents can be filed in multiple offices. Hence the same innovation can give rise to multiple patents, globally. A patent family is therefore defined as the set of patents with the same originating inventor and innovation claims. Patent reports from the same family may for instance differ in language, timing and patent office application identifications.

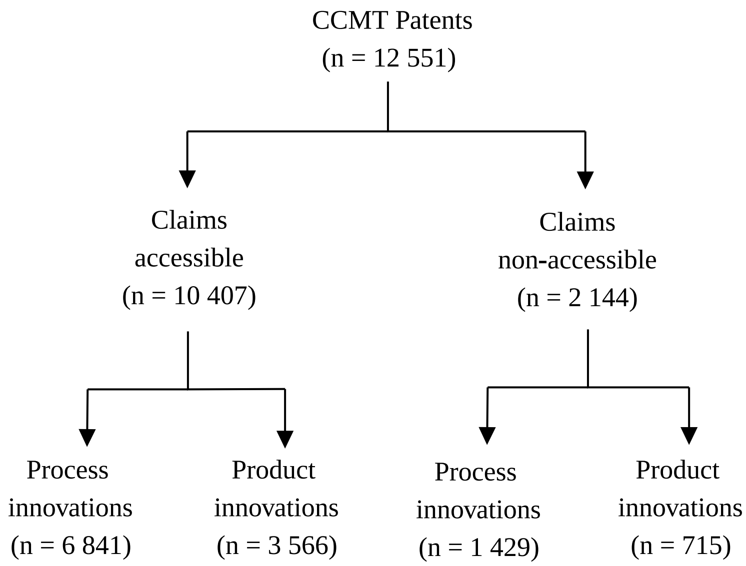

Figure A.1: Dimensions of the patent application text mining procedure.

Finally, we manually trace – for each patent – the Belgian VAT number of the applicant which is used as the identifier to merge in all other data sources. A firm is subsequently tagged as a process innovator (Green process innovation$_i$=1) if it has patented at least one green process innovation. A firm is tagged as a product innovator (Green product innovation$_i$=1) if it has patented at least one green product innovation.

Knowledge is typically fungible within a corporate group (Giroud et al., 2022; Chang and Hong, 2000). Given our objective to document green externalities on other firms, we are especially interested in spillovers on firms beyond the confinements of an individual group. We therefore map the green activity of individual members to other members of the same corporate group. Such an approach is also desirable for a second reason: close inspection of patent applications reveals that patents are often filed (or owned) by dedicated R&D establishments (separate legal entities) within a corporate group (Belenzon and Berkovitz, 2010). Externalities of the green innovation, however, are most likely to be found with firms neighbouring the group members of the R&D establishment who effectively implement or market the innovation – not with the external firms directly neighbouring the R&D entity.

A.2 Sanity check & mechanisms

Mechanisms. In order to test the validity of the procedure described above, we verify whether the implementation of environmental process innovation (as established from our our textual analysis) correlates with incidence of less wastage and less energy consumption. Table A.1 associates types of green activity with measurements of energy consumption (electricity and gas) and waste (solid and wastewater). The first row in the table corroborates that process innovators are less polluting per unit of value added, which constitutes a sanity check on our text-based sorting procedure. The first and third row also show that green process innovators and green adopters have lower expenses in these categories which is likely to give them an edge over their peers in the product market which speaks to the underlying economic mechanism.

Table A.1: GREEN ACTIVITIES, ENERGY CONSUMPTION AND WASTAGE

	$\frac{\text{Electricity}_{it}}{\text{Value added}_{it}}$	$\frac{\text{Gas}_{it}}{\text{Value added}_{it}}$	$\frac{\text{Waste}_{it}}{\text{Value added}_{it}}$	$\frac{\text{Wastewater}_{it}}{\text{Value added}_{it}}$
Green process innovation$_i$	-0.185^{**}	-0.135^{*}	-0.363^{*}	-0.063^{**}
	(0.078)	(0.080)	(0.197)	(0.030)
Green product innovation$_i$	-0.136	-0.053	-0.058	-0.032
	(0.130)	(0.318)	(1.350)	(1.200)
Green adoption$_i$	-0.057^{***}	0.078	-0.078^{***}	-0.046^{***}
	(0.009)	(0.091)	(0.022)	(0.003)
Green provision$_i$	-0.136^{**}	-0.004	-0.051	-0.025
	(0.058)	(0.006)	(0.143)	(0.135)

Notes: The dependent variables proxy waste generation or energy efficiency per unit of value added. All dependent variables are standardized within the 4–digit NACE code in which the firm resides. Electricity is the sum of firm level purchases from sector 35.1 ("Electric power generation, transmission and distribution"). Gas purchases are purchases from sector 35.2 ("Manufacture of gas; distribution of gaseous fuels through mains"). Waste purchases are purchases from sectors 38 ("Waste collection, treatment and disposal activities; materials recovery") and 39 ("Remediation activities and other waste management services"). Wastewater purchases are purchases from sectors 36 ("Water collection, treatment and supply") and 37 ("Sewerage"). We exclude firms that procure from organizations operative in sector 84.1 ("Administration of the State and the economic and social policy of the community"). The latter are governmental organizations ("intercomunales") that often act as intermediaries for provision of electricity/gas/waste/wastewater but also non-environmental expenses such as telecommunications/mobility/etc.

Process innovations as marketable products. Following previous work, the analysis in the body of the text assumes that process innovations are not marketed (but implemented) by the innovating firm (Bena et al., 2021; Bena and Simintzi, 2019). To verify the validity of this assumption, we draw on the SBS survey which requires firms to report the share of their revenues related to their intellectual property (i.e., revenues from selling patented products and/or licensing). We find that 3% of the firms we classify as exclusively process innovators report such revenues, whereas 88% of the exclusively product innovators report positive revenues. To the extent the patenters also own non-green patents, this statistic is distorted (because the SBS does not focus on revenues from CCMT Intellectual property). However the pattern does suggest our assumption is reasonable.

A.3 Replication material

Replication material to extract and sort individual patent claims is available upon request.

A.4 Patent application examples

(continued on next page)

Page 1 - AB Inbev patent application EP 2 871 227 A1

(19) Europäisches Patentamt European Patent Office Office européen des brevets

(11) **EP 2 871 227 A1**

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Title

(54) **Method for treating a wort in a boiling kettle**

Abstract

(57) The present invention concerns a process for treating a wort in a kettle, said method comprising the steps of:
(a) providing:
• a kettle (1) provided with an inlet (1 u) suitable for feeding a wort into the kettle and with an outlet (1 d) suitable for flowing the wort out of the kettle,
• heating means (2) suitable for bringing the wort contained in the kettle close to or at boiling temperature, as well as for controlling said temperature,
• a gas sparging system suitable for sparging an inert gas into said wort, ,
(b) feeding wort from a lautering step into said boiling kettle through the inlet, said wort being at a temperature below its boiling temperature;
(c) while sparging an inert gas through the wort, heating said wort to, and maintaining it at a treatment temperature, T_a, which is below the boiling temperature, T_b, of the wort for a duration, ttreat, comprised between 15 and 90 min, and no longer than required to evaporate at most 4 wt.% of water initially present in the wort;
(d) transferring the treated wort to a trub separation step through the outlet.

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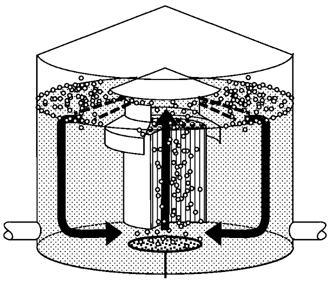

(b)

FIG.3

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Figure A.2: Patent example AB Inbev. Keywords used to sort between process/product innovations are highlighted in green.

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Table 2: comparison of energy consumption between boiling and pseudo-boiling processes

	EX.2 INV	REX.2 internal boiler with natural convection	REX.3 internal boiler with forced convection
evaporation (wt.%)	1.5	8	5
energy consumption (kJ/hl)	3,387	18,063	11,290
energy (kWh / hl)	0.94	5.02	3.14
relative energy consumption (relative REX.2) (%)	19%	100%	63%
consumption for 400,000 hl (MWh)	376	2,007	1,254

[0042] The pseudo-boiling process of the present invention is an advantageous alternative to conventional wort boiling yielding beer of comparable quality with over 80% energy saving. All observed quality parameters of the produced worts and beers according to the present invention were comparable or better than their corresponding reference beers, while the evaporation rate of the pseudo-boiling process was only 20 to 30% of the reference evaporation rate. The potential energy savings of the process of the present invention are very high (up to 4 kWh/hL), which is an asset, since energy becomes more expensive every day.

[0043] The pseudo-boiling process of the present invention combines the advantages of wort boiling systems with forced convection, hot holding or stripping and provides an excellent means to meet the requirements of wort boiling:

- Evacuation of volatiles is enhanced without the need for extensive evaporation and thus, energy.
- Forced convection is ensured by a continuous upward stream of nitrogen bubbles (gas lift). The convection is therefore completely independent of the heating intensity
- No boiling temperature is needed. Hot holding is sufficient.
- Coagulation of proteins occurs without the presence of vapour bubbles. The small nitrogen bubbles provide a large interface, which allows the denatured proteins to coagulate. The results of the final beers show good haze and foam stability (cf. Table 1).

Claims

Claims

1. Process for treating a wort in a kettle, said method comprising the steps of:

   (a) providing:

   - a kettle (1) provided with an inlet (1 u) suitable for feeding a wort into the kettle and with an outlet (1 d) suitable for flowing the wort out of the kettle,
   - heating means (2) suitable for bringing the wort contained in the kettle close to or at boiling temperature, as well as for controlling said temperature,
   - a gas sparging system (3) suitable for sparging an inert gas into said wort,

   (b) feeding wort from a lautering step into said boiling kettle through the inlet, said wort being at a temperature below its boiling temperature, T_b;
   (c) while sparging an inert gas through the wort, heating said wort to, and maintaining it at a treatment temperature, T_a, which is below the boiling temperature, T_b, of the wort for a duration, t_{treat}, comprised between 1 5 and 90 min, and no longer than required to evaporate at most 4 wt.% of water initially present in the wort;
   (d) transferring the treated wort to a trub separation step through the outlet.

2. Method according to claim 1, wherein the wort does not reach the boiling temperature, T_b, thereof during the whole duration of its residence in said boiling kettle.

3. Method according to claim 1 or 2, wherein the treatment temperature, T_a, is greater than 90°C, preferably greater than 97°C, more preferably between (T_b - 2°C) and T_b, wherein T_b is the boiling temperature of the wort.

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Figure A.2: Patent example AB Inbev. Keywords used to sort between process/product innovations are highlighted in green.

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Claims, continued

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4. Method according to any of the preceding claims, wherein the inert gas is sparged into the wort by means of a gas sparger (3) located at the bottom of the kettle and oriented upwards, said sparger preferably comprising a circular plate, cylinder or ring provided with a multitude of apertures.

5. Method according to claim 4, wherein the kettle is of the internal boiler type, comprising vertically oriented heating tubes (2a) through which the wort to be heated or to be maintained at elevated temperature flows, said heating tubes being located above the gas sparger.

6. Method according to claim 4, wherein the kettle is of the external boiler type, comprising heating tubes (2a) through which the wort to be heated or to be maintained at elevated temperature flows, said heating tubes being located outside the kettle and in fluid communication therewith through tubing and a pump (8).

7. Method according to any of the preceding claims, wherein the inert gas sparging flow rate has an initial value upon introduction of the wort in the boiling kettle, which is highest and preferably comprised between 0.05 and 50 m^3 / h / hl wort, more preferably between 0.1 and 10 m^3 / h / hl, and decreases progressively as the wort reaches its treatment temperature, T_a, to a value preferably comprised between 25 and 75%, more preferably between 37 and 45% of the initial value of the inert gas sparging flow rate.

8. Method according to any of the preceding claims, wherein the treatment time, t_{treat}, is comprised between 20 and 75 min, preferably between 30 and 60 min.

9. Method according to any of the preceding claims, wherein the inert gas is nitrogen or carbon dioxide.

10. Method according to any of the preceding claims, wherein the thus treated wort is transferred to a whirlpool and then to further treatment vessels to produce a beer or a malt based beverage.

11. Method according to the preceding claim, wherein the beer or malt based beverage has one or more of the following properties:

(a) Foam stability (NIBEM) of at least 150s;
(b) Haze measured on fresh beer or malt based beverage lower than 1.0 EBC; and/or
(c) Haze measured on beer or malt based beverage aged for 3 days at 60°C lower than 1.5 EBC.

10

Figure A.2: Patent example AB Inbev. Keywords used to sort between process/product innovations are highlighted in green.

Page 1 - Rietland patent application WO 2018/21588 A1

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Published:
— *with international search report (Art. 21(3))*

WO 2018/215888 A1

(54) **Title:** WATER PURIFICATION

Title

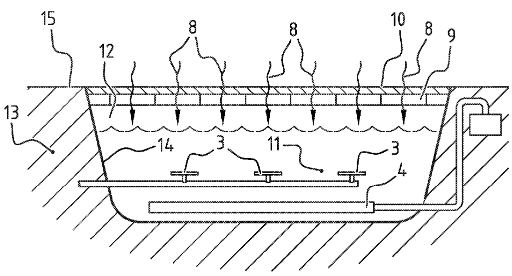

Fig. 2

Abstract

(57) **Abstract:** Device for treating wastewater, comprising: a substantially watertight tub; - an inlet for supplying wastewater to the tub; an outlet for discharging wastewater from the tub; granular substrate which substantially fills the tub, wherein the granular substrate comprises at least 90% granules with a granule size greater than 1 mm and smaller than 120 mm; - an air feed provided at the position of a bottom of the tub; wherein a pressure-distributing layer with a substantially flat finishing layer is provided on the granular substrate at the position of an upper segment of the tub, such that the device can be walked on.

Figure A.3: Patent example Rietland Inc. Keywords used to sort between process/product innovations are highlighted in green.

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Claims

Claims

1. Device for treating wastewater, comprising:
   - a substantially watertight tub (2);
   - an inlet for supplying wastewater to the tub;
   - an outlet for discharging wastewater from the tub;
   - granular substrate (11) which substantially fills the tub, wherein the granular substrate (11) comprises at least 90% granules with a granule size greater than 1 mm and smaller than 120 mm;
   - an air feed (3) provided at the position of a bottom of the tub;

characterized in that a pressure-distributing layer (9) with a substantially flat finishing layer (10) is provided on the granular substrate (11) at the position of an upper segment of the tub, such that the device can be walked on.

2. Device for treating wastewater according to claim 1, wherein the substantially watertight tub (2) is embodied as a combination of an excavation in the ground (13) with a substantially watertight layer (14).

3. Device for treating wastewater according to claim 2, wherein the finishing layer (10) extends at the height of edges of the excavation so that the excavation is covered by the device.

4. Device for treating wastewater according to any of the foregoing claims, wherein the upper side of the pressure-distributing layer (9) is embodied as finishing layer (10).

5. Device for treating wastewater according to any of the foregoing claims, wherein the pressure-distributing layer (9) with the substantially flat finishing layer (10) is configured to be passable by car.

6. Device for treating wastewater according to any of the foregoing claims, wherein the pressure-distributing layer (9) is constructed with a plurality of rigid elements which are placed in a grid in order to cover substantially the whole upper side of the device.

7. Device for treating wastewater according to claim 6, wherein the grid has a plurality of rows and columns and wherein the plurality of rigid elements can be connected to each other.

8. Device for treating wastewater according to claim 6 or 7, wherein the plurality of rigid elements are formed by grass grids.

9. Device for treating wastewater according to any of the foregoing claims, wherein the pressure-distributing layer (9) has a lower segment with crushed granules (12).

10. Device for treating wastewater according to any of the foregoing claims, wherein the pressure-distributing layer (9) is air-permeable such that air, supplied into the tub via the air feed (3), can leave the device via the pressure-distributing layer (9).

Figure A.3: Patent example Rietland Inc. Keywords used to sort between process/product innovations are highlighted in green.

B Externalities: additional results & robustness

This Section compiles robustness tests and additional results for Section 4.

B.1 Business stealing and firm riskiness: alternative measures

Business stealing. Our baseline results relied on two intensive margin measures of generic firm performance. We now define one extensive margin flavoured measure (Δ ln (B2B customers$_{it}$)) – the percentage change in the number of corporate customers – and one variable that conceptually better captures business stealing (Lost B2B$_{it}$). The latter measures the share of the corporate customer portfolio that has likely migrated to green product market competitors from $t-1$ to t. Formally, for every seller$_{it-1}$–buyer$_{jt-1}$ relationship at time $t-1$ that is discontinued at time t, we verify whether buyer$_{jt}$ started up a new sourcing relationship at time t with seller$_{kt}$ that is in the same product space as firm i ($\Pi_{ikt-1} > \Pi^* = 0.75$) and is known to be a green firm. If this is the case, we tag the broken relationship for firm i as "lost B2B business".[47] Lost B2B$_{it}$ quantifies the share of $t-1$ B2B sales volume that is lost to green product market competitors.[48]

Table A.2, column (1)–(2) complement the baseline results and reveal that various forms of enhanced green presence is associated with a decline in the corporate customer portfolio and a shift of business activity towards green competitors.

Impact on bank profit & losses. Central to our asset overhang mechanism is the cost borne by the investor. While Table 6, reveals that PDs move up and down in tandem with green presence, it has not established an actual cost incurred by banks. Consequently, Table A.2 columns (3)–(4) retake the estimation of Table 6 and focus on provisions booked on brown credit facilities. Offering an even tighter link with the theory, columns (3)–(4) reveal that additional (lower) greenness in the proximity of the incumbent corporate portfolio leads banks to book additional (lower) provisions on outstanding brown credit lines.

[47] For example, suppose seller$_{it-1}$ is a logistics firm with NACE code "50400" (= transport of goods over canals and rivers). It sells its logistics services to buyer$_{jt-1}$, which is in NACE code "08122" (= mining of sand). Suppose, this relationship is discontinued and we observe that buyer$_{jt}$ starts buying goods from seller$_{kt}$, which, similar to firm i, is active in "50400", is operative in the product space of firm i but, unlike firm i, is green. In that case, we tag this broken link as stolen business from the viewpoint of firm i.

[48] The variable controls for entry/exit.

Table A.2: ROBUSTNESS – ALTERNATIVE PROXIES EXTERNALITIES

	Firm performance		Bank assessed firm riskiness	
PANEL A: INNOVATION				
	Δ ln (B2B customers$_{it}$)	Lost B2B$_{it}$	Provision up$_{ibt}$	Provision down$_{ibt}$
	(1)	(2)	(3)	(4)
$\overline{\Delta d(i,t)}^{\mathcal{A}=\text{green product innovation}}_{\mathcal{S}=\text{product space}}$	-0.0042^{**} (0.0017)	0.489^{***} (0.040)	4.306^{*} (2.378)	-1.706 (1.795)
$\overline{\Delta d(i,t)}^{\mathcal{A}=\text{green process innovation}}_{\mathcal{S}=\text{product space}}$	-0.0022^{*} (0.0013)	0.288^{***} (0.032)	3.735^{**} (1.631)	-2.470^{*} (1.446)
$\overline{\Delta d(i,t)}^{\mathcal{A}=\text{green product innovation}}_{\mathcal{S}=\text{technology space}}$	0.0003 (0.0010)	0.017 (0.015)	1.194 (0.736)	-0.073 (0.314)
$\overline{\Delta d(i,t)}^{\mathcal{A}=\text{green process innovation}}_{\mathcal{S}=\text{technology space}}$	-0.0013 (0.0011)	-0.027 (0.018)	1.106 (0.994)	-0.423 (1.112)
Controls	Y	Y	Y	Y
Sector × Time FE	4 digit	4 digit	3 digit	3 digit
Location × Time FE	Y	Y	Y	Y
Bank × Time FE	N	N	Y	Y
Firm FE	Y	Y	N	N
Cluster-level	Firm	Firm	Firm	Firm
# Observations	526016	534024	77070	77070
Adj. R^2	0.077	0.429	0.102	0.165
PANEL B: DIFFUSION				
	Firm performance		Bank assessed firm riskiness	
	Δ ln (B2B customers$_{it}$)	Lost B2B$_{it}$	Provision up$_{ibt}$	Provision down$_{ibt}$
	(1)	(2)	(3)	(4)
$\overline{\Delta d(i,t)}^{\mathcal{A}=\text{green provision}}_{\mathcal{S}=\text{product space}}$	-0.0007 (0.0004)	0.012^{*} (0.007)	0.014^{*} (0.008)	-0.003^{***} (0.001)
$\overline{\Delta d(i,t)}^{\mathcal{A}=\text{green adoption}}_{\mathcal{S}=\text{product space}}$	-0.0003^{*} (0.0002)	0.015^{***} (0.001)	0.007^{*} (0.004)	-0.009^{***} (0.003)
$\overline{\Delta d(i,t)}^{\mathcal{A}=\text{green provision}}_{\mathcal{S}=\text{technology space}}$	0.0000 (0.0000)	-0.003 (0.002)	0.007 (0.005)	0.000 (0.000)
$\overline{\Delta d(i,t)}^{\mathcal{A}=\text{green adoption}}_{\mathcal{S}=\text{technology space}}$	0.0000 (0.0000)	0.002 (0.001)	-0.005 (0.003)	0.006 (0.010)
Controls	Y	Y	Y	Y
Sector × Time FE	4 digit	4 digit	3 digit	3 digit
Location × Time FE	Y	Y	Y	Y
Bank × Time FE	N	N	Y	Y
Firm FE	Y	Y	N	N
Cluster-level	Firm	Firm	Firm	Firm
# Observations	453357	454077	66540	66540
Adj. R^2	0.072	0.419	0.097	0.171

Notes: Panel A summarizes the performance/provisioning impact of green process and product innovation on firms that engage in neither of both activities. Panel B summarizes the performance/provisioning impact of green product provision and green capital investment on firms that engage in neither of both activities. In columns (1)–(2) and (3)–(4), the unit of observation is at the firm-year-level and firm-bank-year-level, respectively. The unbalanced sample period runs from $2008-2018$. Controls include lags of ln(Assets$_{it}$), Leverage$_{it}$, ln(Capital age$_{it}$), brown product space entrants$_{it}$ and brown technology space entrants$_{it}$ as defined in Table 1. Provision up$_{ibt}$ is an indicator variables taking on 100 (0) if the total provisions booked on credit to firm i goes up (or not). Provision down$_{ibt}$ is an indicator variables taking on 100 (0) if the total provisions booked on credit to firm i goes down (or not). Columns (1)–(2) include a lag of the dependent variable. Columns (3)–(4) are estimated using linear probability routines. Robust standard errors, reported in parentheses, are clustered at the firm–level. All regressors and regressands are defined in Table 1 and Subsection B.1. *, ** and *** denote significance at the 10%, 5% and 1% level, respectively.

B.2 Covariates: measurement & interpretation

In this Subsection we address three measurement/interpretation aspects of our covariates previously highlighted in Section 4. To formalize these points, we start from an ideal covariate setting and additively decompose it into static and dynamic summands. Although such a decomposition can be made for all covariates, for expositional purposes, we focus on $\overline{d(i,t)}^{\mathcal{A}=\text{green}}_{\mathcal{S}=\text{product space}}$. Henceforth, let firm i (j) denote a brown (green) firm. From Leibniz's rule:

$$\begin{aligned}\overline{\Delta d(i,t)}^{\mathcal{A}=\text{green}}_{\mathcal{S}=\text{product space}} &= M^{-1}\sum_{m=1}^{M}\sum_{j=1}^{J}\Delta\big(\Pi_{ijt-m}\times \text{Green}_{jt-m}\big)\\ &= \underbrace{M^{-1}\sum_{m=1}^{M}\sum_{j=1}^{J}\Delta\big(\Pi_{ijt-m}\big)\text{Green}_{jt-m}}_{(a)} + \underbrace{M^{-1}\sum_{m=1}^{M}\sum_{j=1}^{J}\Pi_{ijt-m}\Delta\big(\text{Green}_{jt-m}\big)}_{(b)}\\ &\quad + \underbrace{M^{-1}\sum_{m=1}^{M}\sum_{j=1}^{J}\Delta\big(\Pi_{ijt-m}\big)\Delta\big(\text{Green}_{jt-m}\big)}_{(c)}\end{aligned} \tag{A.5}$$

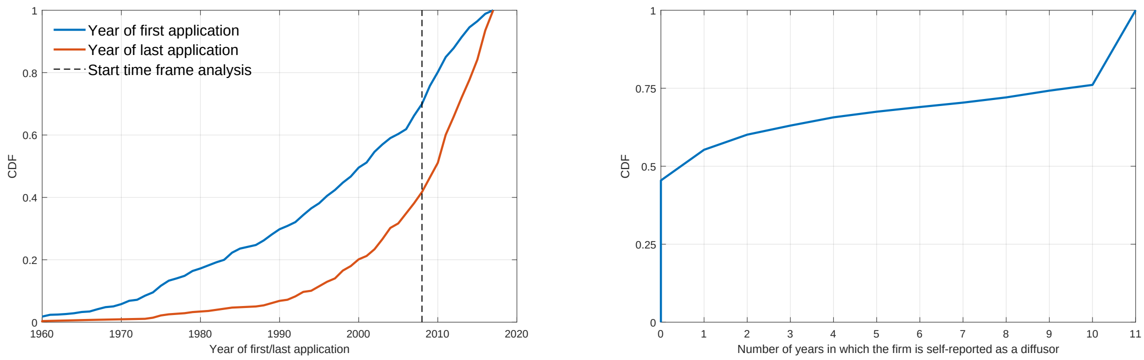
Where $\Delta(\cdot)$ is the first difference operator and Green_{jt-m} is a time variant counterpart to the static variable used in the body of the paper (Green_j). Summand (a) then reflects increased product market exposure by firm i to firms previously already engaged in environmental activities. Components (b) and (c) reflect heightened environmental exposure because new and/or old product market peers suddenly start to engage in environmental activities. In our baseline results, terms $(b)-(c)$ are 0 (as $\Delta\big(\text{Green}_{jt-m}\big)=0$).

B.2.1 Summand $(b)-(c)$: Time variation in green activities

Time variation in innovation variables. The baseline estimates intentionally do no account for time variation in the definition of $\text{Green innovation}_i$. Although PATSTAT would allow us to identify the event where a firm becomes an environmental innovator (e.g., the year of first application of a CCMT patent), such variation is small in our data. The left-hand panel in Figure A.4 documents the CDF of the year in which the in-sample innovators have filed their first CCMT patent. By 2008 (the starting period of our analysis), already 75% of our set of innovators had filed at least one CCMT patent. Half way through our sample, this is true for 95% of the identified innovators.

Other arguments plead in favour of a static approach as time-varying measures are subject to structural measurement issues. E.g., a time invariant measure of a firm's green innovation status sidesteps concerns related to PATSTAT's end-of-sample truncation and the secular trend towards more patenting (Lerner and Seru, 2022). Moreover, patent applications typically lag significantly behind the actual innovation activity (Pakes and Griliches, 1980).

If CCMT patenting is infrequent, however, a static approach raises the concern that the environmental innovation activity was a one–off event, falsely inflating the green identity of firms. The left-hand panel in Figure A.4 plots the CDF of the year in which the in-sample innovators have filed their last CCMT patent. It reveals that 80 % of the in-sample innovators have filed CCMT patents since 2000. 60 % have filed such patents throughout our sample period.



(a) Innovation: PATSTAT

(b) Diffusion: SBS survey

Figure A.4: Time variation in the status of innovation & diffusion.

Time variation in diffusion variables. There is intentionally no time variation in our definition of Green provision$_i$ and Green adoption$_i$. The unbalanced panel set-up of the SBS survey makes it impossible to identify the tipping point where a previously brown firm starts investing in/selling green goods & services. To verify the stringency of this approach, we focus on the subsample of (larger) firms that are in the SBS sample ever year. Figure A.4 documents a large persistence in firm-level responses on whether they buy green or invest green: e.g., approximately 50% of all firms that are surveyed each year never report a positive share of green sales and/or investments. Approximately 25% always report green sales and/or investments, suggesting that time variation in in green diffusion is relatively contained.

B.2.2 Summand (a): Decomposition of changes in firm proximities

Term (a) in eq. A.5 can be disentangled further as follows (ignoring time variation in green activities following Subsection B.2.1),

$$M^{-1}\sum_{m=1}^{M}\sum_{j=1}^{J}\Delta\big(\Pi_{ijt-m}\big)\text{Green}_j = \underbrace{M^{-1}\sum_{m=1}^{M}\sum_{j=1}^{J}\Delta\Big(\frac{\boldsymbol{\pi}'_{it-m}}{\sqrt{\boldsymbol{\pi}'_{it-m}\boldsymbol{\pi}_{it-m}}}\Big)\frac{\boldsymbol{\pi}_{jt-m}}{\sqrt{\boldsymbol{\pi}'_{jt-m}\boldsymbol{\pi}_{jt-m}}}\text{Green}_j}_{(a')}$$
$$+\underbrace{M^{-1}\sum_{m=1}^{M}\sum_{j=1}^{J}\frac{\boldsymbol{\pi}'_{it-m}}{\sqrt{\boldsymbol{\pi}'_{it-m}\boldsymbol{\pi}_{it-m}}}\Delta\Big(\frac{\boldsymbol{\pi}_{jt-m}}{\sqrt{\boldsymbol{\pi}'_{jt-m}\boldsymbol{\pi}_{jt-m}}}\Big)\text{Green}_j}_{(a'')}$$
$$+\underbrace{M^{-1}\sum_{m=1}^{M}\sum_{j=1}^{J}\Delta\Big(\frac{\boldsymbol{\pi}'_{it-m}}{\sqrt{\boldsymbol{\pi}'_{it-m}\boldsymbol{\pi}_{it-m}}}\Big)\Delta\Big(\frac{\boldsymbol{\pi}_{jt-m}}{\sqrt{\boldsymbol{\pi}'_{jt-m}\boldsymbol{\pi}_{jt-m}}}\Big)\text{Green}_j}_{(a''')}$$

where (a') reflects entry/exit of brown firm i into/from the product space of green firm j (keeping constant the output market composition of j), (a'') captures entry/exit of green firm j into/from the product space of brown firm i (keeping constant the output market composition of firm i) and (a''') quantifies a joint movement of brown firm i and green firm j into (out of) markets previously unserved (served) by both.

Our baseline results aggregated $(a') - (a''')$ while one could argue that the performance and asset devaluation externalities would mostly be triggered by (a'') – and to a lesser extent (a') & (a''') as the latter components involve actions of firm i itself (who is likely to minimize its exposure). To corroborate this, we re–estimate the baseline model where we substitute (a) with (a''). The results, presented in table A.3, reflect that, once we tease out the movement of green firms to brown firm, the size of the externalities become stronger and tighter identified.

Table A.3: ROBUSTNESS – LEIBNIZ DECOMPOSITION

PANEL A: INNOVATION

	Δ ln (HH sales$_{it}$)	Writedowns$_{it}$
	(1)	(2)
$M^{-1}\sum_{m=1}^{M}\sum_{j=1}^{J}\frac{\boldsymbol{\pi}'_{it-m}}{\sqrt{\boldsymbol{\pi}'_{it-m}\boldsymbol{\pi}_{it-m}}}\Delta\left(\frac{\pi_{jt-m}}{\sqrt{\boldsymbol{\pi}'_{jt-m}\boldsymbol{\pi}_{jt-m}}}\right)$ Green product innovation$_j$	-0.2111^{***}	-0.428
	(0.0251)	(0.989)
$M^{-1}\sum_{m=1}^{M}\sum_{j=1}^{J}\frac{\boldsymbol{\pi}'_{it-m}}{\sqrt{\boldsymbol{\pi}'_{it-m}\boldsymbol{\pi}_{it-m}}}\Delta\left(\frac{\pi_{jt-m}}{\sqrt{\boldsymbol{\pi}'_{jt-m}\boldsymbol{\pi}_{jt-m}}}\right)$ Green process innovation$_j$	-0.0773^{***}	-1.111
	(0.0184)	(0.799)
$M^{-1}\sum_{m=1}^{M}\sum_{j=1}^{J}\frac{\boldsymbol{\tau}'_{it-m}}{\sqrt{\boldsymbol{\tau}'_{it-m}\boldsymbol{\tau}_{it-m}}}\Delta\left(\frac{\tau_{jt-m}}{\sqrt{\boldsymbol{\tau}'_{jt-m}\boldsymbol{\tau}_{jt-m}}}\right)$ Green product innovation$_j$	-0.0122	-0.521
	(0.0100)	(0.325)
$M^{-1}\sum_{m=1}^{M}\sum_{j=1}^{J}\frac{\boldsymbol{\tau}'_{it-m}}{\sqrt{\boldsymbol{\tau}'_{it-m}\boldsymbol{\tau}_{it-m}}}\Delta\left(\frac{\tau_{jt-m}}{\sqrt{\boldsymbol{\tau}'_{jt-m}\boldsymbol{\tau}_{jt-m}}}\right)$ Green process innovation$_j$	0.0003	0.637^{*}
	(0.0081)	(0.363)
Controls	Y	Y
Sector $\times$ Time FE	4 digit	3 digit
Location $\times$ Time FE	Y	Y
Firm FE	Y	Y
Cluster-level	Firm	Firm
# Observations	428180	76397
Adj. R^2	0.172	0.024

PANEL B: DIFFUSION

	Δ ln (HH sales$_{it}$)	Writedowns$_{it}$
	(1)	(2)
$M^{-1}\sum_{m=1}^{M}\sum_{j=1}^{J}\frac{\boldsymbol{\pi}'_{it-m}}{\sqrt{\boldsymbol{\pi}'_{it-m}\boldsymbol{\pi}_{it-m}}}\Delta\left(\frac{\boldsymbol{\pi}_{jt-m}}{\sqrt{\boldsymbol{\pi}'_{jt-m}\boldsymbol{\pi}_{jt-m}}}\right)$ Green provision$_j$	-0.0278^{***}	0.246
	(0.0041)	(0.192)
$M^{-1}\sum_{m=1}^{M}\sum_{j=1}^{J}\frac{\boldsymbol{\pi}'_{it-m}}{\sqrt{\boldsymbol{\pi}'_{it-m}\boldsymbol{\pi}_{it-m}}}\Delta\left(\frac{\boldsymbol{\pi}_{jt-m}}{\sqrt{\boldsymbol{\pi}'_{jt-m}\boldsymbol{\pi}_{jt-m}}}\right)$ Green adoption$_j$	-0.0094^{***}	-0.145
	(0.0008)	(0.105)
$M^{-1}\sum_{m=1}^{M}\sum_{j=1}^{J}\frac{\boldsymbol{\tau}'_{it-m}}{\sqrt{\boldsymbol{\tau}'_{it-m}\boldsymbol{\tau}_{it-m}}}\Delta\left(\frac{\boldsymbol{\tau}_{jt-m}}{\sqrt{\boldsymbol{\tau}'_{jt-m}\boldsymbol{\tau}_{jt-m}}}\right)$ Green provision$_j$	-0.0003	0.002
	(0.0003)	(0.011)
$M^{-1}\sum_{m=1}^{M}\sum_{j=1}^{J}\frac{\boldsymbol{\tau}'_{it-m}}{\sqrt{\boldsymbol{\tau}'_{it-m}\boldsymbol{\tau}_{it-m}}}\Delta\left(\frac{\boldsymbol{\tau}_{jt-m}}{\sqrt{\boldsymbol{\tau}'_{jt-m}\boldsymbol{\tau}_{jt-m}}}\right)$ Green adoption$_j$	-0.0001	0.009^{**}
	(0.0001)	(0.005)
Controls	Y	Y
Sector $\times$ Time FE	4 digit	3 digit
Location $\times$ Time FE	Y	Y
Firm FE	Y	Y
Cluster-level	Firm	Firm
# Observations	360260	47743
Adj. R^2	0.176	0.018

Notes: Panel A summarizes the performance/asset pledgeability impact of green process and product innovation on firms that engage in neither of both activities. Panel B summarizes the performance/asset pledgeability impact of green product provision and green capital investment on firms that engage in neither of both activities. The unbalanced sample period runs from $2008-2018$. Controls include lags of ln(Assets$_{it}$), Leverage$_{it}$, ln(Capital age$_{it}$), brown product space entrants$_{it}$ and brown technology space entrants$_{it}$ as defined in Table 1. Column (1) includes a lag of the dependent variable (Columns (2) does not given that, due to the idiosyncratic nature of the dependant variable, the panel is highly unbalanced). Columns (2) is estimated using linear probability routines. All regressors are defined in Table 1 and Subsection B.2.2. Robust standard errors, reported in parentheses, are clustered at the firm–level. *, ** and *** denote significance at the 10%, 5% and 1% level, respectively.

B.2.3 Summand (a): Alternative distance measures

This Subsection addresses the measurement of our proximity variables.

Alternative distance measure – Mahalanobis. We next substitute the Jaffe (1988) proximity measure with the Mahalanobis distance measure. This alternative distance measure has the benign property that it takes on board how close two technology/customer markets are (see Bloom et al. (2013) and Lucking et al. (2019) for algebraic details). Table A.4, panel A reveals that our results remain largely unchanged when leveraging this augmented concept of proximity.

Measurement – Falsification. The calibration of the product and technology space closeness relies on a particular level of granularity. Our baseline results relied on the 5-digit level (the most granular level available). Taking a more aggregated view is expected to render these measures less informative and therefore serves as an interesting falsification test. Table A.4 panel B re-estimates models (1) & (2) setting a level of granularity in the calibration of $\boldsymbol{\pi}_{it}, \boldsymbol{\tau}_{it}$ at the 2-digit level. The complete absence of statistical significance reveals that a granular measurement of proximity is instrumental for a proper identification of spillovers.

Alternative distance measure – Geography. Externalities are often driven by the geographical distance between the source and the receptor (Jaffe et al., 1993; Bloom et al., 2013). To corroborate this in our framework, we augment the economic distance measures in Definition 3.4 with a spatial component. More precisely, let $\boldsymbol{\pi}_{it}^{geo} = (\pi_{i11t}, ..., \pi_{igkt}, ..., \pi_{iGKt})'$ denote the vector containing the share of firm–level sales to sector k in geographical area g. Substituting $\boldsymbol{\pi}_{it}$ for $\boldsymbol{\pi}_{it}^{geo}$ in the computation of Π_{ijt}, the latter now factors in how close firms are in their product *and* geographical space. Firms serving similar output markets, but in only partially overlapping geographical spheres are now qualified as being less close than before. Similarly, we take $\boldsymbol{\tau}_{it}^{geo} = (\tau_{i11t}, ..., \tau_{igkt}, ..., \tau_{iGKt})'$. Table A.5 quantifies our results when we define G at the regional level. As expected, the size of the established externalities are stronger for economically *and* geographically close firms.

Table A.4: Robustness – Mahalanobis distance & falsification

Panel A: Mahalanobis distance measure

	Innovation			Diffusion	
	Δ ln (HH sales$_{it}$)	Writedowns$_{it}$		Δ ln (HH sales$_{it}$)	Writedowns$_{it}$
	(1)	(2)		(3)	(4)
$\overline{\Delta mh(i,t)}^{\mathcal{A}=\text{green product innovation}}_{\mathcal{S}=\text{product space}}$	-0.0633^{***} (0.0045)	-0.033 (0.165)	$\overline{\Delta mh(i,t)}^{\mathcal{A}=\text{green provision}}_{\mathcal{S}=\text{product space}}$	-0.009^{***} (0.001)	0.002 (0.002)
$\overline{\Delta mh(i,t)}^{\mathcal{A}=\text{green process innovation}}_{\mathcal{S}=\text{product space}}$	-0.0191^{***} (0.0030)	-0.070 (0.135)	$\overline{\Delta mh(i,t)}^{\mathcal{A}=\text{green adoption}}_{\mathcal{S}=\text{product space}}$	0.000^{***} (0.000)	0.000 (0.000)
$\overline{\Delta mh(i,t)}^{\mathcal{A}=\text{green product innovation}}_{\mathcal{S}=\text{technology space}}$	0.0013 (0.0026)	-0.010 (0.026)	$\overline{\Delta mh(i,t)}^{\mathcal{A}=\text{green provision}}_{\mathcal{S}=\text{technology space}}$	0.000 (0.000)	-0.001 (0.003)
$\overline{\Delta mh(i,t)}^{\mathcal{A}=\text{green process innovation}}_{\mathcal{S}=\text{technology space}}$	0.0021 (0.0028)	0.193^{***} (0.073)	$\overline{\Delta mh(i,t)}^{\mathcal{A}=\text{green adoption}}_{\mathcal{S}=\text{technology space}}$	0.000 (0.000)	0.002 (0.001)
Controls	Y	Y		Y	Y
Sector × Time FE	4 digit	3 digit		4 digit	3 digit
Location × Time FE	Y	Y		Y	Y
Firm FE	Y	N		Y	N
Cluster-level	Firm	Firm		Firm	Firm
# Observations	428180	76397		360260	47742
Adj. R^2	0.159	0.024		0.163	0.018

Panel B: Falsification

	Innovation			Diffusion	
	Δ ln (HH sales$_{it}$)	Writedowns$_{it}$		Δ ln (HH sales$_{it}$)	Writedowns$_{it}$
	(1)	(2)		(3)	(4)
$\overline{\Delta f(i,t)}^{\mathcal{A}=\text{green product innovation}}_{\mathcal{S}=\text{product space}}$	0.0012 (0.0020)	-0.016 (0.017)	$\overline{\Delta f(i,t)}^{\mathcal{A}=\text{green provision}}_{\mathcal{S}=\text{product space}}$	0.001 (0.002)	-0.018 (0.017)
$\overline{\Delta f(i,t)}^{\mathcal{A}=\text{green process innovation}}_{\mathcal{S}=\text{product space}}$	0.0026 (0.0023)	0.007 (0.021)	$\overline{\Delta f(i,t)}^{\mathcal{A}=\text{green adoption}}_{\mathcal{S}=\text{product space}}$	-0.001 (0.001)	0.004 (0.003)
$\overline{\Delta f(i,t)}^{\mathcal{A}=\text{green product innovation}}_{\mathcal{S}=\text{technology space}}$	0.0000 (0.0033)	0.002 (0.019)	$\overline{\Delta f(i,t)}^{\mathcal{A}=\text{green provision}}_{\mathcal{S}=\text{technology space}}$	-0.002 (0.002)	-0.002 (0.004)
$\overline{\Delta f(i,t)}^{\mathcal{A}=\text{green process innovation}}_{\mathcal{S}=\text{technology space}}$	0.0007 (0.0033)	0.037 (0.061)	$\overline{\Delta f(i,t)}^{\mathcal{A}=\text{green adoption}}_{\mathcal{S}=\text{technology space}}$	0.001 (0.001)	0.001 (0.002)
Controls	Y	Y		Y	Y
Sector × Time FE	4 digit	3 digit		4 digit	3 digit
Location × Time FE	Y	Y		Y	Y
Firm FE	Y	N		Y	N
Cluster-level	Firm	Firm		Firm	Firm
# Observations	428180	76397		360260	47742
Adj. R^2	0.159	0.024		0.136	0.018

Notes: Column (1) and (2) summarize the performance/tangible asset pledgeability impact of green process and product innovation on firms that engage in neither of both activities. Column (3) and (4) summarize the performance/tangible asset pledgeability impact of green product provision and green capital investment on firms that engage in neither of both activities. In panel A, the covariates rely on the Mahalanobis distance measure. In panel B, the covariates rely on an aggregate concept of sector definitions. In both panels, the unit of observation is the firm-year-level. The unbalanced sample period runs from $2008-2018$. Controls include lags of ln(Assets$_{it}$), Leverage$_{it}$, ln(Capital age$_{it}$), brown product space entrants$_{it}$ and brown technology space entrants$_{it}$ as defined in Table 1. Columns (1) and (3) include a lag of the dependent variable (Columns (2) and (4) do not given that, due to the idiosyncratic nature of the dependant variable, the panel is highly unbalanced). Columns (2) and (4) are estimated using linear probability routines. Robust standard errors, reported in parentheses, are clustered at the firm–level. All regressors and regressands are defined in Table 1 and Subsection B.2.3. *, ** and *** denote significance at the 10%, 5% and 1% level, respectively.

Table A.5: ROBUSTNESS – ACCOUNTING FOR GEOGRAPHICAL PROXIMITY

PANEL A: INNOVATION		
	Δ ln (HH sales$_{it}$)	Writedowns$_{it}$
	(1)	(2)
$\overline{\Delta geo(i,t)}^{\mathcal{A}=\text{green product innovation}}_{\mathcal{S}=\text{product space}}$	-0.0955^{***} (0.0044)	-0.034 (0.158)
$\overline{\Delta geo(i,t)}^{\mathcal{A}=\text{green process innovation}}_{\mathcal{S}=\text{product space}}$	-0.0382^{***} (0.0031)	-0.048 (0.134)
$\overline{\Delta geo(i,t)}^{\mathcal{A}=\text{green product innovation}}_{\mathcal{S}=\text{technology space}}$	0.0011 (0.0081)	-0.051 (0.088)
$\overline{\Delta geo(i,t)}^{\mathcal{A}=\text{green process innovation}}_{\mathcal{S}=\text{technology space}}$	0.0017 (0.0072)	0.227^{**} (0.093)
Controls	Y	Y
Sector × Time FE	4 digit	3 digit
Location × Time FE	Y	Y
Firm FE	Y	N
Cluster-level	Firm	Firm
# Observations	428180	76397
Adj. R^2	0.135	0.024

PANEL B: DIFFUSION		
	Δ ln (HH sales$_{it}$)	Writedowns$_{it}$
	(1)	(2)
$\overline{\Delta geo(i,t)}^{\mathcal{A}=\text{green provision}}_{\mathcal{S}=\text{product space}}$	-0.0128^{***} (0.0008)	0.002 (0.002)
$\overline{\Delta geo(i,t)}^{\mathcal{A}=\text{green provision}}_{\mathcal{S}=\text{product space}}$	-0.0008^{***} (0.0001)	0.000 (0.000)
$\overline{\Delta geo(i,t)}^{\mathcal{A}=\text{green adoption}}_{\mathcal{S}=\text{technology space}}$	0.0003 (0.0004)	-0.003 (0.003)
$\overline{\Delta geo(i,t)}^{\mathcal{A}=\text{green adoption}}_{\mathcal{S}=\text{technology space}}$	-0.0001 (0.0002)	0.003^{*} (0.001)
Controls	Y	Y
Sector × Time FE	4 digit	3 digit
Location × Time FE	Y	Y
Firm FE	Y	N
Cluster-level	Firm	Firm
# Observations	360260	47742
Adj. R^2	0.140	0.018

Notes: Panel A summarizes the performance/tangible asset pledgeability impact of green process and product innovation on firms that engage in neither of both activities. Panel B summarizes the performance/tangible asset pledgeability impact of green product provision and green capital investment on firms that engage in neither of both activities. In both panels, the unit of observation is the firm-year-level. The unbalanced sample period runs from $2008-2018$. Controls include lags of ln(Assets$_{it}$), Leverage$_{it}$, ln(Capital age$_{it}$), brown product space entrants$_{it}$ and brown technology space entrants$_{it}$ as defined in Table 1. Column (1) includes a lag of the dependent variable (Column (2) does not given that, due to the idiosyncratic nature of the dependant variable, the panel is highly unbalanced). Column (2) is estimated using linear probability routines. Robust standard errors, reported in parentheses, are clustered at the firm–level. All regressors and regressands are defined in Table 1 and Subsection B.2.3. *, ** and *** denote significance at the 10%, 5% and 1% level, respectively.

C Rationing: additional results & robustness

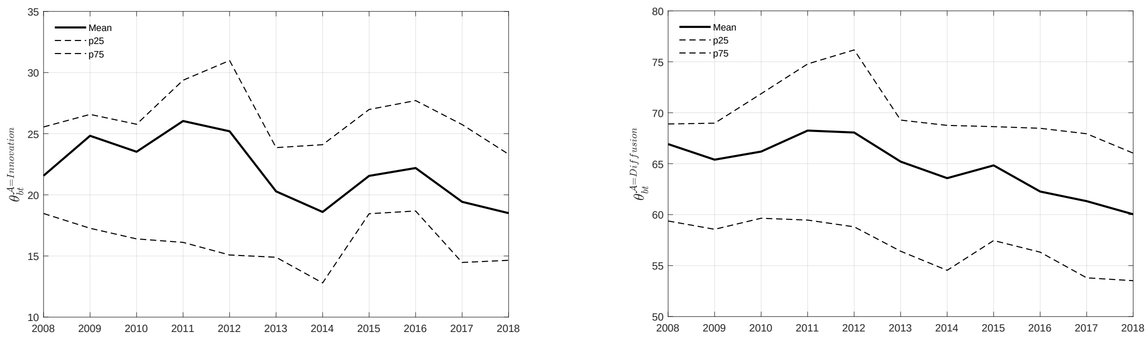
This Section compiles robustness tests and additional results for Section 5.

C.1 Attentiveness towards green externalities

Table 7 highlighted that the threats to legacy portfolios by individual green firms are very small on a case-by-case basis. This finding does not imply that overall legacy threats, integrated over all environmental firms, are small at the bank level. To show this, define

$$\theta_{bt}^{\mathcal{A}} = \sum_{j \in \{\cup_{i=1}^{N} \mathcal{I}_{it}^{\mathcal{A}}\}} c_{jbt}$$

as the share of bank b's corporate portfolio exposed to all firms engaged in green activity $\mathcal{A}$. Figure A.5 plots this statistic and shows that approximately 25% (65%) of the corporate portfolio is at risk to business stealing and/or collateral devaluation from innovators (diffusors) throughout our sample period. This finding underscores the rationale why banks are attentative to the potential destructive nature of green firms and act on it in their firm–level lending decisions.



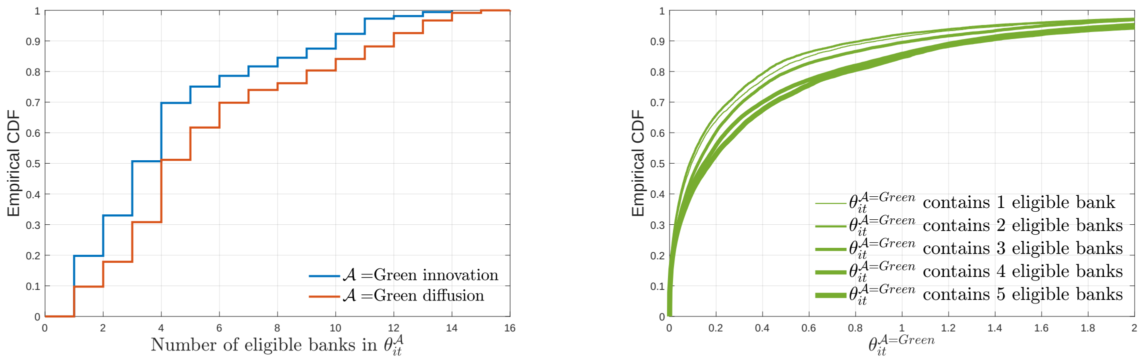
(a) Innovation: $\theta_{bt}^{\mathcal{A}=\text{Green innovation}}$ (b) Innovation: $\theta_{bt}^{\mathcal{A}=\text{Green diffusion}}$

Figure A.5: Bank level legacy positions at risk.

C.2 Additional properties of $\theta_{ibt}^{\mathcal{A}}$

Subsection 5.2 detailed the filters imposed for banks to be qualified as eligible lenders to firm i. Figure A.6 panel (a) provides insights into the number of banks effectively present in $\boldsymbol{\theta}_{it}^{\mathcal{A}}$. It reveals that the set of eligible lenders to firm i is relatively limited, which is consistent with the high concentration of lenders in the Belgian market for corporate bank credit (European Central Bank, 2021).

Figure A.6 panel (b) plots the empirical CDF of $\theta_{ibt}^{\mathcal{A}}$, where firms are binned by the number eligible lenders. It reveals a high level of variation in $\theta_{ibt}^{\mathcal{A}}$, irrespective of the number of banks included in $\boldsymbol{\theta}_{it}^{\mathcal{A}}$.



(a) Number of eligible lenders per green firm

(b) Distribution of $\theta_{ibt}^{\mathcal{A}=\text{Green}}$

Figure A.6: Properties of $\theta_{ibt}^{\mathcal{A}}$.

C.3 Model specification & estimation

Model estimation. For ease of interpretation, our baseline results relied on linear probability routines. This class of models has been used in similar bank credit rationing contexts (see e.g. Jiménez et al. (2012, 2014)). Table A.6, column (1)–(2) show that our estimates of the legacy and market structure effect remain largely unaffected in a logistic regression framework (where we have aggregated the set of sector-time fixed effects to attenuate the incidental parameter bias (Stammann et al., 2016)).

Alternative proxy legacy effect. Our legacy effect relied on the Median operator. Table A.6, column (3)–(4) highlight that an alternative proxy (the sum of legacy positions across the banking sector), delivers the same rationing effects.

Firm fixed effects & green sample restriction. Following eq. (3), legacy positions associated with firm i only rely on bank credit received by other firms (not firm i itself). The concern that unobserved characteristics of firm i, relevant for credit rationing, meaningfully correlate with our measure of legacy positions at risk is therefore minor. To fully take away any potential bias, we follow two strategies.

First, Table A.7, column (1)–(2) take on board a firm-fixed effect. While the estimated legacy and market structure effects are largely unaffected by the inclusion of a firm-fixed effect, the R^2 of the regression rises significantly. In the spirit of Oster (2013), this observation suggests that any correlation between banks legacy positions at risk and time-invariant unobservable firm characteristics of green firms is unlikely to drive our results.

Second, Table A.8 compares the control–covariates included in eq. (4) between brown and green firms. It reveals that both types of firms are structurally different on various time varying dimensions relevant for bank credit supply/demand. To control for the possibility that eq. (4) imperfectly controls for these time-variant covariates (and thereby falsely associates credit rationing to $\theta^{\mathcal{A}}_{ibt}$), we restrict our sample to green firms only in column (3)–(4) of Table A.7. As before, the estimates remain largely unaffected.

Table A.6: ROBUSTNESS RATIONING – MODEL SPECIFICATIONS

	Dependent variable: Borrower_{ibt}			
	Logistic specification		Legacy effect: sum	
	(1)	(2)	(3)	(4)
$Med(\boldsymbol{\theta}_{it-1}^{\mathcal{A}=\text{Green}})$	-6.966^{**}			
	(3.437)			
$Min(\boldsymbol{\theta}_{it-1}^{\mathcal{A}=\text{Green}})$	-16.147^{***}		-2.015^{***}	
	(5.933)		(0.681)	
$Med(\boldsymbol{\theta}_{it-1}^{\mathcal{A}=\text{Green innovation}})$		-59.634^{*}		
		(32.549)		
$Min(\boldsymbol{\theta}_{it-1}^{\mathcal{A}=\text{Green innovation}})$		-100.545^{*}		-6.024
		(54.093)		(3.746)
$Med(\boldsymbol{\theta}_{it-1}^{\mathcal{A}=\text{Green diffusion}})$		-6.991^{**}		
		(3.454)		
$Min(\boldsymbol{\theta}_{it-1}^{\mathcal{A}=\text{Green diffusion}})$		-15.823^{***}		-1.957^{***}
		(5.968)		(0.485)
$Sum(\boldsymbol{\theta}_{it-1}^{\mathcal{A}=\text{Green}})$			-0.100^{**}	
			(0.042)	
$Sum(\boldsymbol{\theta}_{it-1}^{\mathcal{A}=\text{Green innovation}})$				-0.839^{*}
				(0.490)
$Sum(\boldsymbol{\theta}_{it-1}^{\mathcal{A}=\text{Green diffusion}})$				-0.103^{***}
				(0.025)
$\mathcal{A}$: Green				
Legacy effect	-0.896		-1.846	
Market structure effect	-1.194		-0.836	
$\mathcal{A}$: Innovation				
Legacy effect		-5.003		-4.986
Market structure effect		-6.281		-1.648
$\mathcal{A}$: Diffusion				
Legacy effect		-1.086		-1.910
Market structure effect		-1.460		-0.812
Controls	Y	Y	Y	Y
Sector × Time FE	Y	Y	Y	Y
Location × Time FE	2-digit	2-digit	4-digit	4-digit
Cluster	Firm	Firm	Firm	Firm
# Observations	654588	654588	654689	654689
Adj. R^2	0.149	0.149	0.185	0.185

(Table notes on next page)

Notes: This table quantifies the legacy and market structure effect. The dependent variable is an indicator variable taking on 100 if firm i has an authorised bank credit facility at time t (0 otherwise). The covariates of interest, $Med(\boldsymbol{\theta}_{it-1}^{\mathcal{A}})$ and $Min(\boldsymbol{\theta}_{it-1}^{\mathcal{A}})$, measure the median and minimum of the exposed legacy positions across all eligible lenders for green activity $\mathcal{A}$ unfolded by firm i. Controls include lags of ln(Assets$_{it}$), Leverage$_{it}$, ln(Firm age$_{it}$), ln(Capital age$_{it}$), Group$_{it}$, Negative equity$_{it}$, ROA$_{it}$, Intangibles$_{it}$, Patenter$_{i}$, Public equity$_{it}$ and Public debt$_{it}$ as defined in Table 1. The legacy effect quantifies the impact of a one standard deviation increase in $Med(\boldsymbol{\theta}_{it-1}^{\mathcal{A}})$ on the probability of receiving bank credit. The market structure effect quantifies the impact of a one standard deviation increase in $Min(\boldsymbol{\theta}_{it-1}^{\mathcal{A}})$ on the probability of receiving bank credit. Specification (1)–(2) are logit models estimated using maximum likelihood routines. Specification (3)–(4) are estimated using linear probability routines. Column (1) and (3) contain a dummy Green$_{i}$. Column (2) and (4) contain the dummies Green innovation$_{i}$ and Green diffusion$_{i}$. The sample period runs from $2008-2018$ and contains both brown and green firms. Standard errors, reported in parentheses, are clustered at the firm–level. *, ** and *** denote significance at the 10%, 5% and 1% level, respectively.

Table A.7: ROBUSTNESS RATIONING - MODEL SPECIFICATIONS

	Dependent variable: Borrower_{ibt}			
	Firm FE		Green firms only	
	(1)	(2)	(3)	(4)
$Med(\boldsymbol{\theta}_{it-1}^{\mathcal{A}=\text{Green}})$	-1.748^{***}		-0.955	
	(0.377)		(0.595)	
$Min(\boldsymbol{\theta}_{it-1}^{\mathcal{A}=\text{Green}})$	-1.530^{**}		-2.122^{**}	
	(0.649)		(0.992)	
$Med(\boldsymbol{\theta}_{it-1}^{\mathcal{A}=\text{Green innovation}})$		-13.521^{***}		-11.270^{**}
		(4.064)		(5.455)
$Min(\boldsymbol{\theta}_{it-1}^{\mathcal{A}=\text{Green innovation}})$		-21.498^{***}		-14.328^{*}
		(6.165)		(8.639)
$Med(\boldsymbol{\theta}_{it-1}^{\mathcal{A}=\text{Green diffusion}})$		-1.954^{***}		-1.024^{**}
		(0.374)		(0.427)
$Min(\boldsymbol{\theta}_{it-1}^{\mathcal{A}=\text{Green diffusion}})$		-1.529^{**}		-2.158^{***}
		(0.645)		(0.747)
$\mathcal{A}$: Green				
Legacy effect	-1.521		-0.689	
Market structure effect	-0.792		-0.880	
$\mathcal{A}$: Innovation				
Legacy effect		-11.764		-4.352
Market structure effect		-11.128		-3.920
$\mathcal{A}$: Diffusion				
Legacy effect		-1.702		-0.740
Market structure effect		-0.791		-0.895
Controls	Y	Y	Y	Y
Sector × Time FE	Y	Y	Y	Y
Location × Time FE	4-digit	4-digit	4-digit	4-digit
Firm FE	Y	Y	N	N
Cluster	Firm	Firm	Firm	Firm
# Observations	261283	261283	86799	86799
Adj. R^2	0.656	0.654	0.135	0.135

Notes: This table quantifies the legacy and market structure effect. The dependent variable is an indicator variable taking on 100 if firm i has an authorised bank credit facility at time t (0 otherwise). The covariates of interest, $Med(\boldsymbol{\theta}_{it-1}^{\mathcal{A}})$ and $Min(\boldsymbol{\theta}_{it-1}^{\mathcal{A}})$, measure the median and minimum of the exposed legacy positions across all eligible lenders for green activity $\mathcal{A}$ unfolded by firm i. Controls include lags of ln(Assets_{it}), Leverage_{it}, ln(Firm age_{it}), ln(Capital age_{it}), Group_{it}, Negative equity_{it}, ROA_{it}, Intangibles_{it}, Patenter_{i}, Public equity_{it} and Public debt_{it} as defined in Table 1. The legacy effect quantifies the impact of a one standard deviation increase in $Med(\boldsymbol{\theta}_{it-1}^{\mathcal{A}})$ on the probability of receiving bank credit. The market structure effect quantifies the impact of a one standard deviation increase in $Min(\boldsymbol{\theta}_{it-1}^{\mathcal{A}})$ on the probability of receiving bank credit. Specification (1)–(2) are contain firm fixed effects. Specification (3)–(4) condition on green firms only. The sample period runs from $2008 - 2018$ and contains both brown and green firms. Standard errors, reported in parentheses, are clustered at the firm–level. *, ** and *** denote significance at the 10%, 5% and 1% level, respectively.

Table A.8: STRUCTURAL DIFFERENCES BROWN VS. GREEN FIRMS

	Brown vs. Green		
	Brown firm	Green firm	F-test
Covariates in Eq. (4)			
ROA_{it}	0.030	0.033	0.000
Group_{it}	0.293	0.527	0.000
$\ln(\text{Assets}_{it})$	13.399	15.129	0.000
Leverage_{it}	0.728	0.651	0.000
$\text{Negative equity}_{it}$	0.118	0.061	0.000
Intangibles_{it}	0.017	0.014	0.000
$\ln(\text{Capital age}_{it})$	1.910	2.053	0.000
$\ln(\text{Firm age}_{it})$	2.554	2.934	0.000
Patenter_{i}	0.037	0.166	0.000
Public debt_{it}	0.000	0.002	0.000
$\text{Public equity}_{it}$	0.001	0.007	0.000
Dependent variable in Eq. (4)			
Borrower_{it}	71.173	79.264	0.000

Notes: This table gauges the structural differences (means) between green and brown firms. It reports, per type of firm, the within-group mean as well as p-values testing for across-group equivalence. All variables are defined in Table 1.

C.4 Measuring legacy positions

Measurement discretion. Some discretion underlies our measurement of legacy risk $\boldsymbol{\theta}_{it}^{\mathcal{A}}$. First, the cut–off values for Π^*, T^* set the perimeter of what firms are (not) exposed to a particular green firm. Increasing this threshold narrows the list of exposed firms to those closest to the environmental firm (which therefore skews the interpretation of the legacy positions at risk towards the most affected portfolio). At the same time, underestimating banks' legacy risk adds noise to our $Med(\cdot)$ and $Min(\cdot)$ operators. Despite these concerns, Table A.9, panel A, highlights that tighter sets of firms–at–risk suggest rationing barriers that are quantitatively in the same ballpark as our main results.

Second, in determining the list of eligible lenders to firm i, we considered only banks that have at least 50 corporate customers in the sector in which firm i resides. Ranging this threshold from 10 and 100 does not affect our results in a material way (Table A.9, panel B).

Agnostic legacy positions. Section 4 was devoted to the correct identification of the firms negatively exposed to particular green activities. We now show that this preliminary step was instrumental to identify rationing barriers in Section 5. E.g., absent the input from Section 4, one could have taken the overly pessimistic view that green firms negatively affect all technology/product market peers. If we construct a measure of legacy positions based on this agnostic viewpoint, $\widetilde{\boldsymbol{\theta}}_{it}$, the mismeasurement of relevant legacy positions would suggest a complete absence of rationing barriers (Table A.10).

Table A.9: ROBUSTNESS RATIONING: CUT-OFF DEFINITION TECHNOLOGY/PRODUCT SPACE PEERS & ELIGIBLE LENDERS

	Legacy effect			Market structure effect		
	Green	Green innovator	Green diffusor	Green	Green innovator	Green diffusor
PANEL A: CUT-OFF PEERS ($\Pi^* = T^*$)						
0.9	-3.752^{***}	-3.900^{**}	-3.662^{***}	-4.220^{***}	-5.178^{**}	-4.056^{***}
	(0.444)	(1.846)	(0.447)	(0.487)	(2.192)	(0.491)
0.95	-2.194^{***}	-5.804^{**}	-2.210^{***}	-1.427^{***}	-6.949^{**}	-1.418^{***}
	(0.166)	(2.697)	(0.166)	(0.182)	(3.010)	(0.182)
PANEL B: CUT-OFF ELIGIBLE LENDERS						
10 firms	-2.249^{***}	-10.365^{*}	-2.251^{***}	-2.066^{***}	-10.720^{*}	-2.026^{***}
	(0.644)	(5.418)	(0.745)	(0.751)	(5.703)	(0.715)
100 firms	-3.942^{***}	-11.178^{**}	-2.428^{***}	-3.472^{***}	-11.192^{**}	-2.207^{***}
	(1.099)	(5.169)	(0.736)	(1.241)	(5.182)	(0.718)

Notes: This table quantifies the legacy and market structure effect under various assumptions underlying the calibration of $\boldsymbol{\theta}_{it}^{A=\text{Green}}$. First, our baseline results assume that $\Pi^* = T^* = 0.75$. Panel A focuses on the calibration where the threshold was set at 0.9 and 0.95, respectively (see Subsection 4.3). Second, our baseline results assume that $\boldsymbol{\theta}_{it-1}^{A=\text{Green}}$ contains banks that already have 50 firms in their portfolio that reside in the same sector as firm i (see Subsection 5.2). Panel B focuses on the calibration where the perimeter was set at 10 and 100 firms, respectively. All specifications are estimated using linear probability routines. The unit of observation is the firm-year-level. The sample period runs from $2008 - 2018$ and contains both brown and green firms. Standard errors, reported in parentheses, are clustered at the firm–level. *, ** and *** denote significance at the 10%, 5% and 1% level, respectively.

Table A.10: ROBUSTNESS RATIONING: FALSIFICATION TEST

	Dependent variable: Borrower_{it}	
	(1)	(2)
Green_i	-3.126^{***}	
	(0.354)	
$\text{Green innovation}_i$		-1.400
		(2.080)
Green diffusion_i		-3.209^{***}
		(0.349)
$Med(\widetilde{\boldsymbol{\theta}}_{it-1}^{\mathcal{A}=\text{Green}})$	-0.002	
	(0.017)	
$Min(\widetilde{\boldsymbol{\theta}}_{it-1}^{\mathcal{A}=\text{Green}})$	0.161	
	(0.411)	
$Med(\widetilde{\boldsymbol{\theta}}_{it-1}^{\mathcal{A}=\text{Green innovation}})$		-0.365
		(2.379)
$Min(\widetilde{\boldsymbol{\theta}}_{it-1}^{\mathcal{A}=\text{Green innovation}})$		13.256
		(10.686)
$Med(\widetilde{\boldsymbol{\theta}}_{it-1}^{\mathcal{A}=\text{Green diffusion}})$		-0.009
		(0.015)
$Min(\widetilde{\boldsymbol{\theta}}_{it-1}^{\mathcal{A}=\text{Green diffusion}})$		1.200
		(0.746)
Controls	Y	Y
Sector × Time FE	4-digit	4-digit
Location × Time FE	Y	Y
Cluster	Firm	Firm
# Observations	654689	654689
$Adj.\ R^2$	0.185	0.185

Notes: This table quantifies the legacy and market structure effect when our measurement of legacy positions is agnostic ($\widetilde{\boldsymbol{\theta}}_{it-1}^{\mathcal{A}}$ instead of $\boldsymbol{\theta}_{it-1}^{\mathcal{A}}$). The dependent variable is an indicator variable taking on 100 if firm i has an authorised bank credit facility at time t (0 otherwise). The covariates of interest, $Med(\widetilde{\boldsymbol{\theta}}_{it-1}^{\mathcal{A}})$ and $Min(\widetilde{\boldsymbol{\theta}}_{it-1}^{\mathcal{A}})$, measure the median and minimum of the exposed legacy positions across all eligible lenders for green activity $\mathcal{A}$. Controls include lags of ln(Assets_{it}), Leverage_{it}, ln(Firm age_{it}), ln(Capital age_{it}), Group_{it}, Negative equity_{it}, ROA_{it}, Intangibles_{it}, Patenter_i, Public equity_{it} and Public debt_{it} as defined in Table 1. All specifications are estimated using linear probability routines. The unit of observation is the firm-year-level. The sample period runs from $2008-2018$ and contains both brown and green firms. Standard errors, reported in parentheses, are clustered at the firm–level. *, ** and *** denote significance at the 10%, 5% and 1% level, respectively.

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