Asset Overhang and Technological Change[§]

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Investors face reduced incentives to finance projects that devalue their legacy positions. 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 to 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 5.9 p.p. (0.5 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. In 2008, *Tesla Motors* approached *Goldman Sachs* for seed funding and was rejected. Back then, the clean energy company was still a start-up and had not sold any electric vehicle yet. While acknowledging *Tesla*'s business potential, *Goldman Sachs* rejected the funding application partly on the basis that the proposed business model did not align with *Goldman Sachs*' vested interests, including its longstanding exposures to the combustion engine automotive industry.[1]

In this paper we study the presence and impact of such an "asset overhang" problem, i.e., a financier's reduced incentive to fund a firm's profitable innovation due to externalities imposed by the project on the financier's legacy investment (e.g. through business stealing, devaluation of pledged collateral, etc.).[2] Importantly, we assess how the interaction between innovation externalities and the structure of the financial market drive the funding capacity of disruptive firms.

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 investors' original portfolio. Second, we develop the models' main result that the market structure of the intermediary system plays a crucial role in determining the extent of funding supply to innovative firms. In particular, we demonstrate that the presence of investors with less or no exposures to asset devaluations triggers capital supply by the *entire* system. Finally, we discuss how the various moving parts in the model – e.g., nature of pledged collateral, information structure, fungibility of the legacy exposures – affect rationing outcomes and levels of technological conservatism.

According to our theory, the heterogeneity of legacy positions is key to observe the economic effects of an asset overhang problem. In order to test our predictions, we consider the technological transition towards environmentally friendly economies. In fact, climate change uniquely combines large threats of disruptive innovation by green activity and strong exposures across the population of investors toward brown industries. As a result, our empirical application studies whether the financing of green technology suffers from an asset overhang problem. In particular, we investigate how banks ration firms engaged in developing and/or diffusing environmental technologies (e.g. solar panels, biodegradable plastics, etc.). 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, as novel green technologies embody threats to performance and capital values of laggard firms (ECB, 2019). The analysis reveals that banks have jointly delayed the transition to a carbon-neutral economy by rationing environmental innovators and adopters in both product and technology spaces where

[1] Elon Musk's ground-breaking electric car – John Reed (2009).

[2] 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. In contrast, asset overhang captures how a financier' legacy positions may hinder the external financing of a firm's project in presence of technological spillovers.

the banking system holds large stakes.

Data, identification & results. The empirical strategy proceeds in two steps. In the first step we pin down the externalities to which laggard 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 (2004), 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 and incumbent green technology). Such a bifurcated view is warranted as both activities differ in their disruptive capacity (Jovanovic and MacDonald (1994)) – 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 space using granular information on the distribution of firms' input and output markets (inferred from granular B2B transactions). This allows us to construct distinct measures of the distance between (green and brown) firms in the technology (input) and product (output) market dimensions.[3]

We leverage both ingredients to trace out externalities of green activities on close product/ technology peers. We focus on two types of externalities that were previously documented to heavily weigh 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 $2008 - 2018$, and document that firms with green innovation and/or green diffusion generate negative spillovers on brown firms through deteriorated firm performance and asset devaluations. We provide further corroborating evidence that these firm-level externalities effectively feed into the banks' assessments of their incumbent laggard borrowers. First, we associate the decline in borrower performance with elevated probabilities of default and additional provisioning reported by banks. Second, we observe – leveraging granular data on market values of pledged collateral – downward adjustments in market values of laggard firms' capital in the face of (particular types of) innovation & adoption by technology peers. Taken together, these findings underpin spillover mechanisms 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,

[3]The notion of sorting between product spaces and technology spaces dates back to Jaffe (1988). Proximity measures in product and/or technology spaces were previously leveraged by Branstetter and Sakakibara (2002); Bloom et al. (2013); Lucking et al. (2018).

at the extensive margin, an environmental innovator (diffusor) which generates an average negative impact on each bank in the credit market is around 5.9 p.p. (0.5 p.p.) less likely to receive bank credit compared to an environmental innovator (diffusor) that does not have an impact on banks' legacy positions. This average effect is largely muted when there is an intermediary without asset overhang (i.e., a bank without legacy position). This empirical finding corroborates our theoretical result which posits that the investor market structure, i.e., the minimum asset overhang faced by an intermediary, is an important determinant of systemwide credit rationing.

We further study, conditional on lending, which bank in the asset overhang spectrum is "breaking the barrier" and is matching up with a green firm. We find that the bank with the smallest asset overhang is 13 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 does not play a role in credit supply to the environmental firm. Instead, a 1 s.d. decrease in the the lowest asset overhang position (potentially, but not necessarily, that of the incumbent lender) drives up credit supply by the incumbent lender to disruptive firms by 0.06 s.d. This results highlights that the asset overhang remains to play a role in driving credit supply to borrowing disruptive firms.

Policy implications. The results from this paper talk to a number of ongoing policy debates. First is the promoting of financial institutions that do not hold legacy exposures. Since these legacy-free investors do not face an overhang problem, they are able to promote entry of profitable firms despite the possibility of negative spillovers. In the context of climate change, 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.

Second – and perhaps more importantly – our results on the role of the intermediary market structure suggest that limited interventions can produce large aggregate effects. In fact, once spillovers materialise, losses occur to incumbents irrespective of the stakes and the rationing barrier is broken. Other investors will therefore take the losses and channel their funding towards projects using this same technology. As such, entry of a single legacy-free (green) bank in the economy could induce incumbent banks to extend credit to green firms which they would have rationed otherwise. This effect gets more pronounced the more incumbent banks share homogeneous legacies. As a result, the total capacity of credit provisions to the green economy gets compounded beyond the individual capacities of green banks, ultimately including all banks in the system.

Finally, our results suggest that macro prudential policies concerned with technological disruption could introduce costs related to legacy exposures. In the climate change context, such 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 penalise the use of assets exposed to the type of green externalities documented in our paper.

Contribution to the literature. Our work connects to several research agendas. First, the asset overhang problem shares features with a nascent literature on common ownership.[4] 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 impact on technology development and diffusion (Anton et al., 2021).

Second, our work speaks to a broad research agenda on the role of financial intermediation 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 better finance environments lead to higher economic growth through 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 & adoption.

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' decision to finance innovation (Cestone and White, 2003; Cetorelli and Strahan, 2006; Cornaggia et al., 2015).[5] With respect to this literature, our paper shows that the capacity to promote innovation is affected by the interplay between structure of the banking system and the distribution of legacy exposures to the externalities of innovation.

The fourth 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

[4]While this literature dates back to Rubinstein et al. (1983) and Rotemberg (1984), a burgeoning literature has recently emerged on this topic. See e.g. Ederer and Pellegrino (2022); Shekita (2020); 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.

[5]In a model that combines a financial market and a product market, 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.

emissions. In a cross-country, cross-industry panel analysis, de Haas and Popov (2019) 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 ones. The authors further suggest that banks may prevent loans to firms exposed to adverse environmental liability. In more recent work, Bolton and Kacperczyk (2020) 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.

Finally, our setting is also related to the role of policy makers in directing financing towards sustainable and environmentally friendly innovation. Acemoglu et al. (2012, 2016) study optimal policies in terms of taxes and subsidies in order to induce innovation towards cleaner technologies. Our results highlight the need to design an incentive compatible financing environments in conjunction with tax and subsidy policies. As such, some emission outcomes can be addressed by effectively promoting competition and diversity among the banking and alternative sources of funding for green innovation.

Outline of the paper. The remainder of the paper is organized as follows. Section 2 introduces our theoretical model which studies investor's asset overhang. Section 3 introduces the data sources and 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 Theory

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.[6] First, we present an asset-side overhang mechanism in the context of a monopoly investor. We then move to analyse how the resulting rationing of new firms interacts with the structure of the financial market.

[6] In our empirical application, we turn our focus on banks and a negative externally driven by green technology innovation and diffusion.

We close the section by discussing some of the implications and underlying assumptions of our model and results.

2.1 Asset-side 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 decisions towards funding applications by a new firm. To capture this, we first replicate the standard investment problem of the monopoly investor in presence of moral hazard on the part of the firm. We then turn to decisions towards a new project in the presence of externalities on legacy positions. Our goal is to understand how legacy positions may lead to asset-side overhang and how this effect might have implications for rationing strategies by the monopoly investor.[7]

2.1.1 Investment decision in absence of externalities

To understand the investor's profits, we employ a setup as in Holmstrom and Tirole (1997) or Tirole (2010).

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. When successful, the project yields R whereas it yields zero when unsuccessful. Independent of failure, the project further always gives back the collateral C. When the project fails, the investor grabs the collateral of value C.[8] The investor's capacity for rent extraction is limited by the following moral hazard problem. When the entrepreneur (i.e., firm) works, its success probability is P_H. It is P_L when the entrepreneur shirks. The entrepreneur enjoys private benefits from shirking B. We assume that the project has a positive net present value (NPV) when 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 than by shirking:

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

[7] In our analysis, we focus on negative externalities because we think these are most relevant to our setting. However, this does not imply we exclude the possibility of positive externalities, i.e., cases where new projects would increase the collateral values of the investor's legacy positions or decrease their default probabilities.

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

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 his or 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 in expected terms not 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:

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 summarises the standard results 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-side 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: a firm approaches the monopoly investor requesting funding for an innovative project whose successful implementation would entail a devaluation of (some of) the monopoly investor's portfolio of legacy assets. This would be the case for example of a construction company implementing a novel energy-efficient technology. Should this technology enter the market, it could adversely affect incumbents using polluting technology by increasing their probability of default (e.g., loss of market shares) or the collateral they have pledged to the investor (e.g., devaluation of energy-inefficient machines or buildings). This implies that the investor, when deciding on the provision of external financing to firm 2, takes into account the adverse shock it faces from its legacy positions (in this case firm 1). We refer to this effect as an asset-side overhang.

To keep the exposition simple, we proceed by considering two firms: firm 1 is the incumbent energy-inefficient company who has already been granted external financing by the monopoly investor under the conditions stated in Section 2.1.1 (i.e., collateral pledged by firm 1 is such that: $C_1 \geq \underline{C}$); firm 2 is the firm requesting a new loan related to an energy-efficient project.

Firm 2 approaches the monopoly investor for external finance. Let us for now focus on the collateral externality brought by firm 2's project.[9] A characteristic of firm 2's project is therefore that when implemented, it generates a negative externality on the value of the collateral of firm 1. That is, the collateral value of the machines brought into firm 1's project drops by ΔC.[10] Assuming that the investor cannot pass on this loss by repricing external financing to firm 1, the lender's expected profits on firm 1 will then drop by ΔC.[11] Finally note that our 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 at the end of the Section.

Firm 2's project. Firm 2 approaches the monopoly investor to obtain funding for a project that requires a total investment of I. For sake of simplicity and without loss of generality, we assume the firm has cash at hand $A < I$, but no collateral. Similar to Section 2.1.1, the monopoly investor faces a moral hazard problem regarding the entrepreneur of firm 2. When the entrepreneur of firm 2 works, its success probability is P_H. It is P_L when the entrepreneur shirks. When successful, the project yields Z. The entrepreneur enjoys private benefits from shirking B. We assume that the project has a positive NPV when the entrepreneur behaves. In contrast, the NPV is negative in case the entrepreneur shirks. That is

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

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

[10] For simplicity and tractability, 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.

[11] We relax this assumption at the end of the Section.

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.[12]

Investor's external 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 the previous section, 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. This implies that the entrepreneur should at least expect to receive as much by working than by shirking.

- The IR constraint is as follows:

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

  The IR_2 constraint implies that the entrepreneur in expected terms should at least get A back from participating in the project.

In absence of 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 fact, 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 to $P_H R - I - \Delta C > 0$.[13] 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 is the asset-side overhang that the investor faces which may influence its financing decision towards firm 2.

This result implies that the individual rationality constraint of the investor now considers the additional profit obtained from externally financing both firms. Put differently, the monopoly investor

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

[13] 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.

only wants to fund firm 2 whenever it makes additional profits which are larger than 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. We need to consider two cases.

1. $P_H Z - I - \Delta C < 0$. In this event, firm 2 is rationed independent 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 now becomes 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 of the monopoly investor on firm 2 then becomes:

   $$P_H Z - I - \Delta C > 0.$$

   - $A \leq \hat{A}$, 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 summarises the results for a monopoly investor's decision to fund a new project 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 credit 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*

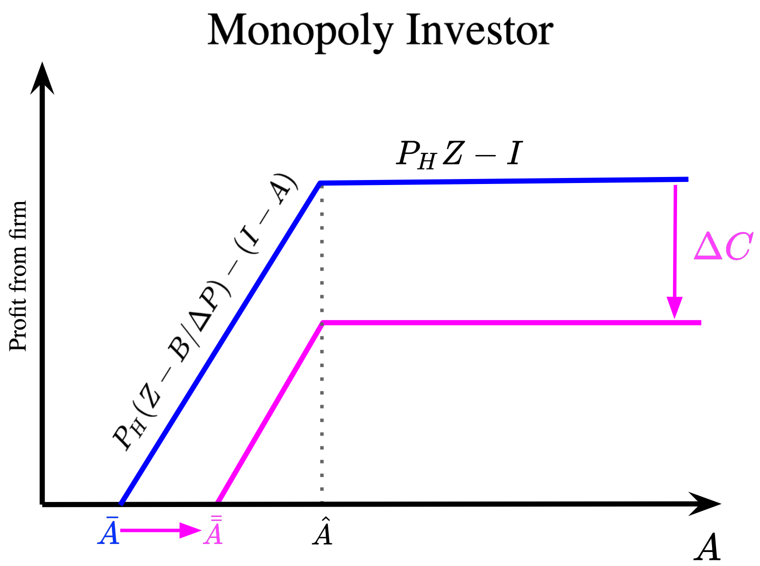

Figure 1: Monopoly profits from investor funding a firm in presence of externality ΔC, as a function of the amount of cash brought by the firm A

Figure 1 further illustrates the investor's profit from funding the firm's new project in presence of externality. The purple 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 purple line). Note that when ΔC is larger than the NPV of the project, the purple line shifts so much down that the investor would make negative profits. In that case, it rations firm 2 independent of its amount of cash at hand, i.e., the asset-side overhang faced by the monopoly investor rations firm 2.

2.2 The role of intermediary market structure

Previous results assume that conditional on funding, the investor was extracting all the remaining rents. We now study a market where intermediaries or investors are competing with each other, i.e., all the bargaining power is transferred to the firm.[14] Below, we show that previous results depend

[14] In a competitive setting, we indeed 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 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 $P_H R - I$.

on the distribution of the asset-side overhangs stemming from legacy positions the different investors are facing. The homogeneity or heterogeneity 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 (e.g., energy-efficient technology) project which entails a devaluation of incumbent firms' collateral (e.g., energy-inefficient machines). Investors are so far assumed to be homogeneous in that they have the same legacy of granted loans, i.e., face an identical asset-side overhang. This uniformly exposes them to the negative externality. 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 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 summarises the rationing result.

Proposition 2. *In presence of a homogeneous externality $\Delta C > 0$, a competitive investor face 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.*

2.2.2 Investors with heterogeneous asset-side overhang

In the previous, we assumed investors with identical asset-side overhang. We now consider investors with different legacy positions and thus heterogeneous asset-side overhang. 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 even when investors have equal market shares but ΔC_i is different across investors, for example 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: $i^* = \min_i\{\Delta C_i\}$. 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 smallest negative externality. 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 reduces the overall profits on their legacy positions and the new firm. 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. By aligning their rationing barrier with i^*, the competing investor would then be able to recover part of the loss due to ΔC_i in case the firm enters, irrespective of who provides the external financing.

Proposition 3 summarises 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 $i^* = \min_i\{\Delta C_i\}$, 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

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 extension of our results to include negative externalities on the probabilities of default of incumbent firm in the absence or jointly with the effects over collateral, the impact of information structure on our results, 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 owner's house or government bonds) can be made. While cash or outside collateral is not subject to

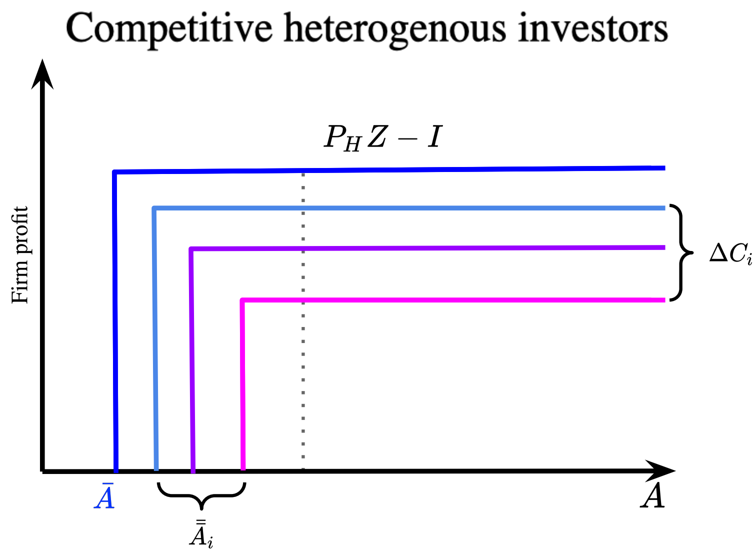

Figure 2: Firm profits with external financing from competitive investor in presence of heterogeneous externalities ΔC_i, as a function of the amount of cash A brought by the firm.

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 extend they have different exposure to shocks.[15]

Our model assumes that the monopoly investor absorbs the negative shock on collateral when firm 1 is successful, i.e., the investor is junior to the entrepreneur. Alternatively, we could assume the investor is a senior claimholder such that the negative externality is only important if firm 1 fails. This would be equivalent to consider only the relevance of collateral in case the project fails (as e.g., Stiglitz and Weiss (1981)). Even in that case, the externality on collateral (compared to cash) remains relevant as the investor is always affected when it needs to grab the collateral when firm 1's project fails.

Type of investments. While our modeling of investors is generic, the asset-side 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.

[15] 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.

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. However, 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.

First, note that, in practice, a complete information scenario could be obtained through mandatory disclosure frameworks such as the publication of annual accounts 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, transparency exercises related to climate stress tests organized by financial supervisors could also lead towards complete information regarding exposures.

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 offer 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 required information. That is, when a competing investor i decides to make an offer or ration the firm, it can either chose 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-side overhang problem. 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 the firm gets an offer below his 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 a rationing barrier in absence of the externality, similar to the set up of Lemma 1. As a result, in presence of perturbations such a trembling hands, the market may unravel and the effect of the externality on firm 2 disappear.

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 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., bank $i^* = \min_i\{qR_{Bi}\}$.

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, we can formulate 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" effect An increase in heterogeneity of exposures to the negative externality should lead to less rationing. This implication derives from Proposition 3.

The next sections investigate these empirical predictions.

3 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 their negative 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 significant repricing of capital embodying non-environmental technologies (e.g., stranded assets).[16]

[16]See for instance European Central Bank (2021), which flags deteriorating brown performance and collateral valuation as key transition risks faced by the financial sector.

Furthermore, banks are a type of investors relevant to our theory, that is, they are highly exposed to green transition risks[17] and typically hold illiquid legacy positions exposed to such externality. The Belgian economy presents itself as an appropriate case study because (a) it is highly bank-based with limited alternative financing opportunities, (b) the banking market structure is heterogeneous[18] and (c) (part of) the economy is exposed to green transition shocks.[19]

Empirical strategy. 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 environmental and brown firms meet, and various externality measures. Table 1 collects and summarizes all variables/concepts discussed hereafter. Summary statistics are included in Table 3. 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 externality of the green firm. Based on these findings, Section 5 constructs a measure of a firm's green impact on banks' portfolios. Leveraging this metric, we investigate whether banks decide to ration environmental firms whose activity threatens to devalue the banks' legacy corporate credit portfolio.

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

[17] 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).

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

[19] For instance, a report by the National Bank of Belgium on 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).

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 mitigation technology (CCMT).[20] 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.*[21]
- ***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 neighboring firms. On the one hand, by offering a novel green alternative, product innovation can radically disrupt performance of incumbent brown market rivals thereby driving up their probabilities of default. On the other hand, by greening current production facilities, process innovation can lower marketability of environmental 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 to which 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. For instance, an individual claim could read "[*1*] *A device for treating wastewater...*". In practice, we 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. We rely on a validated dictionary prepared by Banholzer et al. (2019). Relevant details are provided in Appendix A.[22] In our baseline estimates, a firm is tagged as a process innovator (Green process innovator$_i$=1) if it has patented at least one green process innovation. A firm is tagged as a product innovator (Green product innovator$_i$=1) if it has patented at least one green process innovation. We consider time-variant alternatives in additional results.

[20]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 (2019); Popp (2019).

[21]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 fossils fuels to bioenergy (Xie et al., 2019). It also covers environmentally friendly production of a non-environmental product

[22]Our textual analysis is similar in spirit to Bena et al. (2021), Bena and Simintzi (2019) and Banholzer et al. (2019). While Bena et al. (2021) and Banholzer et al. (2019) strictly focus on US and EU patents, respectively, our approach considers the entire population of patents for which an entry is reported by a firm established in Belgium.

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 $2008 - 2018$. 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 in a way 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 a 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*[23]*:*

- ***Green adoption*** *entails the investment in environmental capital goods that embody clean technologies and/or end-of-pipe technologies.*[24]
- ***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 neighboring firms. On the one hand, a green provider offering green substitutes potentially distorts performance of incumbent brown firms operating in the same product market thereby driving up their probabilities of default. On the other hand, a transportation firm investing in a green truck fleet could affect asset valuation of competing transporters that exclusively operate fossil-fueled trucks thereby driving down the value of the collateral pledged to banks.

Leveraging the SBS data, we tag a firm as a green provider ($\text{Green provider}_i = 1$) if it is engaged in green provision. Note that we further condition the selection on the firm not being a green product innovator as we focus on firms that sell/adopt incumbent technologies rather than firms that develop green technologies. Similarly, we tag a firm as a green adopter ($\text{Green adopter}_i = 1$) 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 ($\text{Diffusor}_i = 1$). As for innovation, we consider time-variant proxies in robustness checks.

Taking stock. Our framework distinguishes between four forms of green activities: process innovation, product innovation, diffusion by selling, diffusion by adopting. As discussed above, each activity

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

[24]*End-of-pipe technologies* encompass (ex-post) pollution control technologies, using equipment that is added as a final process step to capture pollutants and wastes 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).

can have a distinct impact on a bank's legacy portfolio either via the change in (a) the performance of incumbent clients or (b) the value of the collateral they pledged. Figure 3 provides a schematic illustration and documents the number of firms in our estimation sample that engage in each green activities. In the remainder, we define the variable $\text{Green}_i = 1$ if the firm engages in at least one green activity. Henceforth, we refer to firms that engage in neither of four green activities as brown firms ($\text{Green}_i = 0$).

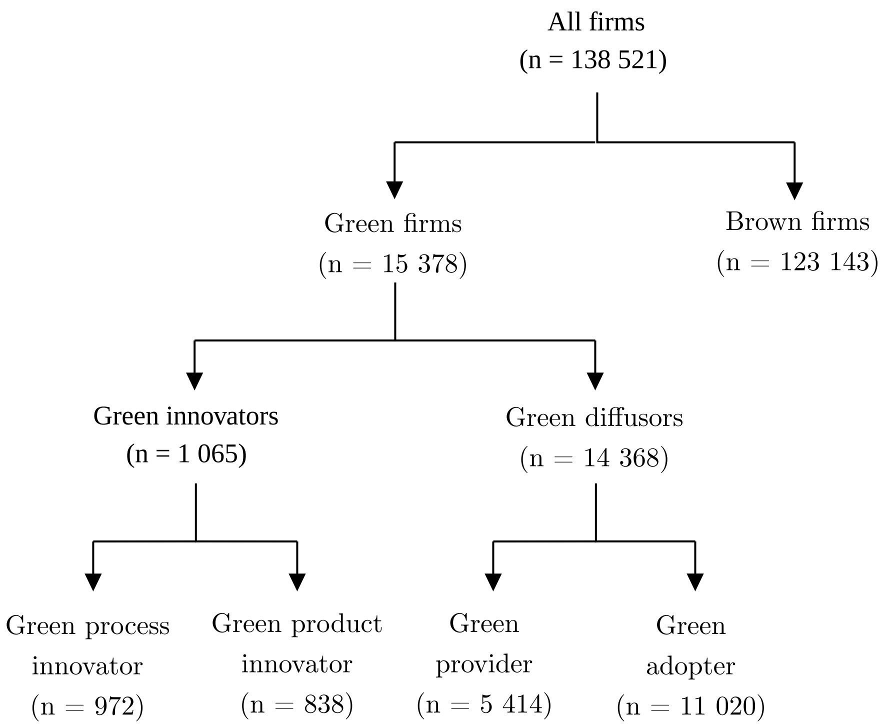

Figure 3: Incidence of various green activities by Belgian non-financial firms.

3.2 Economic spaces: proximity in product & technology markets.

There can be several forms of interactions between firms where spillovers materialise. Following Jaffe (1988), we distinguish between two economic spaces, namely, the *technology space* and the *product space*. For each space, we also consider pairwise proximity measures (i.e., closeness).[25]

Definition 3.4 (Economic spaces). *Green spillovers materialise 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*

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

[25] Proximity measures in product and/or technology spaces were previously leveraged by Branstetter and Sakakibara (2002); Bloom et al. (2013); Lucking et al. (2018).

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 closeness*** *which is 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.[26] Finally, a high value for T_{ijt} signals that both firms have a very similar production technology.

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 in 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.[27]

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 have a fundamentally different customer base (freight vs. customer transport). They 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 very distant in the technology space.

[26]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.

[27]The B2B records sales between two separate VAT identifiers and therefore also records intra–group trade. Consistent with the patenting approach above, 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.

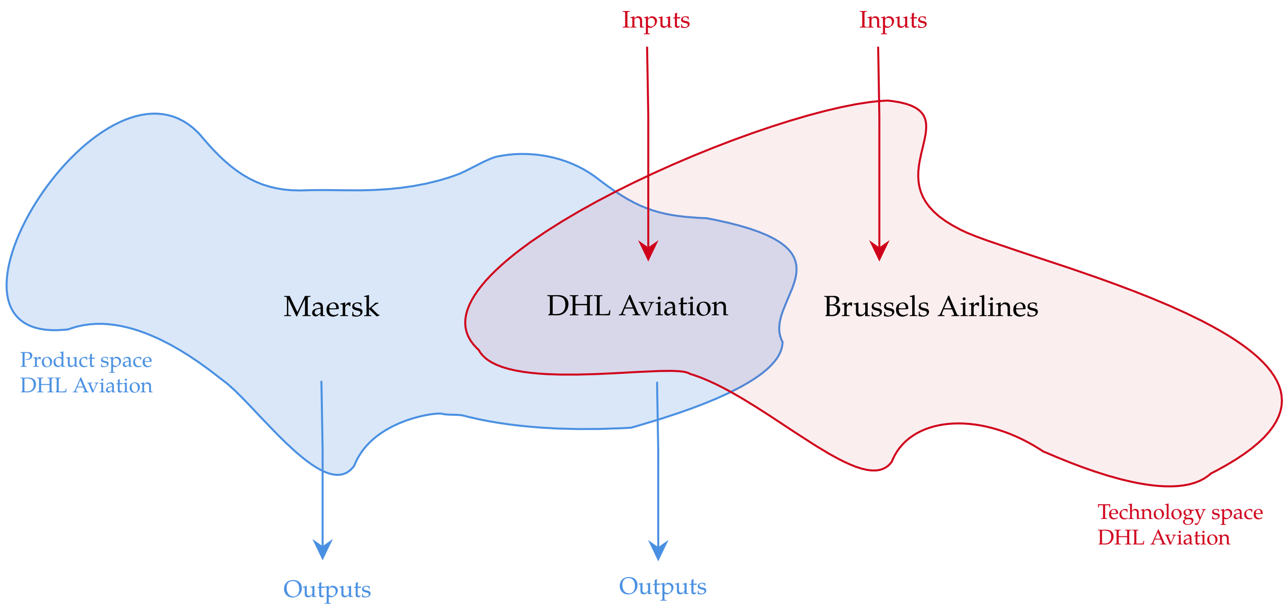

Figure 4: Product & technology spaces.

3.3 Two types of externalities

Our theoretical model relies on two ways in which a firm's green activity may affect a bank's client: (a) an increase in the probability of defaults (i.e., decrease in performance) and (b) a decrease in the value of the collateral pledged by the client (i.e., decrease in asset value). We consider various proxies for both dimensions.

Performance. A firm's green activity may affect another firm's performance by means of competition and business stealing, thereby increasing the other firm's probability of default (i.e., $qR_B > 0$). We measure this firm–level externality via four different metrics that cover various dimensions of performance (all formally defined in Table 1):

1. Change in sales to households: $\Delta \ln \left(\text{HH sales}_{it}\right)$
2. Change in sales to corporate customers: $\Delta \ln \left(\text{B2B sales}_{it}\right)$
3. Change in number of corporate customers: $\Delta \ln \left(\text{B2B customers}_{it}\right)$
4. Loss of corporate customers to green competitors: Lost B2B_{it}

Asset value. Green activities can depress market values of laggard assets that are typically pledged as collateral. For instance, the development of more efficient combustion engines may induce a mark down of fuel–inefficient automobiles (i.e., $\Delta C > 0$). In our baseline setting, we do not exploit direct information on the market value of collateralized assets. Instead, we make standard inference from the annual accounts. By generally accepted accounting principles, a firm needs to resort to an additional write-down of tangible fixed assets if there exists a significant (and persistent) discrepancy between the book value and the value at which the asset could be liquidated. This type of depreciation exists on top of the general, annual fixed depreciation scheme. Among others, text-book cases explicitly include technological progress which reduces the market value of the laggard asset. If greenness devalues brown incumbent assets, we should observe the incidence of these additional writedowns to be positively related to a green presence in the proximity of the firm. We therefore consider two measures of asset devaluation (formally defined in Table 1):

1. Exceptional writedowns: Writedowns_{it}

2. Liquidation losses: $\text{Liquidation loss}_{it}$

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

3.4 Taking stock.

Table 2 summarizes the four granular green activities (and combinations 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 ($\mathcal{S}$). In the following subsection, we set up an econometric framework to tease out whether – and to what extent – a particular green activity by firm j imposes an externality on firm i.

4 Identifying spillovers

4.1 Empirical framework

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

$$
\begin{aligned}
y_{jt} =& \alpha \times \overline{\Delta x(i,t)}^{\mathcal{A}=\text{product innovation}}_{\mathcal{S}=\text{product space}} + \beta \times \overline{\Delta x(i,t)}^{\mathcal{A}=\text{process innovation}}_{\mathcal{S}=\text{product space}} + \\
& \gamma \times \overline{\Delta x(i,t)}^{\mathcal{A}=\text{product innovation}}_{\mathcal{S}=\text{technology space}} + \delta \times \overline{\Delta x(i,t)}^{\mathcal{A}=\text{process innovation}}_{\mathcal{S}=\text{technology space}} + \\
& \boldsymbol{\zeta}' \boldsymbol{z}_{jt-1} + \varepsilon_{jt}
\end{aligned} \tag{1}
$$

Where y_{jt} either equals a performance or asset pledgeability metric.

Covariate $\overline{\Delta x(j,t)}^{\mathcal{A}=\text{product innovation}}_{\mathcal{S}=\text{product space}} = M^{-1}\sum_{m=1}^{M}\sum_{i=1}^{I}\left(\Delta\Pi_{jit-m} \times \text{Product Innovator}_i\right)$ captures the average annual entry of green product innovators in the product space of firm j. In particular, a value of $\overline{\Delta x(j,t)}^{\mathcal{A}=\text{product innovation}}_{\mathcal{S}=\text{product space}} = 1$ implies an average annual entry rate of 1 green product innovator in the exact same product space as firm j throughout $t-1$ and $t-M$. Coefficient α then quantifies the performance/asset markdown due to these increased green product innovation activities of neighbouring firms. The other three covariates of interest are defined in a similar vein and detailed in Table 1. Descriptives can be found in Table 3.

Control vector $\boldsymbol{z}_{jt}$ 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, firm age (logged) and age of fixed capital (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. Similarly, "Brown technology space entrants$_{it-1}$" controls for fresh (but non-environmental) capital investments by firms in the shared technology space.

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

$$
\begin{aligned}
y_{jt} =& \alpha \times \overline{\Delta x(i,t)}^{\mathcal{A}=\text{green provider}}_{\mathcal{S}=\text{product space}} + \beta \times \overline{\Delta x(i,t)}^{\mathcal{A}=\text{green adopter}}_{\mathcal{S}=\text{product space}} + \\
& \gamma \times \overline{\Delta x(i,t)}^{\mathcal{A}=\text{green provider}}_{\mathcal{S}=\text{technology space}} + \delta \times \overline{\Delta x(i,t)}^{\mathcal{A}=\text{green adopter}}_{\mathcal{S}=\text{technology space}} + \\
& \boldsymbol{\zeta}'\boldsymbol{z}_{jt-1} + \varepsilon_{jt}
\end{aligned}
\tag{2}
$$

Covariate $\overline{x(i,t)}^{\mathcal{A}=\text{green provider}}_{\mathcal{S}=\text{product space}} = M^{-1}\sum_{m=1}^{M}\sum_{j=1}^{J}\left(\Pi_{ijt-m} \times \text{Green provider}_j\right)$ captures the average annual entry of green goods/services providers in the product space of firm j. A value of $\overline{x(i,t)}^{\mathcal{A}=\text{green provider}}_{\mathcal{S}=\text{product space}} = 1$ implies an average annual annual entry rate of 1 green firm in the exact same product space of firm j throughout $t-1$ and $t-M$. Coefficient α quantifies the performance/asset markdown due to the increased green alternatives in the product space of firm j. 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–innovators (non–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. Finally, all right-hand side variables refer to $t-1$, while the dependent variable is for t. Nonetheless, there may be other omitted factors, simultaneously affecting both the lagged right-hand side variables and performance/pledgeability. We address a set of endogeneity concerns below which are subsequently addressed in Appendix B.

4.2 Results on externalities: a firms' perspective

Baseline results. Table 4 contains the results for both innovation (Equation 1 in Panel A) and diffusion (Equation 2 in Panel B) when y_{jt} proxies changes in performance (column (1)-(4)) and asset devaluation (column (5)-(6)).

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 3), when it happens, the effect on incumbents is sizeable; an annual entry rate of 1 environmental product innovator in the 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. Our innovation result 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) and shown to be empirically operative by Bloom et al. (2013). Our second result, unsurprisingly, suggests that the same effect holds for diffusion.

Second, Table 4 suggests that both green process innovation and investment in environmental capital by product market rivals has a negative effect on incumbent brown performance. Both activities are likely to give the environmental firms an edge in the product market, thereby driving down performance of brown laggards. The conjecture that process innovation leads to advantages over product market rivals through cost efficiencies and enhanced productivity was previously documented by Grilliches (1995) and Hall et al. (2009). Table A.2 in Appendix A supports a "cost reducing mechanism" by showing a positive correlation between being either a green adopter or a green process innovators and exhibiting 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 capital with market values. Negative externalities on incumbent technology from environmental process innovation directly stems from the seminal work by Aghion and Howitt (1992) which argues that (generic) technological progress imposes losses on others by rendering obsolete their old manufacturing processes. This mechanism reflects a "technology risk" where process innovation lowers pledgeability of assets which embody laggard technologies. Our result also suggest that technological adoption induces similar outcomes.

Robustness. A few points related to eq. (1) & (2) warrant attention. 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 green status of firms, Appendix B.1.2 builds the case that variation through that channel is limited in the time frame under consideration.

Second, increased/decreased 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 previously was active – or vice versa. Appendix B.1.1 teases apart the summands underlying the covariates to drive out the variation less likely to be associated with externalities.

Finally, calibration of 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.1.3).

4.3 Sets of firms at risk

From the baseline results we can construct for a given firm i the set $\mathcal{I}_{it}^{\mathcal{A}}$ of brown firms which are negatively exposed to the green activity $\mathcal{A}$ of firm i. These sets will serve as an input into the calibration of banks' credit portfolio at risk.

First, given that offering novel and incumbent environmental products/services negatively affects product market peers, the sets $\mathcal{I}_{it}^{\mathcal{A}=\text{product innovation}}$ and $\mathcal{I}_{it}^{\mathcal{A}=\text{green provider}}$ contain all brown firms that are in the same product space of firm i. Firms are said to be in the same product space if $\Pi_{ijt} > \Pi^*$. Second, as environmental process innovators and adopters harm technology market peers (asset devaluation) and product market peers (business stealing through enhanced efficiency), the sets $\mathcal{I}_{it}^{\mathcal{A}=\text{process innovation}}$ and $\mathcal{I}_{it}^{\mathcal{A}=\text{green adopter}}$ contain all brown firms that are in the technology and/or product space of firm i. As before, firms are said to be in the same technology space if $T_{ijt} > T^*$.

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 others 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 find our results to be robust to different thresholds (0.9, 0.95).

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 incumbent laggard borrowers. We then construct a bank–firm specific measure of bank b's legacy at risk due to the green activities unfolded by firm i. Next, 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. We investigate the presence and extent of a rationing barrier both in the extensive and intensive margins.

5.1 Results on externalities: a banks' perspective

Following naturally from the results in Subsection 4.2, we investigate whether green externalities are reflected in a bank's measures of client performance and asset pledgeability. From the central corporate credit register (CCR), we measure changes in performance of a client firm i through changes in the bank b's reported probability of default (PD_{ibt}) and provisioning (Provision_{ibt}).[28] The former directly echoes our qR_b measure from the theory while the latter informs on costs incurred by the bank. For asset pledgeability, we rely on granular collateral price data from the CCR. This datasource contains all collateral items pledged by firms to banks, their type, how they are valued, by whom and when.[29] We aggregate collateral types into three categories: financials (Financials_{ict}), real estate (Real Estate_{ict}) and physical assets ($\text{Physical Assets}_{ict}$), where subscript c refers to an individual collateral item. All variables are formally defined in Table 1. We re-estimate equations (1) & (2), on the subset of bank-borrowers, where y_{jt} now takes on riskiness and collateral valuations. The results are reported in Table 6 where the structure of the table mimics that of Table 4.

First, the results in column (1) and (3) show that increased green presence in the product space - either through innovation (panel A) or diffusion (panel B) - leads to an elevated probability of an upward revision of default probabilities. Banks are also more likely to book additional provisions on these exposures. Importantly, but unsurprisingly, banks mimic the previous firm–level results which suggest that innovation (panel A) is more disruptive than diffusion (panel B).

Second, green process innovation and green investment by firms with whom a client shares the technology space appears to drive down the value of physical assets that are pledged. Interestingly, collateral related to real estate and financials appear immune to green activity. This result speaks directly to our discussion on the nature of collateral at stake as physical assets are more likely to represent inside collateral while outside collateral like real estate or financials are more likely to be driven by other fundamentals.

All in all, these results point to evidence that green activities activate negative spillovers on competing firms which in turn translate into downgrades of credit value by the bank - for those competing firms with a bank credit. Note however that, at this stage, these results do not necessarily show that

[28]The CCR contains all authorised credit relationships between non–financial firms and credit institutions licensed by the NBB. This concerns 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).

[29]We focus exclusively on pledged assets that are (frequently re)valued at market prices. Focusing on a particular (more informative) subset of collateral is warranted because other valuation methods are potentially less informative: 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 is estimated noisily (e.g. by the borrower), etc. We therefore select collateral items that reflect market values and exhibit frequent changes in value. As a result, the number of collateral-firm-bank observations analyzed here represents only a small population subset, but is more informative.

banks are actually aware of the externalities per se. While banks might effectively observe declined performance(e.g., an elevated PD stems from the observed decline in performance), they might not infer that the declined performance originates from green competition. The same reasoning holds for collateral. Table 6 ultimately suggests that banks should care about the green channels: the externalities exist and have rammifications for their legacy portfolio.

5.2 Legacy positions at risk: measurement

Let c_{jbt} denote the share of credit granted by bank b to firm j in aggregate corporate credit granted by bank b at time t. These shares are inferred from the CCR. Using 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 from firm i. More formally, the share of bank b's corporate credit portfolio that is negatively exposed to green activity $\mathcal{A}$ in which firm i is engaged is given by:

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

with $\boldsymbol{\theta}_{it}^{\mathcal{A}} = (\theta_{jbt}^{\mathcal{A}})$. 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 heterogeneity in the legacy positions activity $\mathcal{A}$ of firm i imposes across banks. In line with our theoretical predictions, our baseline estimates take $f_2(\cdot)$ to be the minimum across the corporate credit market (i.e. $f_2(\boldsymbol{\theta}_{it}^{\mathcal{A}}) = Min(\boldsymbol{\theta}_{it}^{\mathcal{A}})$).

Discussion. Our measurement warrants two points of discussion. First, evidently, brown firms create no legacy risk (i.e. $\boldsymbol{\theta}_{it}^{\mathcal{A}} = \mathbf{0}$ if $\text{Green}_i = 0$) and so $f_1(\boldsymbol{\theta}_{it}^{\mathcal{A}}) = f_2(\boldsymbol{\theta}_{it}^{\mathcal{A}}) = 0$ if $\text{Green}_i = 0$. Reversely, note that $\text{Green}_i = 1$ does not imply that $f_1(\boldsymbol{\theta}_{it}^{\mathcal{A}}) > 0$. In words: it is very plausible that a green firm imposes no externality on any bank in the system (i.e. $\boldsymbol{\theta}_{it}^{\mathcal{A}} = \mathbf{0}$ although $\text{Green}_i = 1$). 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 $\mathcal{I}_{it}^{\mathcal{A}} = \varnothing$) or because the brown firms at risk are not bank borrowers.

Second, our choice to select the minimum exposure value for $f_2()$ implies that, when we consider the entire population of banks and established credit relationships in the CCR, this procedure invariantly leads to $f_2(\boldsymbol{\theta}_{it}^{\mathcal{A}}) = 0$. The reason is threefold. First, some financial institutions in the corporate credit register are in–house banks that only lend to their group members (e.g. Volkswagen bank as part of the Volkswagen group). Second, various 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). Third, some banks exclusively target niche industries (e.g. Banque

Eni focuses exclusively on firms operative in "Oil & Natural gas extraction"). Due to their specific nature, these banks have a limited number of firms in their portfolio and are typically legacy free (i.e. $\theta_{ibt} = 0\, \forall i$). At the same time, they are unlikely plausible lenders to firms in the Belgian real economy that do not align with their specific lending policy. For this reason, when computing $f_1(\cdot)$ & $f_2(\cdot)$, 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.

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 banks' portfolio. At the same time, a significant share of the aggregated bank portfolio appears at risk vis-à-vis the population of green firms. Such sizeable exposure makes it rational for banks to integrate their legacy positions into their credit decision strategy.[30]

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):[31]

$$Borrower_{it} = \beta_1 \times \mathcal{A} + \beta_2 \times Med(\boldsymbol{\theta}^{\mathcal{A}}_{it-1}) + \beta_3 \times Min(\boldsymbol{\theta}^{\mathcal{A}}_{it-1}) + \boldsymbol{\zeta}'\boldsymbol{z}_{it-1} + \varepsilon_{it} \tag{3}$$

where $Borrower_{it}$ equals 1 when firm i has a positive exposures in the credit registry at t, zero otherwise. $\mathcal{A} = \{Green_i, Innovator_i, Diffusor_i\}$ is a dummy variable indicating whether the firm engages in a particular activity.

The vector of controls $\boldsymbol{z}_{it}$ provides measures of firm riskiness by including a set of drivers that typically determine access to bank credit. In particular, since green firms are often young – and young firms typically suffer from informational asymmetries that discourages lending – we control for firm age (logged). In addition, green firms (in particular innovators) potentially engage in high risk activities. We control for this by including the standard deviation of return on assets up to time $t-1$. We additionally include a dummy for negative equity to reflect persistency in losses (which potentially stems from high up-front investments by green firms). In 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.

[30] Furthermore, Table 7 provides autocorrelation coefficients of the legacy positions at risk. In general there are two reasons why the level of legacy positions would change (causing autocorrelations smaller than 1). The first obtains when either a brown firm enters or leaves the product or technology space of the green firm. From the data, we observe that the pairing of firms through product and technology spaces is stable throughout our sample period. The data exhibits (a) some entries (birth) and exits (bankruptcies), (b) some marginal passing of space threshold values (T^* or Π^*) and (c) some genuine entry and exit in and out of each firm's spaces. Broadly, however, firms appear to remain stay in each other spaces.

[31] LPM models have been used in similar set–ups, see e.g. Jiménez et al. (2012, 2014).

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. Finally, we add generic controls for firm size (assets), sector $\times$ time FE (4-digit), region $\times$ time FE (region).

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. Below, we estimate various versions of Equation (3), starting from a general baseline and subsequently expanding on several dimensions informed by our theoretical framework.

Baseline results. Table 8 presents the baseline results and establishes two important findings.[32] First, from the coefficients on $Med(\cdot)$, the larger the legacy positions in the banking system that are at risk to the disruptive environmental firm i, the less likely banks are willing to lend to this firm. The *Legacy effect*, reported in the table, gauges the economic significance of these coefficients. It measures the marginal rationing impact for an environmental firm that previously posed no threat to the banking sector, but decides to engage in environmentally disruptive technologies. In case of environmental innovation (column (2)), this leads to a 5.9 p.p. reduction in the probability of receiving bank credit. For environmental diffusors, this rationing sizes up to 0.5 p.p. Note that these results align with the results from the previous section (e.g., Table 4) where innovators were more detrimental than diffusors, both in terms of performance and collateral valuation. In addition, note that this result is net of other sources of finance (debt, equity, intragroup) and firm riskiness.[33]

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 0.5 s.d. drop in the rationing barrier (i.e. the lowest legacy position at risk in the banking spectrum) increases the probability of receiving bank credit by 5.3 p.p. Quantitatively, this largely undoes the initial rationing impact. Similarly, for diffusors the market structure effect fully

[32]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 potentially is 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 legacy positions of green firms that cause rationing.

[33]Note that the legacy positions at risk due to firm i exclusively embody credit to other firms (not firm i), which should be exogenous to firm i.

undoes the initial legacy effect.

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 green activity. In Table 9, we decompose the baseline results into all the forms of green activities present in our framework: process innovation, product innovation, diffusion by provision and diffusion by adoption. The *legacy effects* suggest that process innovators are rationed the most while product innovators appear next in line. Green providers & adopters are rationed more or less equally (and significantly less than innovators). Once again, these findings map with the differential impacts of activities on different externality channels observed in Section 4.[34]

Decomposition by externality. The previous results decomposed legacy positions per activity ($\mathcal{A}$) of firm i. In Table 10, we investigate another type of legacy position decomposition, namely per externality $\mathcal{E}$. Let $\theta^{\mathcal{E}}_{jbt}$ quantify the share of the bank portfolio at risk due to externality $\mathcal{E} = \{Performance, Pledgeability\}$ triggered by firm i. Leveraging the framework from Section 4, we obtain the green activities of each firm and the externality on which they load. As a result, we can proceed with a decomposition per externality.

Column (3) from Table 10, shows that performance is the main driver of banks decisions. The coefficients on collateral value are statistically insignificant, although they have the expected sign.[35]Note that this does not clash with the results in Table 6. Recall that results from Table 6 show an impact of green process innovations and purchasing environmental green capital in driving down the asset values of their competing firms in the technology space. A possible explanation for the discrepancy could be that banks are not capable to sufficiently observe and quantify the collateral externality. This would be less the case for assessing performance for which the relevant information is more easily accessible.

Decomposition by maturity. Next we investigate the effect of residual maturity in legacy positions. In Table 11, we decompose between short term (less than one year residual maturity) and long term (more than five years residual maturity) legacy positions. The results from Table 11 suggest that banks' decision do not rely upon short term exposures. Instead, long term positions do matter. This results 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

[34]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.

[35]The statistical significance in specification (2) arises because of the correlation with performance (i.e. firms that negatively affect collateral typically also affect performance). Once we control for both at the same time (column (3)), collateral becomes insignificant.

exposures are also better reflection of banks' general lending strategies, policies, sector specialization, etc. Such features are exactly the type of core exposures one would expect banks not to securitize (and therefore remain vulnerable to disruption).

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 ones, the former being generally more stable than the latter.

Weighted baseline results. Finally, we consider the potential effect of size. In fact, one can verify that (by construction) there exists no correlation between the size of the legacy positions of firm i and the actual size of firm i (e.g., total assets). Multinationals and local firms could generate the same legacy positions. This scenario might not be reflective of reality where one could expect that more rationing towards larger firms. One reason could be that the size of the project renders them more threatening to the legacy portfolio. Another could be that because of the size, banks spend more time and resources to screen potential impacts on their legacy portfolio. Table 12 informally test for the effect of size by interacting the rationing covariates with asset size. The results indeed suggest that rationing gets more pronounced for large firms as all the interaction terms with logged assets magnify both the effect of the legacy size and market structure.

5.4 Breaking the barrier: who starts lending?

A natural follow up of our results on the extensive margin is: which bank ends up offering credit? Note that our theory is silent on this part. However, uncovering such matching will allow us to investigate the effect of rationing in the intensive margin.

Using LPMs, we therefor estimate the following model on the subset of firms that receive bank credit for the first time at time t:

$$Borrower_{ibt} = \alpha \times \theta^{\mathcal{A}}_{ibt-1} + \beta \times \iota_t(b = \arg\min_b(\boldsymbol{\theta}^{\mathcal{A}}_{it-1})) + \gamma \times \iota_t(b = \arg\max_b(\boldsymbol{\theta}^{\mathcal{A}}_{it-1})) + \varepsilon_{ibt}$$

Where $Borrower_{ibt}$ denotes 1 if firm i is matched with bank b at time t. $Borrower_{ibt}$ denotes 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. This means that if $Borrower_{ibt} = 1$, it must be that $Borrower_{ibt-m} = 0 \forall b, m$. While firm–bank observations where $Borrower_{ibt} = 1$ are directly obtained from data, observations where $Borrower_{ibt} = 0$ are less straightforward. In theory, for each firm, we could have $B - 1$ observations that reflect non–materialized bank–firm matches. However, as discussed in Subsection 5.2, we maintain our assumption that not all banks are valid candidates to lend to firm i. So for a firm i at time t, the eligible list of lenders is restricted.

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 firm i. Table 13 reports the results.

Our findings capture 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 firm is 13 p.p. more likely to receive credit from the bank with the lowest legacy position than from any other bank in the system.[36]

5.5 Bank credit rationing: intensive margin

In this last round of results, we investigate rationing effects in the intensive margin. In particular, we want to assess how the market structure of the banking system remains to affect credit supply after a green firm has become a bank-borrower. In particular, would changes in the legacy position of the incumbent lender matter? Or would it rather be a change in the lowest legacy position of the entire banking market that drives the extent credit rationing when this change originates from a bank other then the incumbent lender?

In order to address this question, we run the following regression:

$$\Delta ln(Credit_{ibt}) = \alpha \times \Delta\theta^{\mathcal{A}=\text{Green}}_{ibt-1} + \beta \times \Delta Min(\boldsymbol{\theta}^{\mathcal{A}=\text{Green}}_{it-1}) + \gamma_{bt} + \gamma_{gt} + \varepsilon_{ibt}$$

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[37]; $\Delta\theta^{\mathcal{A}=\text{Green}}_{ibt-1}$ captures the change in the legacy position of the incumbent borrower and $\Delta Min(\boldsymbol{\theta}^{\mathcal{A}=\text{Green}}_{it-1})$ captures the change in the market level rationing barrier (market structure). Results are presented in Table 14.

First, note that this exercise constitutes a tough test: by virtue of the results in Subsection 5.4 both covariates are expected to be significantly correlated (often, the incumbent borrower is the borrower with the lowest legacy position at risk). What our approach uncovers relates to cases where the two covariates differ (i.e., the change in the lowest legacy position does not originate from the incumbent lender). The results from Table 14 show that a 1 s.d. decrease in the the lowest asset overhang position (potentially, but not necessarily, that of the incumbent lender) drives up credit supply by the incumbent lender to disruptive firms by 0.06 s.d. The legacy positions of the incumbent borrower are irrelevant. This results highlights that the asset overhang remains to play a role in determining credit

[36]Note that, in this setup, concerns about appropriately controlling for demand are muted here: observations relate to firms that request & receive credit. In this case, we are only concerned with with the matching part.

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

supply to disruptive firms .

6 Policy implications

Our theoretical framework suggests that economies may suffer from technological conservatism when new entrants threaten investors' incumbent clients. Proposition 1 formalizes how legacy positions in a financier's portfolio impede funds from being channeled to otherwise profitable firms. Propositions 3 further highlights the role of the intermediary market structure in setting aggregate financing barriers to innovative firms. In the context of climate finance, section 3 presents 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 transit into a green economy. Various policy measures can help to breach the source of this barrier at the investor level.

Legacy-free financiers. First 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 these initiatives are public (or quasi-public), their mandate potentially does not require them to factor in the impact of ΔC (i.e., their behaviour is not governed by our framework). Next, note that in a more general setting, where the demand and needs 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 analysis.

Aggregate effects of individual freedom. Perhaps more important to note is that the presence of at least one legacy-free financier has the capacity to produce larger scale effects. In fact, while Proposition 1 formalizes institution-level lending behaviour, Proposition 2 and Proposition 3 show that the market structure of the intermediary system plays a crucial role in determining the extent of credit provisions to innovative firms. Recall that, according to Proposition 2, in a system where all investors have equal stakes in legacy assets, they can complicitly promote the same rationing policy towards disruptive firms. That is because all suffer equally from the entry of one single firm. In contrast, once legacy positions become heterogeneous, as in 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 materialises irrespective of the loan originator. Therefore, once the entry of a disruptive technology is certain (i.e., investors cannot collude to prevent it), losses will materialise irrespective of the stakes. Accordingly, all investors in the system become theoretically likely to extend credit to disruptive projects using this same technology.

Overall, this set of results suggest that having a single bank with no legacy position (e.g., a green bank with no brown assets) enter the credit market would subsequently induce incumbent banks to engage in green activity which they would have rationed otherwise. Aggregate banking provision of credit directed to disruptive technologies would therefore be amplified beyond the credit capacity of the legacy-free bank, potentially encompassing the whole banking system.

Macroprudential policies. Focusing on incumbent institutions, policymakers have voiced the possibility of leveraging macro prudential policies to address the green transition (ECB, 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 behaviour 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.

7 Conclusion

In this paper, we theoretically and empirically study the role of investors' asset overhang on 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, 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 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 5 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 that 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.

8 Tables

(continued on next page)

Table 1: Variable definitions & data sources

Variable	Description	Type	Source
Firm-level controls			
ROA_{it}	Return on assets at time t.	Continuous	(1)
$\text{ROA volatility}_{it}$	5-year rolling standard deviation of 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)
$\text{Negative equity}_{it}$	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 material fixed asset depreciation over the stock of material 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)
$\text{Public equity}_{it}$	1 if firm i is listed on the stock exchange at time t (0 otherwise)	Binary	(1)
Public debt_{it}	1 if firm i has issued debt securities at time t (0 otherwise)	Binary	(3)
Patenter_{i}	Firm has filed for at least one patent.	Binary	(4)
Green innovation activities			
$\text{Green process innovator}_{i}$	1 if firm (or group member) has filed at least one green process patent according to Appendix A (0 otherwise).	Binary	(4)
$\text{Green product innovator}_{i}$	1 if firm (or group member) has filed at least one green product patent according to Appendix A (0 otherwise).	Binary	(4)
$\text{Green innovator}_{i}$	1 if firm is a green process and/or product innovator (0 otherwise).	Binary	(4)
Green diffusion activities			
Green adopter_{i}	1 if the firm has a non-zero share of capital investments according to Definition 3.3 (0 otherwise)	Binary	(4), (5)
$\text{Green provider}_{i}$	1 if the firm has a non-zero share of sales according to Definition 3.3 (0 otherwise).	Binary	(4), (5)
$\text{Green diffusor}_{i}$	1 if the firm is a green seller 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			
π_{ikt}	The share of firm i sales to firms in sector k in total sales of firm i at time t. Sectors $k = 1, \ldots, K-1$ are defined at the granular 5 digit NACE-level and K captures the household sector.	Continuous	(1), (6)
τ_{ikt}	The share of firm i procurements from firms in sector k in total procurements of firm i at time t. $k = 1, \ldots, K$ sectors are defined at the granular 5 digit NACE-level.	Continuous	(1), (6)

(*Continued on next page*)

Variable	Description	Type	Source
Green presence measures			
$\overline{x(i,t)}^{\mathcal{A}=\text{product innovation}}_{\mathcal{S}=\text{product space}}$	$M^{-1}\sum_{m=1}^{M}\sum_{j=1}^{J}\Delta\big(\Pi_{ijt-m}\times \text{Green product innovator}_j\big)$	Continuous	(1), (4), (6)
$\overline{x(i,t)}^{\mathcal{A}=\text{process innovation}}_{\mathcal{S}=\text{product space}}$	$\text{M}^{-1}\sum_{m=1}^{M}\sum_{j=1}^{J}\Delta\big(\Pi_{ijt-m}\times \text{Green process innovator}_j\big)$	Continuous	(1), (4), (6)
$\overline{x(i,t)}^{\mathcal{A}=\text{product innovation}}_{\mathcal{S}=\text{technology space}}$	$\text{M}^{-1}\sum_{m=1}^{M}\sum_{j=1}^{J}\Delta\big(T_{ijt-m}\times \text{Green product innovator}_j\big)$	Continuous	(1), (4), (6)
$\overline{x(i,t)}^{\mathcal{A}=\text{process innovation}}_{\mathcal{S}=\text{technology space}}$	$\text{M}^{-1}\sum_{m=1}^{M}\sum_{j=1}^{J}\Delta\big(T_{ijt-m}\times \text{Green process innovator}_j\big)$	Continuous	(1), (4), (6)
$\overline{x(i,t)}^{\mathcal{A}=\text{green provider}}_{\mathcal{S}=\text{product space}}$	$\text{M}^{-1}\sum_{m=1}^{M}\sum_{j=1}^{J}\Delta\big(\Pi_{ijt-m}\times \text{Green provider}_j\big)$	Continuous	(1), (4) – (6)
$\overline{x(i,t)}^{\mathcal{A}=\text{green adopter}}_{\mathcal{S}=\text{product space}}$	$\text{M}^{-1}\sum_{m=1}^{M}\sum_{j=1}^{J}\Delta\big(\Pi_{ijt-m}\times \text{Green adopter}_j\big)$	Continuous	(1), (4) – (6)
$\overline{x(i,t)}^{\mathcal{A}=\text{green provider}}_{\mathcal{S}=\text{technology space}}$	$\text{M}^{-1}\sum_{m=1}^{M}\sum_{j=1}^{J}\Delta\big(T_{ijt-m}\times \text{Green provider}_j\big)$	Continuous	(1), (4) – (6)
$\overline{x(i,t)}^{\mathcal{A}=\text{green adopter}}_{\mathcal{S}=\text{technology space}}$	$\text{M}^{-1}\sum_{m=1}^{M}\sum_{j=1}^{J}\Delta\big(T_{ijt-m}\times \text{Green adopter}_j\big)$	Continuous	(1), (4) – (6)
Brown presence measures			
Brown product space entrants$_{it}$	$M^{-1}\sum_{m=1}^{M}\sum_{j=1}^{J}\Delta\big(\Pi_{ijt-m}\times(1-\text{Green}_j)\big)$		
Brown technology space entrants$_{it}$	$M^{-1}\sum_{m=1}^{M}\sum_{j=1}^{J}\Delta\big(T_{ijt-m}\times(1-\text{Investor}_{jt-m})\big)$ where $\text{Investor}_{jt-m}=1$ if the firm has a positive investment flow at time $t-m$ (zero otherwise).		
Firm–level performance/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).	Continuous	(6)
Δ ln (B2B customers$_{it}$)	Y-o-Y percentage change in the number of corporate customers (excl. intra-group counterparties).	Continuous	(6)
Lost B2B$_{it}$	The share of the corporate customer portfolio that is lost to green product market competitors from $t-1$ to t. 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". For example, suppose seller$_{it-1}$ is a logistics firm with NACE code "50.400" (= transport of goods over canals and rivers). It sells its logistics services to buyer$_{jt-1}$, which is in NACE code "08.122" (= 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 "50.400", 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. Lost B2B$_{it}$ quantifies the share of $t-1$ B2B sales volume that is lost to green product market competitors. The variable controls for entry/exit and M&A activity.	Continuous	(4)–(6)
Writedowns$_{it}$	Firm i has booked an exceptional writedown on tangible assets beyond the predetermined amortization scheme at time t (0 otherwise). Only available for large firms†.	Binary	(1)
Liquidation loss$_{it}$	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			
Provision$_{ibt}$	The amount of loss provisions held on or allocated to credit of firm i by bank b at time t.	Continuous	(7)
PD$_{ibt}$	Bank b assessed probability of firm i defaulting within the next 12 months.	Continuous	(7)

(*Continued on next page*)

Variable	Description	Type	Source
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)
Δ ln (Real estate$_{ict}$)	Y-o-Y percentage change in the value of real estate collateral item c (commercial and residential real estate), pledged by firm i in the context of a credit facility. We focus on Real estate$_{ict}$ valued by the bank or third 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$_{it}$	Firm i has an authorised bank credit facility at time t (0 otherwise).	Binary	(7)
Borrower$_{ibt}$	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 credit of firm i.	Continuous	(7)

Notes: Data sources listed: (1) Annual Accounts, (2) Crossroads banks, (3) NBB Securities Settlement System, (4) PATSTAT, (5) SBS Survey, (6) Business–to–business transactions dataset, (7) Central corporate credit register. All datasets are annual 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: Green activities ($\mathcal{A}$), externalities ($\mathcal{E}$) & economic spaces ($\mathcal{S}$)

Green activity ($\mathcal{A}$)	Externality ($\mathcal{E}$)	Economic space ($\mathcal{S}$)
Green innovation	*Performance*	*Product space*
(Innovator_i)	(Δ ln (HH sales_{jt}))	(Π_{ijt})
	(Δ ln (B2B saless_{jt}))	
Green product innovation	(Δ ln (B2B customers_{jt}))	*Technology space*
(Product innovation_i)	(Lost B2B_{jt})	(T_{ijt})
Green process innovation	*Tangible asset pledgeability*	
(Process innovation_i)	(Writedowns_{jt})	
	(Liquidation loss_{jt})	
Green diffusor		
(Green diffusor_i)		
Green provider		
(Green provider_i)		
Green adopter		
(Green adopter_i)		
Green		
(Green_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 ($\mathcal{S}$).

Table 3: DESCRIPTIVE STATISTICS

Variable	N	Mean	Std. dev.	p.10	p.50	p.90
CHANGING GREEN PRESENCE MEASURES						
$\overline{\Delta x(i,t)}^{\mathcal{A}=\text{product innovation}}_{\mathcal{S}=\text{product space}}$	662052	-0.01	0.40	-0.24	0.00	0.21
$\overline{\Delta x(i,t)}^{\mathcal{A}=\text{process innovation}}_{\mathcal{S}=\text{product space}}$	662052	-0.03	0.59	-0.50	0.00	0.35
$\overline{\Delta x(i,t)}^{\mathcal{A}=\text{product innovation}}_{\mathcal{S}=\text{technology space}}$	662052	0.16	0.89	-0.74	0.07	1.20
$\overline{\Delta x(i,t)}^{\mathcal{A}=\text{process innovation}}_{\mathcal{S}=\text{technology space}}$	662052	0.02	0.82	-0.95	0.02	1.01
$\overline{\Delta x(i,t)}^{\mathcal{A}=\text{green provider}}_{\mathcal{S}=\text{product space}}$	662052	0.35	11.22	-9.72	0.05	12.21
$\overline{\Delta x(i,t)}^{\mathcal{A}=\text{green adopter}}_{\mathcal{S}=\text{product space}}$	662052	-3.19	19.48	-25.05	-0.37	16.53
$\overline{\Delta x(i,t)}^{\mathcal{A}=\text{green provider}}_{\mathcal{S}=\text{technology space}}$	662052	4.49	35.12	-43.25	2.78	53.94
$\overline{\Delta x(i,t)}^{\mathcal{A}=\text{green adopter}}_{\mathcal{S}=\text{technology space}}$	662052	3.48	67.82	-90.58	2.41	98.51
FIRM–LEVEL PERFORMANCE/PLEDGEABILITY VARIABLES						
Δ ln (HH sales$_{it}$)	545269	-0.02	1.08	-0.73	0.00	0.65
Δ ln (B2B sales$_{it}$)	660893	0.00	0.69	-0.63	0.02	0.58
Δ ln (B2B customers$_{it}$)	660893	-0.01	0.44	-0.49	0.00	0.42
Lost B2B$_{it}$	660893	0.03	0.10	0.00	0.00	0.10
Writedowns$_{it}$	77805	0.05	0.23	0.00	0.00	0.00
Liquidation loss$_{it}$	35000	0.16	0.37	0.00	0.00	1.00
BANK–FIRM–LEVEL RISK VARIABLES						
PD up$_{ibt}$	81151	0.34	0.47	0.00	0.00	1.00
PD up$_{ibt}$	81151	0.39	0.49	0.00	0.00	1.00
Provision up$_{ibt}$	86637	0.13	0.34	0.00	0.00	1.00
Provision down$_{ibt}$	86637	0.05	0.22	0.00	0.00	0.00
COLLATERAL VARIABLES						
Δ ln (Financials$_{it}$)	16060	0.00	0.21	-0.17	0.00	0.16
Δ ln (Real Estate$_{it}$)	8987	0.00	0.13	-0.01	0.00	0.02
Δ ln (Physical assets$_{it}$)	4025	-0.04	0.26	-0.50	0.00	0.25

Notes: Descriptive statistics for the variables used in Tables 4 & 6. All continuous variables are winsorized at the 1/99 level.

Table 4: Firm perspective – green presence & brown firm performance/pledgeability

Panel A: Innovation

	Firm performance				Tangible asset pledeability	
	Δ ln (HH sales$_{it}$)	Δ ln (B2B sales$_{it}$)	Δ ln (B2B customers$_{it}$)	Lost B2B$_{it}$	Writedowns$_{it}$	Liquid. loss$_{it}$
	(1)	(2)	(3)	(4)	(5)	(6)
$\overline{\Delta x(i,t)}^{\mathcal{A}=\text{product innovator}}_{\mathcal{S}=\text{product space}}$	−0.0673***	−0.0220***	−0.0042**	0.0049***	−0.0500	0.4819
	(0.0046)	(0.0032)	(0.0017)	(0.0004)	(0.1674)	(2.3422)
$\overline{\Delta x(i,t)}^{\mathcal{A}=\text{process innovation}}_{\mathcal{S}=\text{product space}}$	−0.0206***	−0.0044*	−0.0022*	0.0029***	−0.0612	−0.6699
	(0.0031)	(0.0023)	(0.0013)	(0.0003)	(0.1377)	(1.5720)
$\overline{\Delta x(i,t)}^{\mathcal{A}=\text{product innovation}}_{\mathcal{S}=\text{technology space}}$	0.0003	0.0014	0.0003	0.0002	−0.0068	−0.2752
	(0.0031)	(0.0017)	(0.0010)	(0.0002)	(0.0294)	(0.1799)
$\overline{\Delta x(i,t)}^{\mathcal{A}=\text{process innovation}}_{\mathcal{S}=\text{technology space}}$	0.0035	−0.0025	−0.0013	−0.0003	0.1976**	0.3242*
	(0.0034)	(0.0019)	(0.0011)	(0.0002)	(0.0926)	(0.1803)
Controls	Y	Y	Y	Y	Y	Y
Sector × Time FE	4 digit	4 digit	4 digit	4 digit	3 digit	3 digit
Location × Time FE	Y	Y	Y	Y	Y	Y
Firm FE	Y	Y	Y	Y	N	N
Cluster-level	Firm	Firm	Firm	Firm	Firm	Firm
# Clusters	74991	85518	85518	85518	16836	18557
# Observations	428171	526007	526007	526007	77134	33954
Adj. R^2	0.159	0.101	0.077	0.072	0.024	0.128

Panel B: Diffusion

	Firm performance				Tangible asset pledeability	
	Δ ln (HH sales$_{it}$)	Δ ln (B2B sales$_{it}$)	Δ ln (B2B customers$_{it}$)	Lost B2B$_{it}$	Writedowns$_{it}$	Liquid. loss$_{it}$
	(1)	(2)	(3)	(4)	(5)	(6)
$\overline{\Delta x(i,t)}^{\mathcal{A}=\text{green provider}}_{\mathcal{S}=\text{product space}}$	−0.0098***	−0.0040***	−0.0007	0.0001*	0.0011	−0.0003
	(0.0008)	(0.0006)	(0.0004)	(0.0001)	(0.0019)	(0.0004)
$\overline{\Delta x(i,t)}^{\mathcal{A}=\text{green adopter}}_{\mathcal{S}=\text{product space}}$	−0.0004***	−0.0003***	−0.0003*	0.0001***	0.0000	0.0001
	(0.0001)	(0.0000)	(0.0002)	(0.0000)	(0.0002)	(0.0001)
$\overline{\Delta x(i,t)}^{\mathcal{A}=\text{green provider}}_{\mathcal{S}=\text{technology space}}$	0.0001	−0.0001	0.0000	0.0000	−0.0025	−0.0001
	(0.0001)	(0.0001)	(0.0000)	(0.0000)	(0.0028)	(0.0001)
$\overline{\Delta x(i,t)}^{\mathcal{A}=\text{green adopter}}_{\mathcal{S}=\text{technology space}}$	0.0000	0.0000	0.0000	0.0000	0.0022*	0.0018*
	(0.0001)	(0.0000)	(0.0000)	(0.0000)	(0.0012)	(0.0010)
Controls	Y	Y	Y	Y	Y	Y
Sector × Time FE	4 digit	4 digit	4 digit	4 digit	3 digit	3 digit
Location × Time FE	Y	Y	Y	Y	Y	Y
Firm FE	Y	Y	Y	Y	N	N
Cluster-level	Firm	Firm	Firm	Firm	Firm	Firm
# Clusters	64287	74169	74169	74169	11030	13360
# Observations	360255	453353	453353	453353	47743	20857
Adj. R^2	0.163	0.093	0.072	0.072	0.024	0.129

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 sales 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 log(Assets$_{it}$), Leverage$_{it}$, log(Firm age$_{it}$), log(Capital age$_{it}$), brown product space entrants$_{it}$ and brown technology space entrants$_{it}$ as defined in Table 1. Columns (1)-(4) include a lag of the dependent variable and are estimated using the Arellano-Bond estimator. Columns (5)-(6) 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	
Space ($\mathcal{S}$)	Product Innovation	Process Innovation
Product space	Performance: ↓ Pledgeability: ∅	Performance: ↓ Pledgeability: ∅
Technology space	Performance: ∅ Pledgeability: ∅	Performance: ∅ Pledgeability: ↓
	Green activity ($\mathcal{A}$): Diffusion	
	Green providing	Green adopting
Product space	Performance: ↓ Pledgeability: ∅	Performance: ↓ Pledgeability: ∅
Technology space	Performance: ∅ Pledgeability: ∅	Performance: ∅ Pledgeability: ↓

Notes: This table summarizes the established impacts of green activities on neighbouring firms not engaged in said activity.

Table 6: Bank perspective – Green presence & brown riskiness/collateral value

	Bank assessed firm riskiness				Collateral value		
Panel A: Innovation							
	PD up_{ibt}	Provision up_{ibt}	PD down_{ibt}	Provision down_{ibt}	Financials_{ict}	Real Estate_{ict}	Physical assets_{ict}
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
$\overline{\Delta x(i,t)}^{\mathcal{A}=\text{product innovator}}_{\mathcal{S}=\text{product space}}$	0.0429*	0.0732**	−0.0772*	−0.0050**	−0.0033	0.0000	0.0455
	(0.0238)	(0.0346)	(0.0397)	(0.0023)	(0.0284)	(0.0027)	(0.0340)
$\overline{\Delta x(i,t)}^{\mathcal{A}=\text{process innovator}}_{\mathcal{S}=\text{product space}}$	0.0370**	0.0357***	−0.0227**	0.0006	−0.0258	−0.0104	0.0672
	(0.0162)	(0.0134)	(0.0089)	(0.0046)	(0.0394)	(0.0392)	(0.0796)
$\overline{\Delta x(i,t)}^{\mathcal{A}=\text{product innovator}}_{\mathcal{S}=\text{technology space}}$	0.0120	0.0018	−0.0175	−0.0021	0.0003	0.0050	0.0116
	(0.0073)	(0.0103)	(0.0129)	(0.0022)	(0.0024)	(0.0036)	(0.0096)
$\overline{\Delta x(i,t)}^{\mathcal{A}=\text{process innovator}}_{\mathcal{S}=\text{technology space}}$	0.0109	−0.0233	0.0258	0.0050	0.0002	−0.0058	−0.0242*
	(0.0099)	(0.0216)	(0.0197)	(0.0033)	(0.0030)	(0.0049)	(0.0140)
Controls	Y	Y	Y	Y	Y	Y	Y
Sector × Time FE	4 digit	4 digit	4 digit	4 digit	3 digit	3 digit	3 digit
Location × Time FE	Y	Y	Y	Y	Y	Y	Y
Cluster-level	Firm	Firm	Firm	Firm	Firm	Firm	Firm
# Observations	77087	74948	79814	74948	14943	8394	3791
Adj. R^2	0.250	0.281	0.055	0.067	0.005	0.031	0.038
Panel B: Diffusion							
	Bank assessed firm riskiness				Collateral value		
	PD up_{ibt}	Provision up_{ibt}	PD down_{ibt}	Provision down_{ibt}	Financials_{ict}	Real Estate_{ict}	Physical assets_{ict}
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
$\overline{\Delta x(i,t)}^{\mathcal{A}=\text{green provider}}_{\mathcal{S}=\text{product space}}$	0.0001*	0.0019***	−0.0008	−0.0007**	−0.0011	0.0000	0.0007
	(0.0000)	(0.0007)	(0.0005)	(0.0003)	(0.0012)	(0.0000)	(0.0009)
$\overline{\Delta x(i,t)}^{\mathcal{A}=\text{green adopter}}_{\mathcal{S}=\text{product space}}$	0.0000*	0.0000**	−0.0004*	−0.0003	0.0006	−0.0004	0.0005
	(0.0000)	(0.0000)	(0.0002)	(0.0003)	(0.0006)	(0.0004)	(0.0007)
$\overline{\Delta x(i,t)}^{\mathcal{A}=\text{green provider}}_{\mathcal{S}=\text{technology space}}$	−0.0003	0.0003	0.0001	−0.0001	0.0004	0.0001	0.0001
	(0.0004)	(0.0003)	(0.0000)	(0.0001)	(0.0004)	(0.0001)	(0.0004)
$\overline{\Delta x(i,t)}^{\mathcal{A}=\text{green adopter}}_{\mathcal{S}=\text{technology space}}$	0.0000	0.0000	0.0000	0.0001	−0.0001	0.0000	−0.0003*
	(0.0002)	(0.0000)	(0.0000)	(0.0001)	(0.0002)	(0.0001)	(0.0002)
Controls	Y	Y	Y	Y	Y	Y	Y
Sector × Time FE	4 digit	4 digit	4 digit	4 digit	3 digit	3 digit	3 digit
Location × Time FE	Y	Y	Y	Y	Y	Y	Y
Cluster-level	Firm	Firm	Firm	Firm	Firm	Firm	Firm
# Observations	64031	59969	64436	62323	12321	4164	2790
Adj. R^2	0.100	0.028	0.0434	0.004	0.007	0.013	0.041

Notes: Panel A summarizes the impact of green process and product innovation on the riskiness/collateral value of firms that engage in neither of both activities. Panel B summarizes the impact of green product sales and green capital investment on the riskiness/collateral value of firms that engage in neither of both activities. The sample period runs from $2017 - 2019$. The unit of observation is the firm-bank-year level. Controls include lags of log(Assets_{it}), Leverage_{it}, log(Firm age_{it}), log(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. All specifications are estimated using linear probability routines. PD up_{ibt} is an indicator variable taking on 1 if PD_{ibt} goes up vis-a-vis last year (0 otherwise). PD down_{ibt} is an indicator variable taking on 1 if PD_{ibt} goes down vis-a-vis last year (0 otherwise). Provision up_{ibt} and Provision down_{ibt} are defined in a similar way. All other regressors and regressands and are defined in Table 1. *, ** 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	Autocorrelations $\rho(t,t-1)$	$\rho(t,t-2)$	$\rho(t,t-3)$
Legacy positions and market structure - By broad activities								
$\theta_{ibt}^{\mathcal{A}=\text{Green}}$	0.0210	0.0867	0.0001	0.0047	0.0394	0.9805	0.9734	0.9635
$Med(\boldsymbol{\theta}_{it}^{\mathcal{A}=\text{Green}})$	0.0151	0.0481	0.0001	0.0034	0.0323	0.9633	0.9540	0.9392
$Min(\boldsymbol{\theta}_{it}^{\mathcal{A}=\text{Green}})$	0.0074	0.0113	0.0000	0.0022	0.0253	0.7457	0.6058	0.4885
$\theta_{ibt}^{\mathcal{A}=\text{Innovation}}$	0.0090	0.0269	0.0000	0.0031	0.0222	0.9289	0.9125	0.8842
$Med(\boldsymbol{\theta}_{it}^{\mathcal{A}=\text{Innovation}})$	0.0072	0.0120	0.0000	0.0028	0.0182	0.7457	0.6058	0.4885
$Min(\boldsymbol{\theta}_{it}^{\mathcal{A}=\text{Innovation}})$	0.0054	0.0102	0.0000	0.0017	0.0130	0.7345	0.6521	0.5024
$\theta_{ibt}^{\mathcal{A}=\text{Diffusion}}$	0.0212	0.0872	0.0001	0.0048	0.0396	0.9806	0.9735	0.9636
$Med(\boldsymbol{\theta}_{it}^{\mathcal{A}=\text{Diffusion}})$	0.0152	0.0491	0.0001	0.0034	0.0323	0.7345	0.6521	0.5024
$Min(\boldsymbol{\theta}_{it}^{\mathcal{A}=\text{Diffusion}})$	0.0074	0.0113	0.0000	0.0022	0.0253	0.7461	0.6053	0.4885
Legacy positions and market structure - By narrow activities								
$\theta_{ibt}^{\mathcal{A}=\text{Process innovation}}$	0.0107	0.0312	0.0001	0.0040	0.0269	0.9428	0.9275	0.9037
$Med(\boldsymbol{\theta}_{it}^{\mathcal{A}=\text{Process innovation}})$	0.0074	0.0129	0.0000	0.0027	0.0184	0.7461	0.6053	0.4885
$Min(\boldsymbol{\theta}_{it}^{\mathcal{A}=\text{Process innovation}})$	0.0060	0.0114	0.0000	0.0020	0.0110	0.6842	0.4284	0.3806
$\theta_{ibt}^{\mathcal{A}=\text{Product innovation}}$	0.0042	0.0086	0.0000	0.0010	0.0123	0.4422	0.3921	0.3062
$Med(\boldsymbol{\theta}_{it}^{\mathcal{A}=\text{Product innovation}})$	0.0013	0.0046	0.0000	0.0000	0.0030	0.6842	0.4284	0.3806
$Min(\boldsymbol{\theta}_{it}^{\mathcal{A}=\text{Product innovation}})$	0.0016	0.0033	0.0000	0.0002	0.0056	0.5202	0.3677	0.1408
$\theta_{ibt}^{\mathcal{A}=\text{Adoption}}$	0.0256	0.0968	0.0002	0.0073	0.0447	0.9822	0.9761	0.9652
$Med(\boldsymbol{\theta}_{it}^{\mathcal{A}=\text{Adoption}})$	0.0206	0.0769	0.0001	0.0048	0.0361	0.5202	0.3677	0.1408
$Min(\boldsymbol{\theta}_{it}^{\mathcal{A}=\text{Adoption}})$	0.0092	0.0176	0.0001	0.0034	0.0275	0.6775	0.5597	0.3947
$\theta_{ibt}^{\mathcal{A}=\text{Provision}}$	0.0040	0.0237	0.0000	0.0007	0.0095	0.7657	0.7579	0.8445
$Med(\boldsymbol{\theta}_{it}^{\mathcal{A}=\text{Provision}})$	0.0031	0.0107	0.0000	0.0005	0.0077	0.6775	0.5597	0.3947
$Min(\boldsymbol{\theta}_{it}^{\mathcal{A}=\text{Provision}})$	0.0023	0.0053	0.0000	0.0004	0.0063	0.5600	0.3981	0.3268
Legacy positions and market structure - By externality								
$\theta_{ibt}^{\mathcal{E}=\text{Pledgeability}}$	0.0115	0.0798	0.0000	0.0012	0.0131	0.9496	0.9434	0.9228
$Med(\boldsymbol{\theta}_{it}^{\mathcal{E}=\text{Pledgeability}})$	0.0103	0.0660	0.0000	0.0008	0.0113	0.5600	0.3981	0.3268
$Min(\boldsymbol{\theta}_{it}^{\mathcal{E}=\text{Pledgeability}})$	0.0029	0.0123	0.0000	0.0006	0.0083	0.6238	0.5287	0.3329
$\theta_{ibt}^{\mathcal{E}=\text{Performance}}$	0.0211	0.0807	0.0000	0.0042	0.0404	0.9633	0.9540	0.9392
$Med(\boldsymbol{\theta}_{it}^{\mathcal{E}=\text{Performance}})$	0.0154	0.0545	0.0000	0.0021	0.0322	0.6238	0.5287	0.3329
$Min(\boldsymbol{\theta}_{it}^{\mathcal{E}=\text{Performance}})$	0.0075	0.0119	0.0000	0.0017	0.0261	0.7646	0.6167	0.5018
Borrowing metrics								
Borrower$_{it}$	0.7475	0.4344	0	1	1			
Δ ln(Credit$_{ibt}$)	0.0399	0.4078	-0.3811	-0.0001	0.5629			

Notes: Descriptive statistics. Legacy positions are bound between 0 and 1 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)
Estimation sample:	Brown Firms + Green Firms	Brown Firms + Green Firms	Brown Firms + Green Firms	Brown Firms + Green Firms
Green_i	-0.026^{***}	-0.024^{***}		
	(0.004)	(0.002)		
Green innovator_i			-0.035^{**}	-0.042^{***}
			(0.015)	(0.014)
Green diffusor_i			-0.027^{***}	-0.025^{***}
			(0.002)	(0.002)
$Med(\boldsymbol{\theta}_{it-1}^{\mathcal{A}=\text{Green}})$		-0.997^{***}		
		(0.251)		
$Min(\boldsymbol{\theta}_{it-1}^{\mathcal{A}=\text{Green}})$		-0.212^{***}		
		(0.068)		
$Med(\boldsymbol{\theta}_{it-1}^{\mathcal{A}=\text{Innovator}})$				-7.517^{***}
				(2.794)
$Min(\boldsymbol{\theta}_{it-1}^{\mathcal{A}=\text{Innovator}})$				-10.274^{**}
				(4.713)
$Med(\boldsymbol{\theta}_{it-1}^{\mathcal{A}=\text{Diffusor}})$				-0.186^{***}
				(0.042)
$Min(\boldsymbol{\theta}_{it-1}^{\mathcal{A}=\text{Diffusor}})$				-0.941^{***}
				(0.184)
$\mathcal{A}$: Green				
Legacy effect		-0.003		
Market structure effect		0.006		
$\mathcal{A}$: Innovator				
Legacy effect				-0.059
Market structure effect				0.053
$\mathcal{A}$: Diffusor				
Legacy effect				-0.005
Market structure effect				0.005
Controls	Y	Y	Y	Y
Sector FE × Time FE	Y	Y	Y	Y
Location FE × Time FE	Y	Y	Y	Y
Cluster	Firm	Firm	Firm	Firm
# Clusters	90749	90749	90749	90749
# Observations	502067	502067	502067	502067
Adj. R^2	0.164	0.164	0.164	0.161

Notes: The unit of observation is the firm-year-level. The sample period runs from $2008 - 2018$ and contains both brown and green firms. Controls include lags of $\ln(\text{Assets}_{it})$, Leverage_{it}, $\ln(\text{Firm age}_{it})$, $\ln(\text{Capital age}_{it})$, Group_{it}, $\text{Negative equity}_{it}$, ROA_{it}, $\text{ROA volatility}_{it}$, Intangibles_{it}, Patenter_i, $\text{Public equity}_{it}$ and Public debt_{it} as defined in Table 1. All specifications are estimated using linear probability routines. 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 for activities

	Dependent variable: $Borrower_{it}$					
	(1)	(2)	(3)	(4)	(5)	(6)
Estimation sample:	Brown Firms + Process innovators	Brown Firms + Product innovators	Brown Firms + Process & product innovators	Brown Firms + Providers	Brown Firms + Adopters	Brown Firms + Providers & adopters
Process $innovator_i$	-0.074^{***}		-0.079^{***}			
	(0.029)		(0.021)			
Product $innovator_i$		-0.062^{**}	-0.038^{*}			
		(0.026)	(0.023)			
$Provider_i$				-0.029^{***}		-0.019^{***}
				(0.006)		(0.006)
$Adopter_i$					-0.026^{***}	-0.019^{***}
					(0.004)	(0.004)
$Med(\boldsymbol{\theta}_{it-1}^{\mathcal{A}=\text{Process innovation}})$	-7.343^{***}		-4.651^{**}			
	(2.115)		(2.197)			
$Min(\boldsymbol{\theta}_{it-1}^{\mathcal{A}=\text{Process innovation}})$	-11.209^{**}		-5.868^{**}			
	(5.006)		(2.709)			
$Med(\boldsymbol{\theta}_{it-1}^{\mathcal{A}=\text{Product innovation}})$		-32.282^{***}	-12.059^{**}			
		(9.961)	(5.334)			
$Min(\boldsymbol{\theta}_{it-1}^{\mathcal{A}=\text{Product innovation}})$		-38.524^{*}	-11.354			
		(21.156)	(13.431)			
$Med(\boldsymbol{\theta}_{it-1}^{\mathcal{A}=\text{Provision}})$				-0.506^{*}		-0.528^{**}
				(0.265)		(0.248)
$Min(\boldsymbol{\theta}_{it-1}^{\mathcal{A}=\text{Provision}})$				-2.374^{**}		-2.624^{***}
				(0.993)		(0.992)
$Med(\boldsymbol{\theta}_{it-1}^{\mathcal{A}=\text{Adoption}})$					-0.183^{**}	-0.170^{*}
					(0.089)	(0.089)
$Min(\boldsymbol{\theta}_{it-1}^{\mathcal{A}=\text{Adoption}})$					-0.619^{***}	-0.648^{***}
					(0.206)	(0.212)
$\mathcal{A}$: Process innovator						
Legacy effect	-0.083		-0.050			
Market structure effect	0.073		0.038			
$\mathcal{A}$: Product innovator						
Legacy effect		-0.083	-0.041			
Market structure effect		0.034	0.022			
$\mathcal{A}$: Provider						
Legacy effect				-0.007		-0.004
Market structure effect				0.005		0.006
$\mathcal{A}$: Adopter						
Legacy effect					-0.009	-0.009
Market structure effect					0.005	0.005
Controls	Y	Y	Y	Y	Y	Y
Sector FE × Time FE	Y	Y	Y	Y	Y	Y
Location FE × Time FE	Y	Y	Y	Y	Y	Y
Cluster	Firm	Firm	Firm	Firm	Firm	Firm
# Clusters	80523	80514	10320	83774	88081	90668
# Observations	440338	440296	440345	460000	486015	501625
Adj. R^2	0.166	0.166	0.166	0.165	0.166	0.164

Notes: The unit of observation is the firm-year-level. The sample period runs from $2008 - 2018$ and contains both brown and green firms. Controls include lags of $\ln(\text{Assets}_{it})$, Leverage_{it}, $\ln(\text{Firm age}_{it})$, $\ln(\text{Capital age}_{it})$, Group_{it}, Negative equity_{it}, ROA_{it}, ROA volatility_{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. 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: granular results per externality

	Dependent variable: Borrower_{it}		
	(1)	(2)	(3)
Performance_i	-0.024***		-0.029***
	(0.002)		(0.004)
Pledgeability_i		-0.021***	0.006
		(0.002)	(0.004)
$Med(\boldsymbol{\theta}_{it-1}^{\mathcal{S}=\text{Performance}})$	-0.133*		-0.341*
	(0.071)		(0.187)
$Min(\boldsymbol{\theta}_{it-1}^{\mathcal{S}=\text{Performance}})$	-2.075***		-2.422***
	(0.538)		(0.598)
$Med(\boldsymbol{\theta}_{it-1}^{\mathcal{S}=\text{Pledgeability}})$		-0.137**	0.395
		(0.064)	(0.243)
$Min(\boldsymbol{\theta}_{it-1}^{\mathcal{S}=\text{Pledgeability}})$		-0.830***	0.502
		(0.286)	(0.402)
$\mathcal{E}$: Performance			
Legacy effect	-0.002		-0.003
Market structure effect	0.005		0.006
$\mathcal{E}$: Pledgeability			
Legacy effect		-0.004	-0.008
Market structure effect		0.005	0.003
Controls	Y	Y	Y
Sector FE × Time FE	Y	Y	Y
Location FE × Time FE	Y	Y	Y
Cluster	Firm	Firm	Firm
# Clusters	90749	90749	90749
# Observations	502067	502067	502067
$Adj.\ R^2$	0.161	0.164	0.161
] $Adj.\ R^2$	0.161	0.164	0.161

Notes: The unit of observation is the firm-year-level. The sample period runs from $2008-2018$ and contains both brown and green firms. Controls include lags of $\ln(\text{Assets}_{it})$, Leverage_{it}, $\ln(\text{Firm age}_{it})$, $\ln(\text{Capital age}_{it})$, Group_{it}, Negative equity_{it}, ROA_{it}, ROA volatility_{it}, Intangibles_{it}, Patenter_i, Public equity_{it} and Public debt_{it} as defined in Table 1. The reported regressors and regressand and are defined in Table 1. All specifications are estimated using linear probability routines. Standard errors, reported in parentheses, are clustered at the firm–level. *, ** and *** denote significance at the 10%, 5% and 1% level, respectively.

Table 11: Rationing extensive margin: residual maturity of legacy positions

	Dependent variable: Borrower_{it}		
covariate		covariate	
Green_i	-0.015^{***}	Green innovator_i	-0.071^{**}
	(0.004)		(0.030)
$Med(\boldsymbol{\theta}_{it-1}^{A=\text{Green}}; LT)$	-0.244^{**}	Green diffusor_i	-0.017^{***}
	(0.114)		(0.004)
$Min(\boldsymbol{\theta}_{it-1}^{A=\text{Green}}; LT)$	-2.411^{***}	$Med(\boldsymbol{\theta}_{it-1}^{A=\text{Innovator}}; LT)$	-39.083^{***}
	(0.640)		(14.421)
$Med(\boldsymbol{\theta}_{it-1}^{A=\text{Green}}; ST)$	-1.297	$Min(\boldsymbol{\theta}_{it-1}^{A=\text{Innovator}}; LT)$	-36.839^{**}
	(1.086)		(16.658)
$Min(\boldsymbol{\theta}_{it-1}^{A=\text{Green}}; ST)$	-1.024	$Med(\boldsymbol{\theta}_{it-1}^{A=\text{Innovator}}; ST)$	-19.195
	(1.802)		(66.554)
		$Min(\boldsymbol{\theta}_{it-1}^{A=\text{Innovator}}; ST)$	-52.029
			(94.959)
		$Med(\boldsymbol{\theta}_{it-1}^{A=\text{Diffusor}}; LT)$	-0.222^{*}
			(0.114)
		$Min(\boldsymbol{\theta}_{it-1}^{A=\text{Diffusor}}; LT)$	-2.348^{***}
			(0.640)
		$Med(\boldsymbol{\theta}_{it-1}^{A=\text{Diffusor}}; ST)$	-1.266
			(1.095)
		$Min(\boldsymbol{\theta}_{it-1}^{A=\text{Diffusor}}; ST)$	-1.128
			(1.826)
Controls	Y		Y
Sector FE × Time FE	Y		Y
Location FE × Time FE	Y		Y
Cluster	Firm		Firm
# Clusters	85988		85988
# Observations	297991		297991
Adj. R^2	0.147		0.147

Notes: The unit of observation is the firm-year-level. The sample period runs from $2008-2018$ and contains both brown and green firms. Controls include lags of $\ln(\text{Assets}_{it})$, Leverage_{it}, $\ln(\text{Firm age}_{it})$, $\ln(\text{Capital age}_{it})$, Group_{it}, $\text{Negative equity}_{it}$, ROA_{it}, $\text{ROA volatility}_{it}$, Intangibles_{it}, Patenter_i, $\text{Public equity}_{it}$ and Public debt_{it} as defined in Table 1. The reported regressors and regressand and are defined in Table 1. All specifications are estimated using linear probability routines. The Belgian CCR only reports information on maturities as of 2012, which explains the drop in observations. Standard errors, reported in parentheses, are clustered at the firm–level. *, ** and *** denote significance at the 10%, 5% and 1% level, respectively.

Table 12: Rationing extensive margin: weighted baseline results

Dependent variable: Borrower_{it}	(1)	(2)
Green_i	-0.021^{***}	
	(0.004)	
Green innovator_i		-0.047^{***}
		(0.015)
Green diffusor_i		-0.023^{***}
		(0.002)
$Med(\boldsymbol{\theta}_{it-1}^{\mathcal{A}=\text{Green}})$	-5.796^{***}	
	(0.710)	
$Min(\boldsymbol{\theta}_{it-1}^{\mathcal{A}=\text{Green}})$	-12.918^{***}	
	(2.763)	
$Med(\boldsymbol{\theta}_{it-1}^{\mathcal{A}=\text{innovator}})$		-99.214^{**}
		(44.596)
$Min(\boldsymbol{\theta}_{it-1}^{\mathcal{A}=\text{innovator}})$		-197.171^{***}
		(66.658)
$Med(\boldsymbol{\theta}_{it-1}^{\mathcal{A}=\text{diffusor}})$		-99.214^{**}
		(44.596)
$Min(\boldsymbol{\theta}_{it-1}^{\mathcal{A}=\text{diffusor}})$		-197.171^{***}
		(66.658)
$Med(\boldsymbol{\theta}_{it-1}^{\mathcal{A}=\text{Green}}) \times log(\text{Assets}_{it-1})$	-0.373^{***}	
	(0.048)	
$Min(\boldsymbol{\theta}_{it-1}^{\mathcal{A}=\text{Green}}) \times log(\text{Assets}_{it-1})$	-0.806^{***}	
	(0.189)	
$Med(\boldsymbol{\theta}_{it-1}^{\mathcal{A}=\text{innovator}}) \times log(\text{Assets}_{it-1})$		-7.043^{**}
		(2.929)
$Min(\boldsymbol{\theta}_{it-1}^{\mathcal{A}=\text{innovator}}) \times log(\text{Assets}_{it-1})$		-13.887^{***}
		(4.417)
$Med(\boldsymbol{\theta}_{it-1}^{\mathcal{A}=\text{diffusor}}) \times log(\text{Assets}_{it-1})$		-7.043^{**}
		(2.929)
$Min(\boldsymbol{\theta}_{it-1}^{\mathcal{A}=\text{diffusor}}) \times log(\text{Assets}_{it-1})$		-13.887^{***}
		(4.417)
Controls	Y	Y
Sector FE × Time FE	Y	Y
Location FE × Time FE	Y	Y
Cluster	Firm	Firm
# Clusters	90749	90749
# Observations	502067	502067
Adj. R^2	0.165	0.165

Notes: The unit of observation is the firm-year-level. The sample period runs from $2008 - 2018$ and contains both brown and green firms. Controls include lags of $\ln(\text{Assets}_{it})$, Leverage_{it}, $\ln(\text{Firm age}_{it})$, $\ln(\text{Capital age}_{it})$, Group_{it}, $\text{Negative equity}_{it}$, ROA_{it}, $\text{ROA volatility}_{it}$, Intangibles_{it}, Patenter_i, $\text{Public equity}_{it}$ and Public debt_{it} as defined in Table 1. The reported regressors and regressand and are defined in Table 1. All specifications are estimated using linear probability routines. Standard errors, reported in parentheses, are clustered at the firm–level. *, ** and *** denote significance at the 10%, 5% and 1% level, respectively.

Table 13: Rationing extensive margin: who is breaking the barrier?

	Dependent variable: Borrower_{ibt}					
	(1)	(2)	(3)	(4)	(5)	(6)
Estimation sample:	$\text{Green}_i = 1$		$\text{Innovation}_i = 1$		$\text{Diffusor}_i = 1$	
$\theta_{ibt-1}^{\mathcal{A}=\text{Green}}$	-0.721^{***}	-0.940^{***}				
	(0.160)	(0.146)				
$\iota_t(b = \arg\min_b(\boldsymbol{\theta}_{it-1}^{\mathcal{A}=\text{Green}}))$		0.130^{***}				
		(0.024)				
$\iota_t(b = \arg\max_b(\boldsymbol{\theta}_{it-1}^{\mathcal{A}=\text{Green}}))$		-0.016				
		(0.020)				
$\theta_{ibt-1}^{\mathcal{A}=\text{Innovation}}$			-2.620	-8.143		
			(2.490)	(5.022)		
$\iota_t(b = \arg\min_b(\boldsymbol{\theta}_{it-1}^{\mathcal{A}=\text{Innovation}}))$				0.262^{***}		
				(0.090)		
$\iota_t(b = \arg\max_b(\boldsymbol{\theta}_{it-1}^{\mathcal{A}=\text{Innovation}}))$				0.065		
				(0.130)		
$\theta_{ibt-1}^{\mathcal{A}=\text{Diffusion}}$					-0.725^{***}	-0.935^{***}
					(0.159)	(0.146)
$\iota_t(b = \arg\min_b(\boldsymbol{\theta}_{it-1}^{\mathcal{A}=\text{Diffusion}}))$						0.130^{***}
						(0.024)
$\iota_t(b = \arg\max_b(\boldsymbol{\theta}_{it-1}^{\mathcal{A}=\text{Diffusion}}))$						-0.011
						(0.020)
Sector FE × Time FE	4-digit	4-digit	1-digit	1-digit	4-digit	4-digit
Location FE × Time FE	Y	Y	Y	Y	Y	Y
Cluster	Y	Y	Y	Y	Y	Y
# Clusters	871	871	26	26	859	859
# Observations	4434	4434	122	122	4339	4339
Adj. R^2	0.154	0.168	0.229	0.285	0.154	0.168

Notes: The unit of observation is the firm-bank-year-level and are restricted to the first year in which the firm received a credit line. The sample period runs from 2008 − 2018. $Borrower_{ibt}$ is a dummy taking on value 1 if bank b lend to firms i at time t. $Borrower_{ibt} = 0$(zero otherwise). $\iota_t(b = \arg\min_b(\boldsymbol{\theta}_{it-1}^{\mathcal{A}=\text{Green}}))$ is an indicator function value taking the value 1 if bank b has the smallest legacy position at risk (to firm i's activity) in the banking sector (zero otherwise). $\iota_t(b = \arg\max_b(\boldsymbol{\theta}_{it-1}^{\mathcal{A}=\text{Green}}))$ is an indicator function value taking the value 1 if bank b has the largest legacy position at risk (to firm i's activity) in the banking sector (zero otherwise). *, ** and *** denote significance at the 10%, 5% and 1% level, respectively.

Table 14: Rationing intensive margin: baseline results

	Dependent variable: Δ ln(Credit$_{ibt}$)		
	(1)	(2)	(3)
Estimation sample:	Green	Innovators	Diffusors
$\Delta\theta^{\mathcal{A}=\text{Green}}_{ibt-1}$	0.120		
	(0.147)		
$\Delta Min(\boldsymbol{\theta}^{\mathcal{A}=\text{Green}}_{it-1})$	-0.060^{***}		
	(0.010)		
$\Delta\theta^{\mathcal{A}=\text{Innovator}}_{ibt-1}$		-1.792	
		(1.748)	
$\Delta Min(\boldsymbol{\theta}^{\mathcal{A}=\text{Innovator}}_{it-1})$		-0.141^{**}	
		(0.068)	
$\Delta\theta^{\mathcal{A}=\text{Diffusor}}_{ibt-1}$			-0.006
			(0.302)
$\Delta Min(\boldsymbol{\theta}^{\mathcal{A}=\text{Diffusor}}_{it-1})$			-0.062^{***}
			(0.010)
$\mathcal{A}$: Green			
Δ Market structure effect	-0.061		
$\mathcal{A}$: Innovator			
Δ Market structure effect		-0.037	
$\mathcal{A}$: Diffusor			
Δ Market structure effect			-0.061
Controls	Y	Y	Y
Bank × Time FE	Y	Y	Y
Loc. ×Sect. × Size × Time FE	Y	Y	Y
Location	Region	Region	Region
Assets	Decile	Decile	Decile
Sector	3 digits	2 digits	3 digits
Cluster	Firm	Firm	Firm
# Clusters	10533	300	10143
# Observations	120238	3262	117012
Adj. R^2	0.003	0.002	0.004

Notes: 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) and location–sector–size fixed effects (to control for firm–level credit demand) as in Degryse et al. (2019). 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

Hans Degryse, Tarik Roukny, Joris Tielens

Appendix

A Procedure to distinguish product & process innovations

This section provides details on our procedure to classify patents between product and 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 claimed by the invention and what is sought to be protected. It carefully stipulates what subject-matter the patent does – and does not – cover. 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 brewing process, resulting in a reduction of water consumption and carbon emissions.

2. Patent: WO 2018/215888 Al, owned by Rietland – a firm offering 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 CCMT technologies, 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. Our procedure consists of importing all available claims associated with a patent's family (in all languages possible). Patents can be filed in multiple offices. Patents associated with the same originating inventor and innovation belong to the same patent family. Because of irregularities in their reporting, not all patents have claims directly associated to them. Parsing through the entire family-related patents allows to expand to scope of claims collection. In the minority of case where claims cannot be recovered from our import, we turn to a textual analysis of the abstract of the patent.

For each patent, we first treat each claim by filtering off non-alpha terms and tokenising, 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' treated vector. Figure A.1 provides a full account of the dimensions of this sorting process.[38]

[38] Knowledge is typically fungible within a corporate group (Chang and Hong, 2000). Given our objective to document green externalities on other firms, we are especially interested in spillovers beyond the confinements of an individual group. We therefore map the greenness 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 invention, 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 neighbouring firms of the R&D entity.

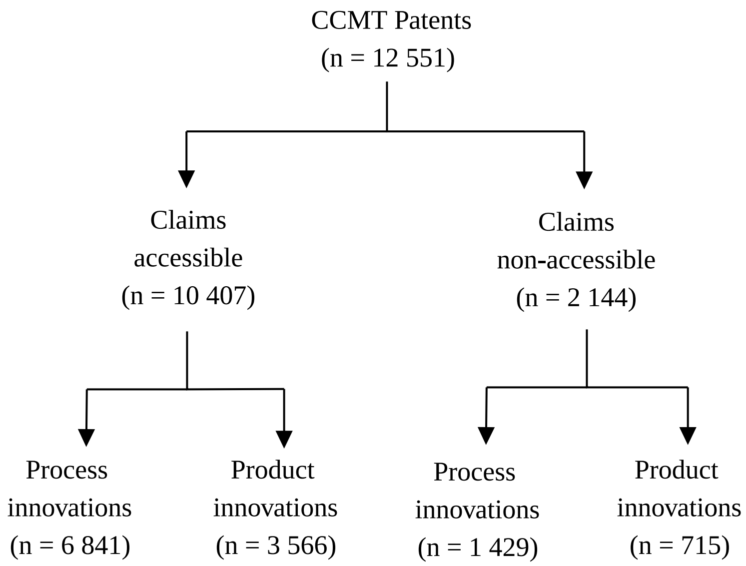

Figure A.1: Dimensions of the patent application text mining procedure.

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 innovator_i=1) if it has patented at least one green process innovation. A firm is tagged as a product innovator (Green product innovator_i=1) if it has patented at least one green process innovation.

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.2 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 gives 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 innovator$_i$	-0.031^{**}	-0.015^{***}	-0.061^{*}	-0.044
	(0.015)	(0.004)	(0.032)	(0.031)
Green product innovator$_i$	0.051	-0.041	-0.043	0.123
	(0.491)	(0.031)	(0.081)	(0.156)
Green adopter$_i$	-0.051^{**}	-0.061	-0.055^{***}	-0.024^{**}
	(0.025)	(0.041)	(0.020)	(0.010)
Green provider$_i$	-0.041	0.044	0.031	0.001
	(0.031)	(0.064)	(0.028)	(0.003)

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 telecommunications/mobility/etc. Results are for 2018.

Process innovations as marketable products. The analysis in the body of the text assumes that process innovations are not marketed (but implemented) by the innovating firm. Previous work, such as Bena et al. (2021); Bena and Simintzi (2019), make a similar assumption. To verify the validity of this assumption, we can use 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 file non-green patents, this statistic is be distorted (because the SBS does not focus on revenues from CCMPT IP). However such 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

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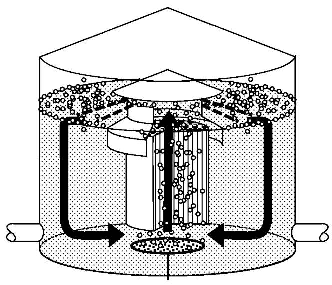
Title

(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.



(b)

FIG.3

EP 2 871 227 A1

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

Page 9 - AB Inbev patent application EP 2 871 227 A1

EP 2 871 227 A1

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,

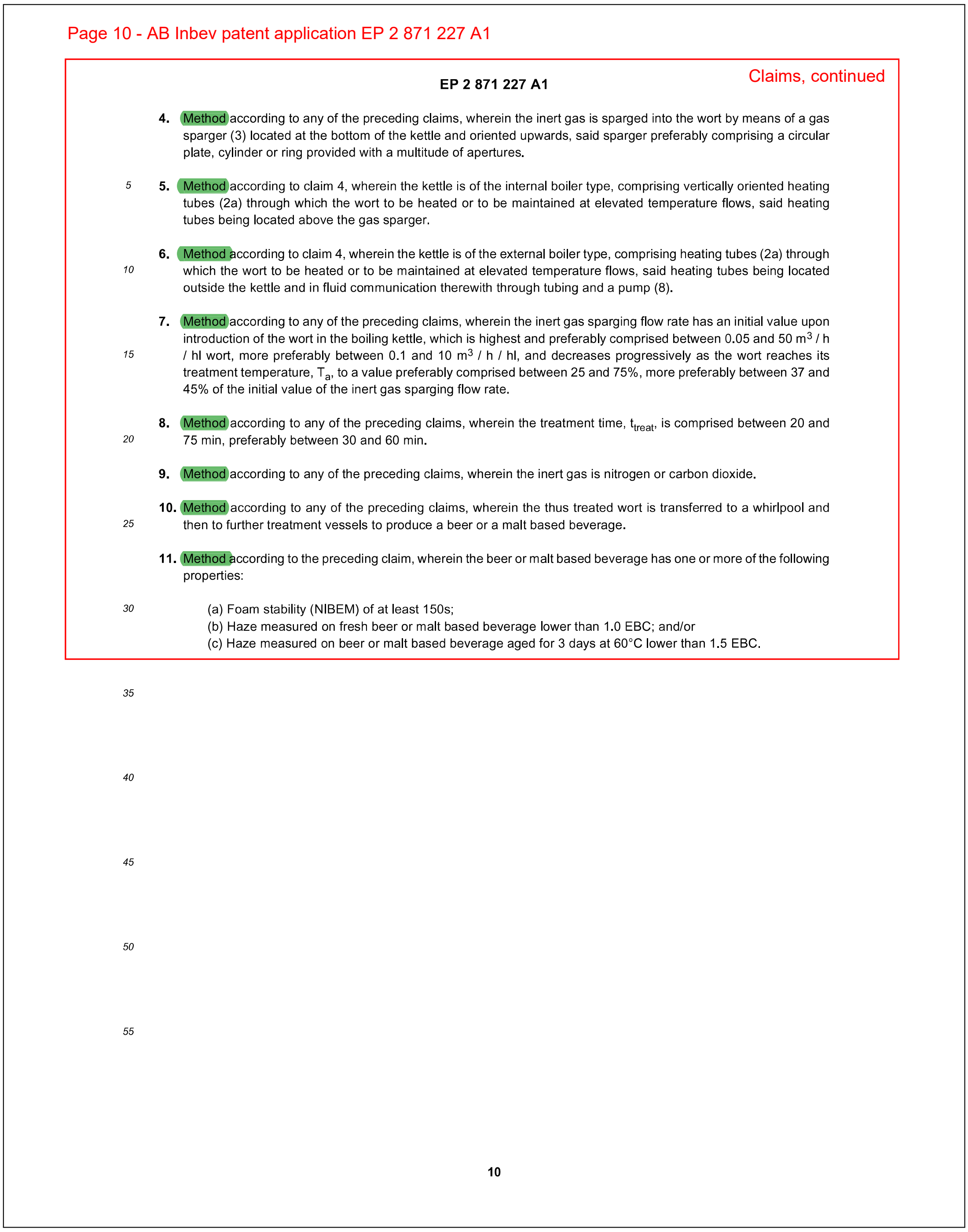
   (b) feeding wort from a lautering step into said boiling kettle through the inlet, said wort being at a temperature below its boiling temperature, T_b;
   (c) while sparging an inert gas through the wort, heating said wort to, and maintaining it at a treatment temperature, T_a, which is below the boiling 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.

9

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



Page 10 - AB Inbev patent application EP 2 871 227 A1

Claims, continued

EP 2 871 227 A1

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 innovation are highlighted in green.

Page 1 - Rietland patent application WO 2018/21588 A1

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Published:
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WO 2018/215888 A1

(54) **Title:** WATER PURIFICATION

Title

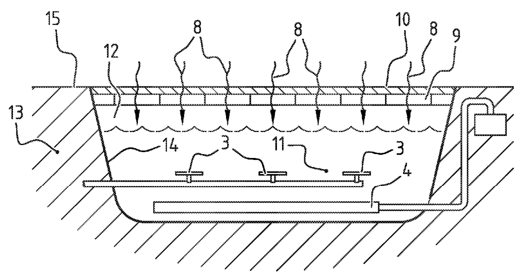


Fig. 2

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 innovation are highlighted in green.

Page 10 - Rietland patent application WO 2018/21588 A1

WO 2018/215888 PCT/IB2018/053423

10

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 innovation are highlighted in green.

B Additional results & Robustness

B.1 Covariates: measurement & interpretation

In this subsection we address three measurement/interpretation aspects of our covariates previously highlighted in Section 3. 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 $\overline{x(i,t)}^{\mathcal{A}=\text{Green}}_{\mathcal{S}=\text{product space}}$. From Leibniz's rule:

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

Where $\Delta(\cdot)$ is the first difference operator and Green_{jt} 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 already engaged in environmental activities. Components (b) and (c) reflected enhanced environmental exposure because (new) product market peers suddenly start to engage in environmental activities. In our baseline results, terms $(b)-(c)$ are 0 (as $\Delta\big(\text{Green}_{jt}\big)=0$).

B.1.1 Summand (a): Decomposition of changes in firm proximities.

Term (a) can be disentangled further as follows

$$\begin{aligned}M^{-1}\sum_{m=1}^{M}\sum_{j=1}^{J}\Delta\big(\Pi_{ijt-m}\big)\text{Green}_{jt} &= \underbrace{M^{-1}\sum_{m=1}^{M}\sum_{j=1}^{J}\Delta\big(\pi'_{it-m}\big)\pi_{jt-m}\text{Green}_{jt}}_{(a')} + \underbrace{M^{-1}\sum_{m=1}^{M}\sum_{j=1}^{J}\pi'_{it-m}\Delta\big(\pi_{jt-m}\big)\text{Green}_{jt}}_{(a'')}\\ &\quad + \underbrace{M^{-1}\sum_{m=1}^{M}\sum_{j=1}^{J}\Delta\big(\pi'_{it-m}\big)\Delta\big(\pi_{jt-m}\big)\text{Green}_{jt}}_{(a''')}\end{aligned}$$

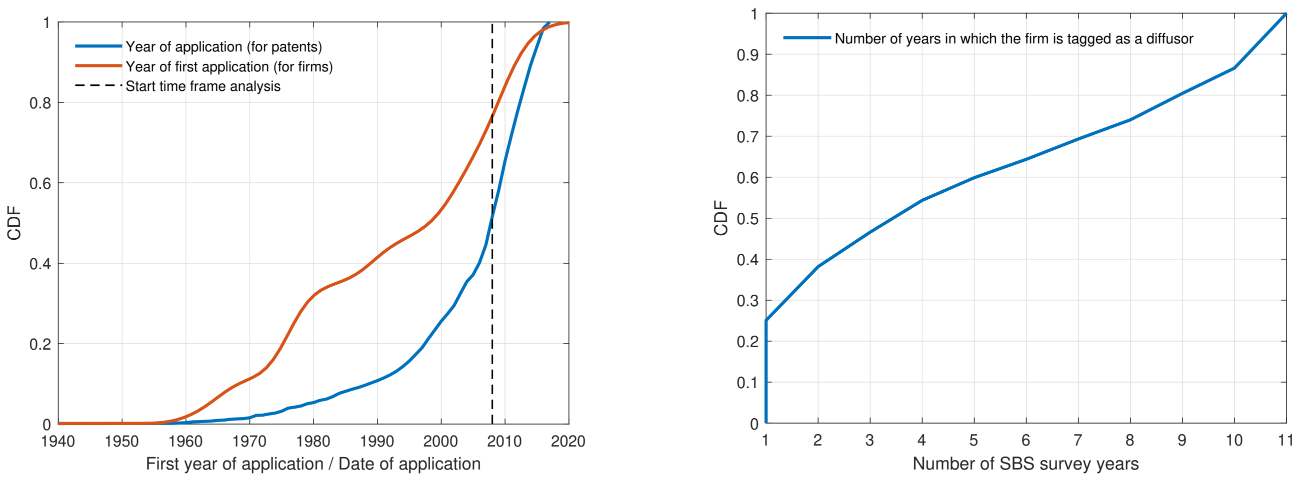
where (a') reflects entry of brown firm i into the product space of green firm j (keeping constant the output market composition of j), (a'') captures entry of green firm j in the product space of brown firm i (keeping constant the output market composition of firm i) and (a''') quantifies a joint movement of brown firm i and green firm j into markets previously unserved 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, available upon request, reflect that, once we tease out the movement of green firms to brown firm, the size of the externalities become stronger and tighter identified.

B.1.2 Summand $(b) - (c)$: Decomposition in changes in firm green activities.

The baseline estimates intentionally do no account for time variation in the definition of Innovation$_i$. Although PATSTAT would allow us to identify the event where a firm becomes an environmental innovator (e.g. year of first application of a CCMT patent), such variation is small in our data. Figure A.4 documents that by 2008 (the starting period of our analysis), already 80% of our set of innovators has filed at least one CCMT patent. Half way through our sample, this is true for 95% of the identified innovators. Moreover, given that the patent application lags behind the actual innovation activities, a static approach seems prefered.

If CCMT patenting is infrequent, a static approach, raises the concern that the environmental innovation activity was a one–off event, falsely inflating the green identify of firms. Figure A.4 however documents that environmental innovators are very active throughout our sample periods: 50% of all CCMT patents are applied for during our sample period.



(a) Innovation: PATSTAT (b) Diffusion: SBS survey

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

Similarly, there is intentionally no time variation in our definition of Green provider$_i$ and Green adopter$_i$. The unbalanced panel set-up of the SBS survey makes it impossible to identify any 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 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: 60% of all firms that report a non–zero fraction of green sales and investments in a particular survey-year have a nonzero green share in 5 years of the SBS survey, suggesting that little time variation would exist in the ideal set-up of a fully balanced panel.

B.1.3 Summand $(a) - (c)$: Falsification test based on noisy proximity measures

The calibration of the product and technology space closeness relies on a level of granularity. Taking a more aggregated view makes these measures less informative. Table A.2 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.

Table A.2: Firm perspective – green presence & brown firm performance/pledgeability

	Firm performance				Tangible asset pledeability	
Panel A: Innovation						
	Δ ln (HH sales$_{it}$)	Δ ln (B2B sales$_{it}$)	Δ ln (B2B customers$_{it}$)	Lost B2B$_{it}$	Writedowns$_{it}$	Liquid. loss$_{it}$
	(1)	(2)	(3)	(4)	(5)	(6)
$\overline{\Delta x(i,t)}^{\mathcal{A}=\text{product innovator}}_{\mathcal{S}=\text{product space}}$	0.0000	−0.0001	0.0000*	0.0000	1.0015	1.0015
	(0.0000)	(0.0001)	(0.0000)	(0.0000)	(0.0021)	(0.0015)
$\overline{\Delta x(i,t)}^{\mathcal{A}=\text{process innovation}}_{\mathcal{S}=\text{product space}}$	−0.0001	−0.0001	0.0000	−0.0003	1.0054	1.0000
	(0.0003)	(0.0001)	(0.0000)	(0.0002)	(0.0093)	(0.0000)
$\overline{\Delta x(i,t)}^{\mathcal{A}=\text{product innovation}}_{\mathcal{S}=\text{technology space}}$	0.0001	0.0001	0.0000	0.0001	0.9998	0.9999
	(0.0001)	(0.0001)	(0.0000)	(0.0001)	(0.0004)	(0.0001)
$\overline{\Delta x(i,t)}^{\mathcal{A}=\text{process innovation}}_{\mathcal{S}=\text{technology space}}$	0.0000	0.0000	0.0003	0.0001	0.9914	1.0122
	(0.0000)	(0.0000)	(0.0008)	(0.0003)	(0.0070)	(0.0084)
Sector × Time FE	4 digit	4 digit	4 digit	4 digit	3 digit	3 digit
Location × Time FE	Y	Y	Y	Y	Y	Y
Firm FE	Y	Y	Y	Y	N	N
Cluster-level	Firm	Firm	Firm	Firm	Firm	Firm
# Clusters	74991	85518	85518	85518	16836	18557
# Observations	428171	526007	526007	526007	77134	33954
Panel B: Diffusion						
	Firm performance				Tangible asset pledeability	
	Δ ln (HH sales$_{it}$)	Δ ln (B2B sales$_{it}$)	Δ ln (B2B customers$_{it}$)	Lost B2B$_{it}$	Writedowns$_{it}$	Liquid. loss$_{it}$
	(1)	(2)	(3)	(4)	(5)	(6)
$\overline{\Delta x(i,t)}^{\mathcal{A}=\text{green provider}}_{\mathcal{S}=\text{product space}}$	0.0000	−0.0001	0.0000	0.0000	1.0015	1.0015
	(0.0000)	(0.0001)	(0.0000)	(0.0000)	(0.0078)	(0.0015)
$\overline{\Delta x(i,t)}^{\mathcal{A}=\text{green adopter}}_{\mathcal{S}=\text{product space}}$	0.0001	−0.0002	0.0000	−0.0003	1.0054	1.0000
	(0.0003)	(0.0002)	(0.0000)	(0.0004)	(0.0121)	(0.0000)
$\overline{\Delta x(i,t)}^{\mathcal{A}=\text{green provider}}_{\mathcal{S}=\text{technology space}}$	0.0002	0.0001	0.0000	0.0001	0.9998	0.9999
	(0.0001)	(0.0001)	(0.0000)	(0.0005)	(0.0004)	(0.0001)
$\overline{\Delta x(i,t)}^{\mathcal{A}=\text{green adopter}}_{\mathcal{S}=\text{technology space}}$	0.0000	0.0000	0.0003	0.0001	0.9914	1.0122
	(0.0001)	(0.0000)	(0.0004)	(0.0002)	(0.0070)	(0.0084)
Sector × Time FE	4 digit	4 digit	4 digit	4 digit	3 digit	3 digit
Location × Time FE	Y	Y	Y	Y	Y	Y
Firm FE	Y	Y	Y	Y	N	N
Cluster-level	Firm	Firm	Firm	Firm	Firm	Firm
# Clusters	64287	74169	74169	74169	11030	13360
# Observations	360255	453353	453353	453353	47743	20857

Notes: See notes of Table 4. The sector disaggregation underlying the covariates are based on the 2-digit level.

B.1.4 Rationing & firm size

Table A.3: Rationing intensive margin: baseline results for granular activities

	Dependent variable: Δ ln(Credit$_{ibt}$)			
	Innovators		Diffusors	
Estimation sample:	Process innovators	Product innovators	Providers	Investors
	(1)	(2)	(3)	(4)
$Med(\boldsymbol{\theta}_{it-1}^{A=\text{Process innovator}})$	-2.5571			
	(2.126)			
$Min(\boldsymbol{\theta}_{it-1}^{A=\text{Process innovator}})$	-0.1511			
	(0.072)			
$Med(\boldsymbol{\theta}_{it-1}^{A=\text{Product innovator}})$		-2.411		
		(1.597)		
$Min(\boldsymbol{\theta}_{it-1}^{A=\text{Product innovator}})$		-0.113		
		(0.050)		
$Med(\boldsymbol{\theta}_{it-1}^{A=\text{Adopter}})$			0.029	
			(0.313)	
$Min(\boldsymbol{\theta}_{it-1}^{A=\text{Adopter}})$			-0.052	
			(0.012)	
$Med(\boldsymbol{\theta}_{it-1}^{A=\text{Provider}})$				0.336
				(0.586)
$Min(\boldsymbol{\theta}_{it-1}^{A=\text{Provider}})$				-0.102^{***}
				(0.015)
Controls	Y	Y	Y	Y
Bank × Time FE	Y	Y	Y	Y
Loc. ×Sect. × Size × Time FE	Y	Y	Y	Y
Location	Region	Region	Region	Region
Assets	Assets	Assets	Assets	Assets
Sector	2 digit	2 digit	3 digit	3 digit
Cluster	Firm	Firm	Firm	Firm
Firm				
# Clusters	564	117	8019	4211
# Observations	5469	1312	92446	52951
Adj. R^2	0.001	0.001	0.013	0.030

Notes: 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) and location–sector–size fixed effects (to control for firm–level credit demand) as in Degryse et al. (2019). 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.

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