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# Managerial and Financial Barriers to the Net-Zero Transition

Ralph De Haas\*, Ralf Martin†, Mirabelle Muûls‡ and Helena Schweiger§

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## Abstract

We use data on 11,233 firms across 22 emerging markets to analyze how credit constraints and low-quality firm management inhibit corporate investment in green technologies. For identification we exploit quasi-exogenous variation in local credit conditions and in exposure to weather shocks. Our results suggest that both financial frictions and managerial constraints slow down firm investment in more energy efficient and less polluting technologies. Complementary analysis of data from the European Pollutant Release and Transfer Register (E-PRTR) corroborates some of this evidence by revealing that in areas where banks deleveraged more after the global financial crisis, industrial facilities reduced their carbon emissions by less. On aggregate this kept local emissions 15% above the level they would have been in the absence of financial frictions.

**JEL classification:** D22, L23, G32, L20, Q52, Q53

**Keywords:** Financial frictions, management practices, CO<sub>2</sub> emissions, energy efficiency

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# 1 Introduction

The severe impact that climate change will have on future generations is becoming increasingly clear. Droughts, extreme temperatures, floods, and storms all cause substantial human and financial losses in the short term and ecological and economic costs in the longer run (Cavallo et al., 2013; Felbermayr and Gröschl, 2014). There now exists incontrovertible evidence that carbon emissions from industrial production are the principal cause of climate change (IPCC, 2019; Nordhaus, 2019). In the absence of technologies to remove carbon dioxide from the biosphere, mitigating climate change therefore requires a drastic reduction of carbon emissions (Pacala and Socolow, 2004).

For this reason, and in line with commitments under the Paris Climate Agreement, many countries aim to produce zero net greenhouse gas emissions by 2050 at the latest. This green transition requires large-scale corporate investment in cleaner technologies to reduce firms' carbon footprint. Yet, even if such green investments are optimal from a societal point of view, they may not be cost-effective from the perspective of individual firms. And even if they are, organizational constraints—of either a financial or managerial nature—can prevent firms from investing in green technologies that would benefit them. Firms not only differ in their ability to access external funding, they also differ widely in terms of their management quality in general (Bloom and Van Reenen, 2007) and their green management practices in particular (Martin, Muûls, de Preux and Wagner, 2012). Those with better access to external funding and those with stronger green management may then invest more in energy-efficient manufacturing technologies and, as a result, cut greenhouse gas emissions more drastically as well.

Against this background, we exploit data on a representative sample of 11,233 firms across 22 emerging markets to analyze how credit and managerial constraints can hold back corporate investment in the abatement of greenhouse gas emissions. Such firm-level constraints may hamper green investments in poor countries in particular. A lack of external finance (Aghion et al., 2005; Bircan and De Haas, 2020), deficient management practices (Bloom et al., 2013), and misaligned incentives within the firm (Atkin et al., 2017) have all been shown to impede technological adoption in the developing world. This is worrying because nearly all of the growth in energy demand and greenhouse gas emissions over the next three decades will come from emerging markets and developing countries (Wolfram et al., 2012). Green investments to reduce the carbon intensity of

firm production are therefore most urgently needed in the poorest parts of the world.

Our data come from unique face-to-face surveys with firm managers. These surveys give us access to information on firms' credit constraints and on their organizational response to climate change in the form of green management practices and green investments. In terms of green management, we collect standardized data on firms' strategic objectives concerning the environment and climate change; whether there is a manager with an explicit mandate to deal with environmental issues; and how the firm sets and monitors targets (if any) related to energy and water usage, CO<sub>2</sub> emissions, and other pollutants. In terms of green investments, we collect data on investments in machinery upgrades; vehicle upgrades; heating, cooling and lighting improvements; the on-site generation of green energy; waste minimization, recycling and waste management; improvements in energy and water management; and measures to control air or other pollution or to increase the energy efficiency of production lines.

We take two complementary approaches to identify the causal effect of credit and managerial constraints on firms' green investments. First, we control for a rich set of firm-level covariates that might otherwise confound the relation between organizational constraints and green investments. Second, we develop a three-pronged instrumentation strategy to isolate the plausibly exogenous component of firm-level constraints. We first construct leave-one-out jackknife instruments that reflect the managerial and credit constraints experienced by other firms in the same country and region except for those in the same 2-digit industry. Second, we combine our firm-level data with precise geo-coded information on the bank branches that surround each individual firm. This allows us to create granular proxies for exogenous differences in local credit conditions in the aftermath of the global financial crisis. Third, we measure firm managers' exposure to extreme weather events during the period 2000-15. We then use these instruments to allow for a causal interpretation of the observed relationship between firms' credit and managerial constraints, on the one hand, and their green investment activity, on the other. Our IV results indicate that both credit constraints and weak management slow down firms' investments in green and carbon abatement technologies. To our knowledge, our paper is the first to explicitly show this link.

If credit constraints and low-quality green management practices prevent firms from investing in greener (more energy efficient) production processes, then one might expect that—perhaps with some delay—they also slow down firms' ability to reduce the emission of greenhouse gases and other

pollutants. We investigate this issue in the second part of the paper, using European Pollutant Release and Transfer Register (E-PRTR) data on the change in greenhouse gas emissions and other air pollutants of a large number of Eastern European industrial facilities.

We use two approaches to uncover the relationship between credit constraints and the quality of green management on the one hand, and air pollution on the other. Our first approach uses the first stage of our earlier IV framework to construct average predicted values of the credit constraints and managerial capabilities in the direct vicinity of E-PRTR facilities. We document a positive (negative) relationship between regional credit constraints (management quality) and the emission of air pollutants.

Our second approach is a difference-in-differences design in which we again exploit exogenous variation in local credit conditions in the aftermath of the global financial crisis. Consistent with our earlier results, we find that although there was a secular decline in carbon emissions during the post-crisis decade, this decline was smaller in localities where banks had to deleverage more. That is, credit constraints not only slowed firms' green investments but they consequently also had a tangible negative impact on firms' ability to produce in a less polluting way. We thus provide evidence for an important channel through which persistent negative environmental impacts of financial crises may come about, namely credit constraints preventing firms from investing in measures that reduce carbon emissions.

Our empirical analysis allows us to contribute to, and to connect, three strands of the literature. First, we provide new insights into the determinants of corporate investment in carbon abatement and energy efficiency.<sup>1</sup> Because low-carbon technologies generate large environmental (and hence social) returns while private profitability is often unclear, managerial adoption decisions may differ from those of regular technologies. Empirical evidence on the diffusion of low-carbon technologies is scarce (Burke et al., 2016) and we shed light on the comparative role of management and access to finance in this regard. Bloom, Genakos, Martin and Sadun (2010) measure management practices in over 300 manufacturing firms in the UK. They find that better managed firms are not only more productive overall but also less energy and carbon intensive. Martin, Muûls, de Preux and Wagner

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<sup>1</sup>Hottenrott, Rexhauser and Veugelers (2016) provide an overview of the literature on the determinants of firm investment in green technologies while Cagno, Worrell, Trianni and Pugliese (2013) propose a taxonomy of barriers to industrial energy efficiency improvement. The adoption of energy efficient technologies remains low (Allcott and Greenstone, 2012). As a result, as much as 44 percent of all reductions in global emissions by 2040 could come from energy efficiency gains (International Energy Agency, 2017).

(2012) find similar results using a measure of specifically “green” management practices. One interpretation of these results is that well-managed firms adopt modern manufacturing practices, which allows them to increase productivity by using energy more efficiently.<sup>2</sup> Our contribution is to provide direct evidence, based on a large cross-country firm-level data set, for a key mechanism through which managerial constraints limit energy efficiency improvements in production: the reduced incidence of investments in green technologies and carbon abatement.

Second, we provide micro evidence on how credit constraints hold back investments in carbon abatement. Credit constrained firms cannot finance all economically viable projects available to them, but instead need to allocate scarce funding to the projects with the highest expected net present value. Earlier evidence shows that credit constraints matter and are responsible for reduced investment even in advanced economies with well-developed capital markets (Almeida and Campello, 2007; Campello, Graham and Harvey, 2010; Duchin, Ozbas and Sensoy, 2010). Because environmental investments often entail large upfront expenditures and have an uncertain cost-savings potential, financially constrained firms may instead prioritize investments in core activities.<sup>3</sup> This may occur in particular in firms with weaker green management where managers are more biased against investments outside the main business activities.<sup>4</sup>

Related empirical work on the U.S. has shown a negative relationship between credit availability and firm pollution, without actually observing firms’ green investments as an intermediary step in the hypothesized causal chain. In particular, Levine, Lin, Wang and Xie (2018) show how positive credit supply shocks in U.S. counties—due to fracking of shale oil in other counties—reduce local air pollution. In a similar vein, Goetz (2019) finds that financially constrained firms reduced toxic emissions when their capital cost decreased as a result of the U.S. Maturity Extension Program. Lastly, Cohn and Deryugina (2018) document a negative relationship between U.S. firms’

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<sup>2</sup>Such firms may be better informed about the costs and benefits of energy efficiency improvements and suffer less from present-biased preferences in which managers focus too much on upfront costs and too little on future recurring energy savings (Allcott, Mullainathan and Taubinsky, 2014).

<sup>3</sup>In line with this, Howell (2017) shows that firms that receive grant funding from the U.S. Small Business Innovation Research Program generate more revenue and patent more (compared with similar but unsuccessful applicants). These effects are largest for financially constrained firms and those in sectors related to clean energy and energy efficiency.

<sup>4</sup>When the cost of external capital is high, and investments in emissions reductions therefore expensive, firms that are forced by environmental regulation to reduce carbon emissions may respond by moving their polluting activities elsewhere instead of by investing in cleaner production. Bartram, Hou and Kim (2019) show how financially constrained firms in California responded to the introduction of a state-level cap-and-trade program by shifting emissions to their plants in other states.



contemporaneous and lagged cash flow and the occurrence of environmental spills. Our contribution is to provide direct evidence, for a large sample of emerging markets, for an important underlying mechanism: credit constraints reduce firms’ investments in pollution abatement.

Third, we offer fresh evidence on the real economic consequences of financial crises. On the one hand, episodes of dysfunction in the financial system can cut back pollution in the short term simply because economic activity and energy usage decline (Sheldon, 2017; De Haas and Popov, 2019). Moreover, if crises mainly force inferior-technology and energy-inefficient firms to exit the market, then the energy efficiency of the average surviving firm will improve.<sup>5</sup> On the other hand, longer-term impacts will be less benign if firms deprioritize adhering to environmental standards and postpone or cancel investments in cleaner technologies (Peters et al., 2012).<sup>6</sup> Indeed, Pacca, Antonarakis, Schroder and Antoniadis (2020) argue that financial crises may be “one step forward, two steps back for air quality”. Our findings are clearly at odds with an environmentally cleansing effect of financial crises. Instead, our analysis of rich cross-country micro-data shows how temporary disruptions in the supply of external finance have long-lasting negative implications for the carbon intensity of manufacturing.

The remainder of this paper is organized as follows. Section 2 discusses our empirical approach after which Section 3 describes the data. Section 4 then provides our empirical results and Section 5 concludes.

## 2 Empirical methodology

### 2.1 OLS estimation

We start our analysis of the link between credit constraints, management practices and green investment by estimating the following OLS regression:

$$Y_{isc} = \beta_0 + \beta_1 CreditConstrained_{isc} + \beta_2 GreenManagement_{isc} + \gamma' \mathbf{X}_{isc} + \xi_c + \zeta_s + \epsilon_{isc} \quad (1)$$

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<sup>5</sup>This cleansing effect (Caballero and Hammour, 1994) will be smaller if some high-productivity firms also fall victim to credit constraints (Osotimehin and Pappada, 2015).

<sup>6</sup>An extensive literature shows how financial crises, and the associated reduction in bank lending, tighten corporate credit constraints and reduce investment in R&D and fixed assets (Campello, Graham and Harvey, 2010; Duchin, Ozbas and Sensoy, 2010; Nanda and Nicholas, 2014; Beck, Degryse, De Haas and Van Horen, 2018).

where  $Y_{isc}$  is an indicator equal to 1 if firm  $i$  in sector  $s$  and country  $c$  made a recent green investment and 0 otherwise. Our data allow us to distinguish between various types of green investments (see Section 3.1.3). Our main independent variables of interest are *Credit Constrained*, an indicator for whether the firm is credit constrained or not (see Section 3.1.1), and *Green Management*, a z-score measuring the quality of green management practices (see Section 3.1.2). The vector  $\mathbf{X}_{isc}$  comprises three types of control variables. First, we include firm characteristics such as exporter status, age, stock exchange listing, sole proprietorship, and whether the firm has audited financial accounts.<sup>7</sup> Second, we use variables on the credit market conditions in the vicinity of each firm. We measure this using characteristics of the bank branches that fall within a 15 km radius of a firm,<sup>8</sup> in particular the number of branches and the amount of assets held by banks owning those branches. Third, we include other locality characteristics, such as the population size class. We take the city or town where a firm is located as the relevant locational unit  $l$ .  $\xi_c$  and  $\zeta_s$  are country and sector fixed effects.<sup>9</sup> In all regressions, we cluster errors at the locality level  $l$ . Appendix Table A1 contains all variable definitions.

## 2.2 IV estimation

While our control variables absorb a range of potential confounders, we cannot rule out all mechanisms that could bias  $\beta_1$  or  $\beta_2$ . For example, past (clean) investments could influence green management practices or credit constraints. Banks might take a more favorable view of an investment project irrespective of its specific merits if the firm has successfully delivered a project in the recent past. Alternatively, they might consider that the company could overstretch and hence take a less favorable view. Investment in environmental technologies—for example, more sophisticated monitoring—could facilitate the adoption of green management practices such as environmental target setting. To strengthen causal identification, we develop an IV strategy to deal with such concerns. This strategy rests on the assumption that a firm’s local environment provides a source of exogenous variation that affects firm outcomes only via financing or (green) managerial quality.

In the case of credit constraints, we observe that many firms—in particular small and medium-

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<sup>7</sup>Some of these firm characteristics, such as exporter status, may themselves be influenced by whether a firm is credit constrained or by the quality of its green management and therefore be “bad controls”. When we exclude all firm-level covariates in a robustness test, our OLS and IV results remain qualitatively unchanged.

<sup>8</sup>We explore variations to this radius in robustness tests.

<sup>9</sup>Results are very similar when we replace country and sector fixed effects with country  $\times$  sector fixed effects.

sized ones —rely on banks in their vicinity. That is, the banking landscape near firms imposes an exogenous geographical limitation on the banks that firms have access to (Berger, Miller, Petersen, Rajan and Stein, 2005).<sup>10</sup> We can then use variation in those banks’ capital availability as a plausibly exogenous driver of financing constraints of firms. More specifically, we look at the change in nearby banks’ Tier 1 ratio. The Tier 1 ratio relates a bank’s core equity capital to its risk-weighted assets. During and after the global financial crisis, and in particular after the 2011 regulatory stress tests by the European Banking Authority, many banks had to improve their regulatory capital ratio within a short period of time. Since raising additional equity was costly due to the difficult situation in the global capital markets, many banks deleveraged by shrinking their risk-weighted assets, including through cuts in lending (Gropp et al., 2019).

The intensity of deleveraging across Emerging Europe varied significantly across banks—even within the same country. Our instrument captures the idea that firms that were surrounded by branches of banks that had to boost their Tier 1 ratio more during the crisis found it more difficult to access bank credit. These firms were more exposed to credit rationing in which banks decline to fund some investment projects that are indistinguishable from other projects they *do* finance (Stiglitz and Weiss, 1981).<sup>11</sup> We therefore expect a positive relationship between the average local increase in banks’ Tier 1 ratio and the likelihood that nearby firms were credit constrained.

To create the instrument  $\Delta Tier1$ , we combine information on the geographic coordinates of both firms and the bank branches that surround them.  $\Delta Tier1$  then captures the average change in the regulatory capital (Tier 1) ratio over the period 2007 (just before the global financial crisis) to 2014 (after both the global financial crisis and the subsequent Eurozone crisis) for all banks in a firm’s vicinity (defined as a circle with a 15 km radius).

Second, to instrument *Green Management* we assume that management practices are (at least in part) a form of intangible capital (Bloom et al., 2016). Local access to this form of capital is determined by knowledge diffusion which varies from area to area. One important factor that

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<sup>10</sup>International evidence shows that due to agency costs, small and medium-sized enterprises can only access nearby banks. For example, the median Belgian SME borrower in Degryse and Ongena (2005) was located 2.5 km from the lending bank branch. In the US data of Petersen and Rajan (1994) and Agarwal and Hauswald (2010), the corresponding median distances were 3.7 km and 4.2 km, respectively. One might argue that the change in Tier 1 ratio instrument is correlated with geographical remoteness because for some reason, banks with branches in more remote locations would have had a lower regulatory capital ratio prior to the financial crisis. We therefore control for locality size in all regressions.

<sup>11</sup>In line with this idea, Popov and Udell (2012) show how firms in localities with financially weaker foreign banks had greater difficulty in accessing credit during the crisis.

can focus managers’ attention to green management practices is the experience of extreme weather events. The increasing severity and frequency of such events is one of the consequences of global warming.<sup>12</sup> Building on earlier literature, such as Herrnstadt and Muehlegger (2014) and Ranson (2014), we expect that managers who themselves (repeatedly) experience extreme weather events, or are informed about such events in their region,<sup>13</sup> are more likely to be concerned about climate change and the environment and will therefore be more amenable to green management practices. To measure variation in managerial exposure to extreme weather, we use granular data on extreme weather events and their geo-location, as taken from the European Severe Weather Database. The resulting instrumental variable, *Extreme Weather*, is the log of the number of extreme weather events that occurred within a 200 km radius of firm  $i$  during the period 2000-15.

Third, we include two additional instruments: the average credit constraint indicator and the average green management z-score of all other firms in the same region. Again, this is motivated by both credit constraints and management practices being determined by local credit market conditions and the local diffusion of management practices. However, to be of use as instruments we also need to assume that an individual firm has only a negligible influence on those regional averages. To ensure that this is likely the case, we compute regional averages excluding observations from a firm’s own sector (2-digit)  $s(i)$ . This is similar to the “leave-one-out” strategy pursued for instance in “jackknife” approaches (Angrist et al., 1999).<sup>14</sup> Hence we compute

$$CreditConstrainedL1O_{isc} = \frac{1}{\#} \sum_{j.s.t.s(j) \neq s(i) \& r(j)=r(i)} CreditConstrained_j$$

and

$$GreenManagementL1O_{isc} = \frac{1}{\#} \sum_{j.s.t.s(j) \neq s(i) \& r(j)=r(i)} GreenManagement_j$$

Consequently, our 2SLS framework comprises the first-stage equations

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<sup>12</sup>There are many examples in the literature of weather-related variables being used as instruments. See, for example, Cachon et al. (2019) and, for a critical discussion, Mellon (2020).

<sup>13</sup>A region is defined as the stratification region used in the Enterprise Surveys. In most countries, these are NUTS (EU nomenclature of territorial units for statistics) regions at the level 1, 2 or 3.

<sup>14</sup>Similar approaches have been used in a number of other studies including Fisman and Svensson (2007), Aterido et al. (2011), and Commander and Svejnar (2011).

$$\begin{aligned}
\Xi_{isc} &= \delta_0 + \delta_1 \textit{CreditConstrainedL1O}_{isc} + \delta_2 \Delta \textit{Tier1}_{isc} \\
&+ \delta_3 \textit{GreenManagementL1O}_{isc} + \delta_4 \textit{ExtremeWeather}_{isc} \\
&+ \gamma' \mathbf{X}_{isc} + \xi_c + \zeta_s + \epsilon_{isc}
\end{aligned} \tag{2}$$

for  $\Xi \in \{\textit{CreditConstrained}, \textit{GreenManagement}\}$ ; and the second-stage equation

$$\begin{aligned}
Y_{isc} &= \delta_0 + \delta_1 \widehat{\textit{CreditConstrained}}_{isc} + \delta_2 \widehat{\textit{GreenManagement}}_{isc} \\
&+ \gamma' \mathbf{X}_{isc} + \xi_c + \zeta_s + \epsilon_{isc}
\end{aligned} \tag{3}$$

where the instrumental variables are as detailed above, and other variables are as described for the OLS estimation Equation (1).

### 3 Data

The implementation of our identification strategy rests on matching three important pieces of information: (i) data from the EBRD-EIB-WB Enterprise Surveys about firms' credit constraints, green management and green investments; (ii) information on the exact location of bank branches from the EBRD Banking Environment and Performance Survey II as well as data on banks' funding structure from Bureau van Dijk's ORBIS database, and (iii) data on extreme weather events.

#### 3.1 Firm-level data

We use the Enterprise Surveys to measure the incidence of credit constraints as well as firms' management practices and green investments. The surveys took place between October 2018 and August 2020 and covered almost 28,000 enterprises in 41 economies. We focus on a sample of 22 countries in Emerging Europe and Central Asia, where 13,353 enterprises were interviewed.<sup>15</sup> They involved face-to-face interviews with the owner or main manager of registered firms with at least five employees. Eligible firms were selected using stratified random sampling. The strata were

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<sup>15</sup>The sample we use in this paper consists of the 11,233 enterprises with non-missing values for all the required variables. Its breakdown by country is presented in Table A2 in the Appendix and summary statistics for all our survey-based variables are presented in Table A3.

sector (manufacturing, retail and other services), size (5-19, 20-99 and 100+ employees) and regions within a country. The main purpose of the survey is to examine the quality of the local business environment in terms of, for example, infrastructure, labor, and business-government relations. It also collects basic information on the firm such as its age, size, and geographic coordinates.

Importantly, the most recent Enterprise Surveys included a new Green Economy module. This unique module gathered information on key aspects of firm behavior related to the environment and climate change, including green management practices and green investments. In most economies, the response rate for the Green Economy module was over 95 per cent. We thus have a representative snapshot—stratified by sector, firm size, and region—of firms’ green credentials in each of these countries.

### **3.1.1 Credit constraints**

By combining answers to various survey questions, we first distinguish between firms with and without a demand for credit. Among the former, we then identify those that were *Credit Constrained* as those that were either discouraged from applying for a loan or were rejected when they applied. Non-credit constrained firms are those that either had no need for credit or whose demand for credit was satisfied.<sup>16</sup>

### **3.1.2 Green management practices**

The unique Green Economy Module contained in the Enterprise Surveys asked firms in considerable detail about their green management practices in four areas. The first area concerns a question about whether firms have strategic objectives related to the environment and climate change. The second area looks at whether firms employ a manager with an explicit mandate to deal with green issues. Conditional on the existence of such an environmental manager, additional information was collected on whom they report to, as well as whether their performance is evaluated against how well the establishment performs on energy consumption, CO<sub>2</sub> emissions or other pollution or

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<sup>16</sup>We start by using the question: “Did the establishment apply for any loans or lines of credit in the last fiscal year?” For firms that answered “No”, we move to the question: “What was the main reason the establishment did not apply for any line of credit or loan in the last fiscal year?” Firms that answered “Yes”, were asked: “In the last fiscal year, did this establishment apply for any new loans or new credit lines that were rejected?” We classify firms that applied for credit and received a loan as unconstrained while we classify firms as credit constrained if they were either rejected or discouraged from applying due to “Interest rates are not favorable”; “Collateral requirements are too high”; “Size of loan and maturity are insufficient”; or “Did not think it would be approved”.

environmental targets.<sup>17</sup> The third area covered by the Green Economy Module asks whether firms have clear and attainable environmental targets. Lastly, the fourth area looks at whether firms actively and frequently monitor their energy and water usage, as well as CO<sub>2</sub> emissions and other pollutants, in order to reduce their environmental footprint.<sup>18</sup>

All in all, 18.3 per cent of firms in our sample have strategic objectives relating to the environment or climate change. However, this average masks large differences between countries. For instance, only 7.4 per cent of all Turkish firms have such strategic objectives, compared with more than 3 out of 10 Slovak firms. A total of 12.8 per cent of firms in the countries in our sample have a manager responsible for environmental and climate change-related issues, with that figure ranging from 3 per cent in Azerbaijan to 22.9 per cent in the Czech Republic. Just over half of these managers are evaluated against how well the firm performs on environmental targets. 59 per cent of these managers report directly to the CEO, Board or owners; 31 per cent to a manager reporting directly to the CEO, Board or owners; and the rest to a manager not reporting directly to the CEO, Board or owners.

When it comes to energy consumption monitoring, just over 60 per cent of firms in our sample do so. About 1 in 6 firms report emitting CO<sub>2</sub> over the last three years and less than half of them monitored these emissions. Of the 9.5 per cent of firms that reported emitting pollutants other than CO<sub>2</sub>, almost three quarters monitored them. More than a quarter of firms had energy consumption targets, ranging from 6.7 per cent in Azerbaijan to 48 per cent in Serbia. Only 5.8 per cent of firms had CO<sub>2</sub> targets, while 7.7 per cent of firms had targets for pollution emissions other than CO<sub>2</sub>.

We normalize the scores for each question such that they have a mean of 0 and a standard deviation of 1 in the sample. We then aggregate them to average z-scores for each of the four areas of green management. Lastly, we create an overall green management z-score as a normalised unweighted average of the four areas. A z-score above zero indicates that a firm's management practices are better than the sample average.

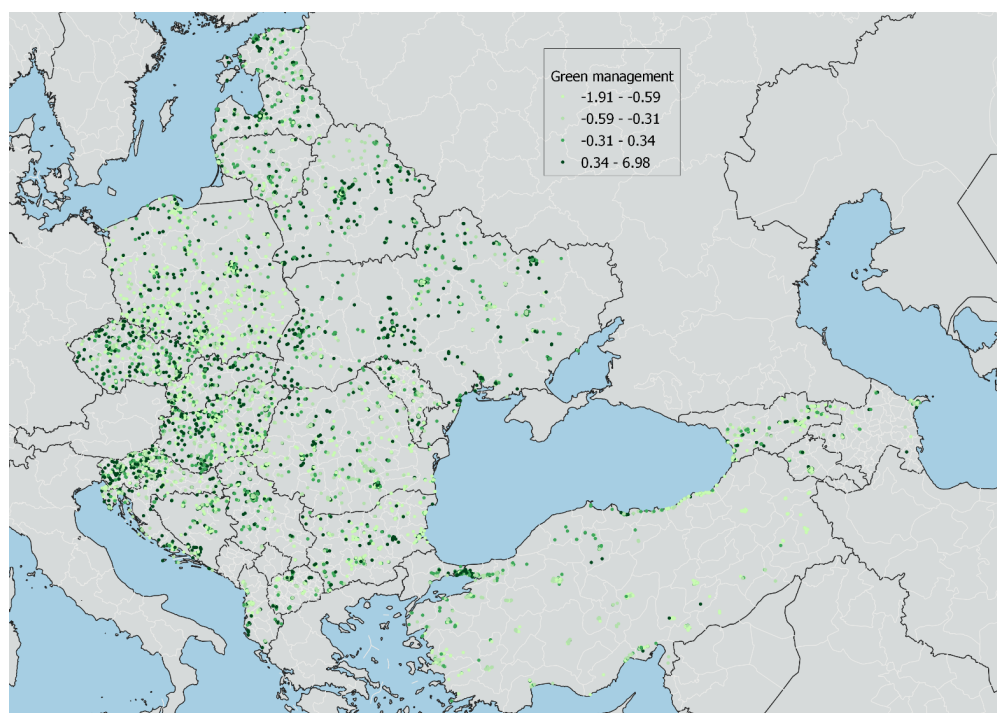
Although there are substantial differences across countries in terms of the average quality of

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<sup>17</sup>Earlier research suggests that the link between a firm's strategic environmental objectives and its day-to-day actions depends crucially on its organisational structure. The closer the person with environmental responsibilities is to the firm's most senior manager, the more they are able to solve problems and overcome ill-defined incentives (Martin, Muùls, de Preux and Wagner, 2012).

<sup>18</sup>Energy use is a key source of greenhouse gas emissions. Others include physical and chemical processing and the transportation of materials, products, waste, and employees.

Figure 1: Geographical Distribution of Firms and the Quality of their Green Management



*Notes:* This map shows the geographical distribution of the 11,233 firms that make up the sample used in Tables 1 and 2. Each dot represents one or several firms in a locality. Darker green colors indicate higher-quality green management. Green management is measured as a z-score based on four areas of green management practices: strategic objectives related to the environment and climate change; whether the firm has a manager with an explicit mandate to deal with green issues, who this manager reports to and whether their performance is evaluated against the establishment's environmental performance; environmental targets; and monitoring of energy and water usage, CO<sub>2</sub> and other pollutant emissions. *Source:* EBRD-WBG-EIB Enterprise Surveys.

green management, most of the variation (91 per cent) is found *within* economies, even after accounting for cross-country differences in sectoral composition. Figure 1 shows that there are firms with low and high green management scores in every economy. This is the granular within-country variation that we will exploit in our empirical analysis.

### 3.1.3 Green investments

The Enterprise Surveys asked firms whether they made any of the following green investments in the last three years: machinery upgrades (*Machinery*); vehicle upgrades (*Vehicles*); improvements to heating, cooling and lighting systems (*Heat/cool/light*); on-site generation of green energy (*Green generation*); waste minimization, recycling and waste management (*Waste minimization*); energy and water management (*Energy/water management*); measures controlling air and other pollution (*Pollution control*); and energy efficiency measures (*Energy efficiency*).



Most of these investments explicitly target an increase in the firm’s energy efficiency and/or a reduction in pollution or other negative environmental impacts. However, some investment types—in particular machinery and vehicle upgrades—mainly have an environmental impact as a by-product of achieving other objectives. For instance, as innovation proceeds, new vintages of machinery and vehicles tend to be more energy efficient than the outdated models they replace. We consider both these direct and indirect types of investments as green ones.

### **3.1.4 Firm covariates**

Firm-level control variables include firm age and dummy variables for whether the firm is publicly listed, a sole proprietorship, an exporter, and whether an external auditor reviews its financial statements. We expect listed and audited firms (in other words, firms that are more transparent) to face fewer credit constraints (Beck et al., 2018).

## **3.2 Bank-level data**

In order to implement the IV strategy described in Section 2.2, as well as to control for local credit market conditions in both the OLS and IV estimation, we use detailed data about the banking sectors in our sample countries.

First of all, the geographical coordinates of 67,559 branches, operated by 609 banks across Emerging Europe, were collected by specialized consultants as part of the second round of the EBRD Banking Environment and Performance Survey (BEPS II). Data collection took place by contacting banks or by downloading data from bank websites. All information was double-checked with the banks as well as with the SNL Financial database. The 609 banks represented 96.5 per cent of all bank assets in these 22 countries in 2013, so that we have a near complete bank branch footprint. As described in Section 2.2, we connect the firm and branch data by drawing circles with a radius of 15 km around the coordinates of each firm and then linking the firm to all branches inside that circle.

For each branch we know the bank it belongs to. We merge this information with bank balance sheet information from Bureau Van Dijk’s (BvD) ORBIS database. We download information about each bank’s pre-financial crisis assets in 2007. For each firm we then first measure the number of bank branches within a 15 km radius. Second, we calculate the branch-weighted average

asset size of banks with branches within this radius. This allows us to control for the number and the size of the banks that make up the local credit market around each firm. The collected bank balance sheets also allow us to construct the Tier 1 ratio described in Section 2.2 as the ratio of a bank’s core equity capital to its total risk-weighted assets. It is calculated in 2007 and 2014 so as to measure, for each firm, the change between those two years in the average Tier 1 ratio of banks with branches within a 15 km radius (weighted by the number of bank branches).

### 3.3 Extreme weather events

In order to implement the IV approach described above, we use data from version 1.60 of the European Severe Weather Database (Dotzek et al., 2009).<sup>19</sup> This database collects information about “important weather events that can endanger people or do damage”. Reports of events can be made by weather services, associations or individuals, and each submission is processed by the European Severe Storms Laboratory or one of its partner organisations. Those events meeting the quality criteria are included in the database. We select all tornado, hail, wind, precipitation and snow extreme events reported between 2000 and 2015 in the countries covered by our survey. To compute the instrument described in Section 2.2, we count how many of these events occurred in a 200 km radius around each firm, and take the log of that value.

### 3.4 Descriptive statistics

Table A3 in the Appendix presents summary statistics. It reports that 76.3 per cent of firms made at least one type of green investment in the past three years. More than half of all firms made improvements to heating, cooling or lighting systems—making this the most common type of green investment. In contrast, only 12.5 per cent invested in green energy generation on site, possibly because such projects typically require very sizable investments. About a third of the firms adopted energy efficiency measures or invested in vehicle upgrades, energy or water management, or recycling and waste management. Only a fifth of all firms recently adopted air or other pollution control measures.

As for the explanatory variables, we find that almost a quarter of all firms are credit constrained (22.6 per cent). The standardized *Green Management* variable is by construction close to zero on

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<sup>19</sup>ESWD, European Weather Observer (<https://www.eswd.eu/ESWD/>)

average but varies considerably between -1.91 and 6.98. The table shows that all firms have at least one bank branch within a 15 km radius, which indicates the IV approach can be implemented. The change in local branch-weighted average Tier 1 ratio between 2007 and 2014, one of the variables we will use as an instrument, was on average 2.08 percentage points. All firms experienced extreme weather events within 200 km of their location, on average more than 500 of them in total between 2000 and 2015.<sup>20</sup> Variation between firms is again substantial.

## 4 Results

This section presents our OLS and IV baseline results regarding the impact of financial frictions and managerial constraints on firms' green investments. We then introduce additional data to explore the impact of credit constraints and management quality on pollution and greenhouse gas emissions.

### 4.1 OLS estimates

Panel A of Table 1 presents regression specifications based on Equation (1) to estimate the association between credit constraints, green management quality, and green investment. More specifically, we look at whether the firm made any type of green investment in the last three years. We then consider the different types of measures adopted or investments made. All regressions include firm-level controls, locality-level credit market controls, and country and sector fixed effects.

We find a significantly negative relationship between whether a firm is credit constrained and the likelihood that it makes a green investment (column 1). Credit constraints reduce the probability of the firm making at least one type of green investment over the past three years by 3.72 per cent. Conversely, the quality of green management is correlated positively and significantly with green investment. A one standard deviation increase in the quality of green management increases the probability of green investment by 8.52 per cent. While the magnitudes of these coefficients are not directly comparable, the "horse race" between financial and managerial constraints suggests that where the investment has at least some component related to reducing pollution or increasing energy efficiency, the quality of green management is the most important factor.

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<sup>20</sup>This is calculated as  $e^{6.243}$ , since the extreme weather variable in Table A3 is reported in logs.

Table 1: Firm-level Credit Constraints, Green Management, and Green Investments

| Dependent variable →   | [1]                    | [2]                    | [3]                    | [4]                    | [5]                    | [6]                    | [7]                    | [8]                   | [9]                   |
|------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|-----------------------|-----------------------|
| <b>Panel A: OLS</b>    |                        |                        |                        |                        |                        |                        |                        |                       |                       |
| Credit constrained     | -0.0372***<br>(0.0126) | -0.0556***<br>(0.0136) | -0.0623***<br>(0.0128) | -0.0490***<br>(0.0146) | -0.0257**<br>(0.0106)  | -0.0356***<br>(0.0130) | -0.0322***<br>(0.0112) | 0.0008<br>(0.0130)    | -0.0225*<br>(0.0131)  |
| Green management       | 0.0852***<br>(0.0047)  | 0.1078***<br>(0.0056)  | 0.0988***<br>(0.0060)  | 0.1183***<br>(0.0058)  | 0.0889***<br>(0.0066)  | 0.1240***<br>(0.0062)  | 0.1755***<br>(0.0050)  | 0.1558***<br>(0.0057) | 0.1623***<br>(0.0058) |
| R-squared              | 0.1432                 | 0.1679                 | 0.1569                 | 0.1841                 | 0.1271                 | 0.2141                 | 0.2515                 | 0.2279                | 0.2234                |
| <b>Panel B: IV</b>     |                        |                        |                        |                        |                        |                        |                        |                       |                       |
| Credit constrained     | -0.5931***<br>(0.1657) | -0.6705***<br>(0.1811) | -0.5278***<br>(0.1620) | -0.5229***<br>(0.1897) | -0.4788***<br>(0.1440) | -0.2710*<br>(0.1485)   | -0.2688**<br>(0.1289)  | -0.1872<br>(0.1436)   | 0.0280<br>(0.1275)    |
| Green management       | 0.3143***<br>(0.0471)  | 0.3084***<br>(0.0578)  | 0.2185***<br>(0.0479)  | 0.3245***<br>(0.0701)  | 0.1784***<br>(0.0518)  | 0.3791***<br>(0.0479)  | 0.4312***<br>(0.0438)  | 0.3789***<br>(0.0598) | 0.4160***<br>(0.0497) |
| Firm controls          | ✓                      | ✓                      | ✓                      | ✓                      | ✓                      | ✓                      | ✓                      | ✓                     | ✓                     |
| Credit market controls | ✓                      | ✓                      | ✓                      | ✓                      | ✓                      | ✓                      | ✓                      | ✓                     | ✓                     |
| Country FE             | ✓                      | ✓                      | ✓                      | ✓                      | ✓                      | ✓                      | ✓                      | ✓                     | ✓                     |
| Sector FE              | ✓                      | ✓                      | ✓                      | ✓                      | ✓                      | ✓                      | ✓                      | ✓                     | ✓                     |
| Locality size FE       | ✓                      | ✓                      | ✓                      | ✓                      | ✓                      | ✓                      | ✓                      | ✓                     | ✓                     |
| Observations           | 11,233                 | 11,233                 | 11,233                 | 11,233                 | 11,233                 | 11,233                 | 11,233                 | 11,233                | 11,233                |
| Clusters (localities)  | 2,226                  | 2,226                  | 2,226                  | 2,226                  | 2,226                  | 2,226                  | 2,226                  | 2,226                 | 2,226                 |

*Notes:* This table presents OLS (Panel A) and Instrumental Variables (Panel B) regressions to estimate the relation between, on the one hand, firm-level credit constraints and the quality of green management and, on the other hand, firm-level green investments. All regressions include firm-level controls (indicators for exporter status, listed firm, sole proprietorship and audited financial accounts, as well as the log of firm age); locality-level credit market controls (log average amount of assets of banks in a 15 km radius and the number of bank branches in a 15 km radius) and population size class; and country and sector fixed effects. Table A1 contains all variable definitions and Table A3 provides summary statistics. Table 2 provides the first stage of the IV regressions in Panel B. Robust standard errors are clustered by locality and shown in parentheses. \*\*\*, \*\*, \* and \* correspond to the 1%, 5%, and 10% level of statistical significance.

Our data allow us to look at these relationships in more detail, using the information on different types of green investment. The estimates in panel A of Table 1 indicate that credit constraints hinder all types of investment except those in air and other pollution controls.<sup>21</sup> The effect is the largest for machinery and vehicle upgrades as well as improved heating/cooling/lighting. This likely reflects the higher investment amounts these types of projects require and hence the higher likelihood that the firm will try to access external funding to realize the investment. The correlation with energy efficiency measures is smaller and less significant, potentially due to the “low-hanging fruit” nature of such investments.

The estimated coefficients on the quality of green management are positive and significant throughout and their absolute magnitude is higher than that of the credit-constraint indicator. The largest effect of green management is on energy or water management, air or other pollution control, and energy efficiency measures. This could be due to such investments being less integral to the firms’ normal operations, whereas upgrades and energy generation are more usual investments.

## 4.2 IV estimates

As discussed in Section 2.2, a firm’s investment decisions can influence its green management practices and credit constraints. We therefore now take an IV approach, with two instruments for each of our variables of interest.

Table 2 shows the results of the first stage. We regress each firm’s credit constraint indicator and green management score against all four instruments in columns 1 and 2, respectively. Column 1 displays positive and significant coefficients for the first two variables. This confirms that firms are more likely to be credit constrained if they are located in regions where firms from other sectors are also credit constrained, as well as if the banks in the firms’ vicinity had to increase their Tier 1 ratio between 2007 and 2014 by a lot. Such banks would have sought to deleverage and reduce their risky assets, and would have issued loans more cautiously. In column 2, the green management score is positively correlated with the two instruments: the average green management practices score of firms in the same region but from different sectors, and the total number of extreme weather events between 2000-15 in a 200 km radius around the firm.

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<sup>21</sup>Table A4 shows that these results are robust to correcting the  $p$ -values for multiple hypothesis testing (Romano-Wolf FWER  $p$ -values) and to correcting standard errors for spatial correlation, following Colella et al. (2019).

Table 2: Firm-level IV regressions: First Stage

| Dependent variable →                            | Credit<br>constrained<br>(indicator) | Green<br>management<br>(z-score) |
|---|--------------------------------------|----------------------------------|
|   | [1]                                  | [2]                              |
| Credit constraints instrument                   | 0.5566***<br>(0.0503)                | 0.0406<br>(0.1544)               |
| Change in local average Tier 1 ratio (% points) | 0.0032**<br>(0.0014)                 | 0.0006<br>(0.0037)               |
| Green management instrument                     | 0.0208<br>(0.0167)                   | 0.5390***<br>(0.0802)            |
| Extreme weather events                          | -0.0020<br>(0.0112)                  | 0.0760***<br>(0.0262)            |
| Firm controls                                   | ✓                                    | ✓                                |
| Credit market controls                          | ✓                                    | ✓                                |
| Country FE                                      | ✓                                    | ✓                                |
| Sector FE                                       | ✓                                    | ✓                                |
| Locality size FE                                | ✓                                    | ✓                                |
| Multivariate F-test of excluded instruments     | 44.11                                | 32.82                            |
| Observations                                    | 11,233                               | 11,233                           |
| Clusters  | 2,226                                | 2,226                            |

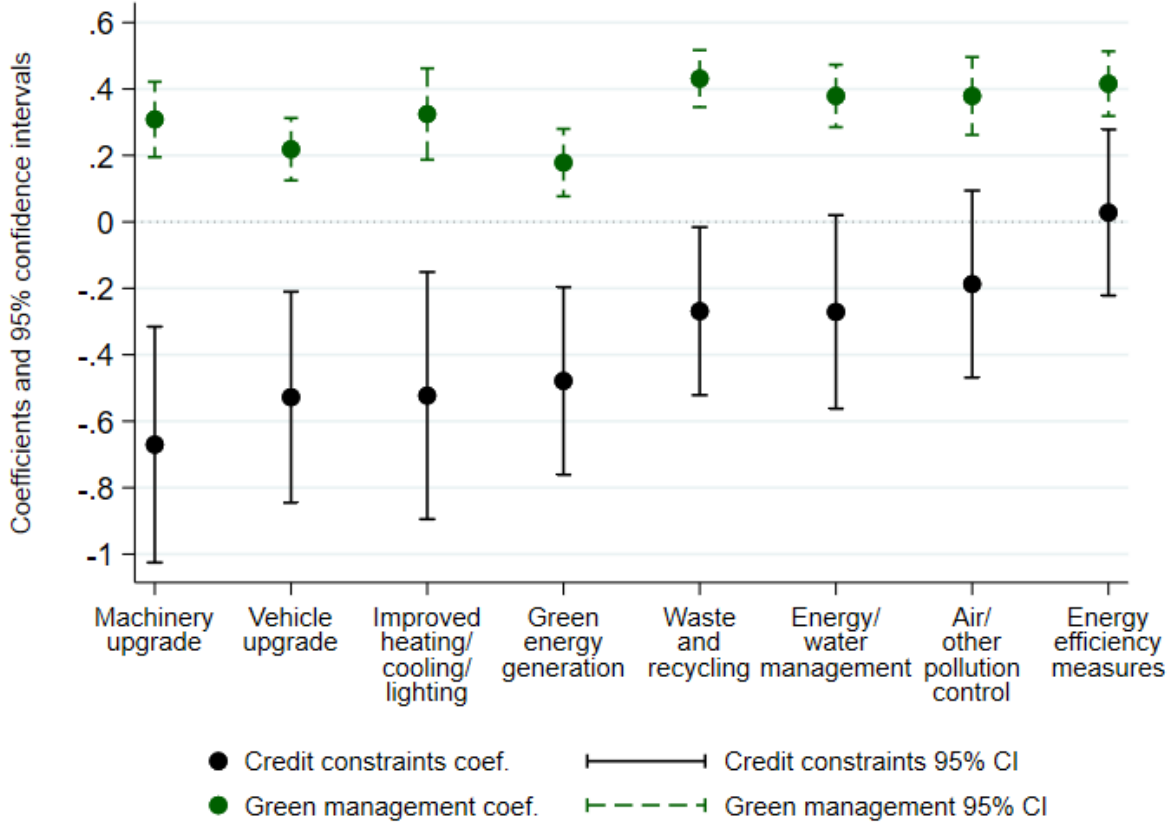
*Notes:* This table presents the first-stage regressions corresponding to Panel B of Table 1. All regressions include firm-level controls (indicators for exporter status, listed firm, sole proprietorship and audited financial accounts, as well as the log of firm age); locality-level credit market controls (log average amount of assets of banks in a 15 km radius and the number of bank branches in a 15 km radius) and population size class; and country and sector fixed effects. Table A1 contains all variable definitions and Table A3 provides summary statistics. Robust standard errors are clustered by locality and shown in parentheses. \*\*\*, \*\* and \* correspond to the 1%, 5%, and 10% level of statistical significance.

The first-stage F-statistics on the excluded instruments are comfortably above the rule-of-thumb of 10.<sup>22</sup> It is also reassuring that the instruments for green management are not correlated with the credit constraints indicator and, vice-versa, those for credit constraints are not correlated with the green management score. This supports the identifying assumptions underlying our instrumentation strategy: the financial health of banks only affects the investment decisions of firms through the impact on local lending conditions, while extreme weather events only affect their investment decisions through green management practices.

The second-stage results in panel B of Table 1 confirm that credit constraints and green man-

<sup>22</sup>Sanderson-Windmeijer multivariate F-tests yield a  $p$ -value of 0.00, indicating that in both cases the null hypothesis of an underidentified endogenous variable can be rejected. Table A6 provides a battery of additional diagnostic tests in support of our instrumentation strategy.

Figure 2: Firm-level Credit Constraints, Green Management, and Green Investments



Notes: This figure summarizes the IV coefficients of Table 1, Panel B, which represent estimates of the relation between, on the one hand, firm-level credit constraints and the quality of green management and, on the other hand, firm-level green investments. Table A1 contains all variable definitions and Table A3 provides summary statistics. Whiskers represents 95 percent confidence intervals.

agement significantly affect the likelihood of firms making green investments.<sup>23</sup> The IV estimates in Column 1 are more than ten times larger than those in panel A, suggesting that omitted variables bias the OLS results downward. The magnitudes of the estimated coefficients suggest that credit constraints matter slightly more for any type of investment.

We summarize the coefficients of Table 1, panel B, in Figure 2. Looking at the relationship between credit constraints and the various types of green investment, the IV estimates show that, as in the OLS, vehicle and machinery upgrades; investments to improve heating, cooling or lighting; as well as investments in green energy generation are the green investments that are most

<sup>23</sup>Table A5 shows that these results, like the OLS ones, are robust to correcting the  $p$ -values for multiple hypothesis testing and for spatial correlation.

negatively affected by credit constraints. The coefficients for waste and recycling, and energy or water management investments are smaller and less significant, while the relationship is insignificant for pollution control and energy efficiency investments. This likely reflects the relative size of the investments that each category involves, and their payback time. In the IV estimation, green management practices are shown to be strongly and significantly correlated with every type of green investment. Firms that are well managed in a green way are more likely to implement green investments and the effect is larger for waste and recycling; energy/water management; pollution control; and energy efficiency measures, as can be seen in columns 6-9 of panel B in Table 1 and in Figure 2.

### **4.3 Access to credit, air pollution and gas emissions**

If credit constraints and weak green management prevent firms from undertaking at least some green investment projects then one might expect that, perhaps with some lag, they can also hamper firms' ability to reduce their emissions of greenhouse gases and other pollutants. Unfortunately, there is no pollution data available for the firms used in the analysis above. However, the EU collects detailed pollution data at the facility level across its member states. We can therefore link these data to the instruments developed above at the regional level. In this section, we first describe the data, then our methodology, and finally discuss the results.

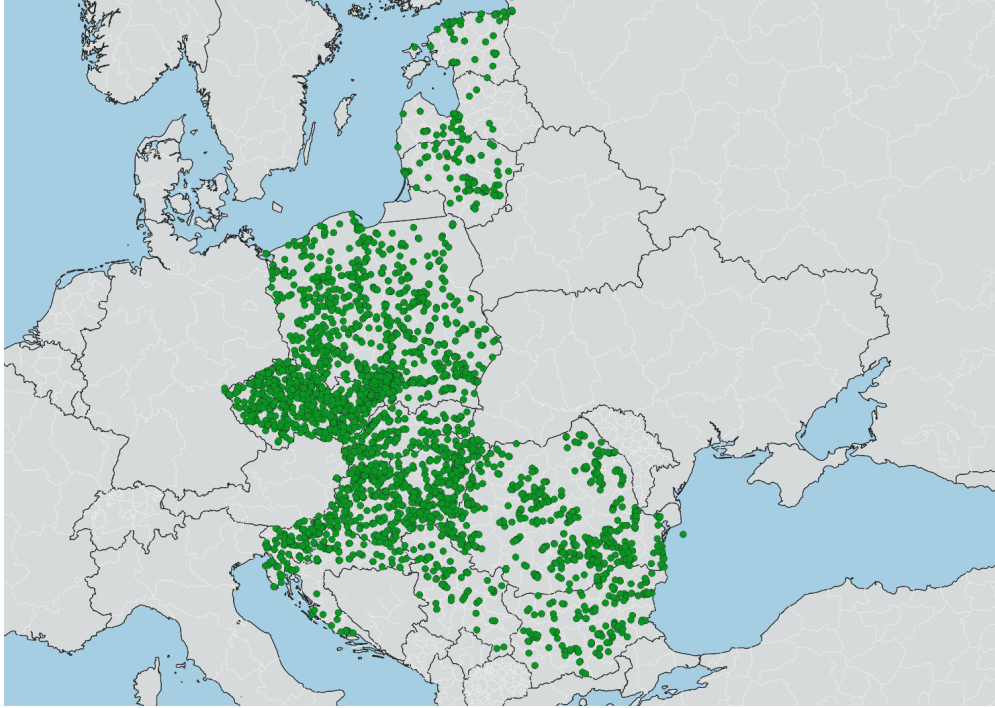
#### **4.3.1 Data**

We use data from the European Pollutant Release and Transfer Register (E-PRTR) v16. The E-PRTR is a register containing annual data on some 30,000 industrial facilities covering 65 economic activities across Europe. For each facility, information is provided on the amounts of pollutant released to air, water, and land (as well as off-site transfers of waste and of pollutants in waste water) from a list of 91 key pollutants including heavy metals, pesticides, greenhouse gases and dioxins. Data are available from 2007 onward. For industrial facilities with missing information on pollutant releases we assume that they were zero.

We focus on the 3,892 industrial facilities in 12 eastern European countries (Bulgaria, Croatia, the Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Serbia, the Slovak



Figure 3: Geographical Distribution of Industrial Facilities across Emerging Europe



*Notes:* This map shows the geographical distribution of the 3,892 industrial facilities across Bulgaria, Croatia, Czech Republic, Estonia, Hungary, Lithuania, Romania, Poland, Serbia, Slovak Republic, and Slovenia that are observed in every year during 2015-17. *Source:* European Pollutant Release and Transfer Register (E-PRTR) v16.

Republic and Slovenia) in the E-PRTR data set that overlap with the Enterprise Surveys data set.<sup>24</sup> The green dots in Figure 3 show the locations of these facilities. We combine the E-PRTR data with information from the BvD ORBIS database on the firms that own the industrial facilities (including their date of registration, listed status and location) and our data on bank branch networks from BEPS II (see Section 3.2).

The summary statistics in Table A3 show substantial variation in total emissions of air pollutants as well as gas emissions across the industrial facilities in our sample. Only 6 per cent of the companies owning these facilities are listed, but all have at least one bank branch within a 15 km radius, allowing us to adopt a similar empirical strategy as in the previous sections.

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<sup>24</sup>Table A2 provides the number of facilities by country. These are all facilities for which data are available for the years 2015, 2016, and 2017 (and in most cases also for all earlier years dating back to 2007). We focus on the facilities with data coverage in 2015-17 as this period is closest to the roll-out of the Enterprise Surveys, on which we base our regional measures of green management practices.

### 4.3.2 Methodology

We use two approaches to uncover the relationship between credit constraints and the quality of green management on the one hand, and air pollution on the other. First, we adopt an approach analogous to our IV specification in Equations (2) and (3). For the E-PRTR we do not have all the variables to construct the IVs used there. However, we can use the IVs and predicted values from the first stages reported in Table 2 to construct predicted values of the credit constraints and managerial capabilities in the vicinity of the E-PRTR firms. We construct  $\widehat{CreditConstraints}_{-s,r(i)}$  and  $\widehat{GreenManagement}_{-s,r(i)}$  as the average predicted value of the credit constraint and green management variables in E-PRTR firm  $i$ 's (NUTS2) region.<sup>25</sup> We can then estimate the following equation:

$$\begin{aligned} \log(1 + Emissions_{isct}) = & \beta_0 + \beta_1 \widehat{CreditConstraints}_{-s,r(i)} + \beta_2 \widehat{GreenManagement}_{-s,r(i)} \\ & + \gamma' \mathbf{X}_{isc} + \xi_c + \zeta_s + \epsilon_{isct} \end{aligned} \quad (4)$$

where  $Emissions$  is either total emissions of air pollutants or emissions of gases into the air by an industrial facility  $i$  in sector  $s$  and region  $r$  from country  $c$  in year  $t$ .  $\mathbf{X}$ ,  $\xi_c$  and  $\zeta_s$  are defined analogously to Equation (1).<sup>26</sup> Bootstrapped standard errors are clustered by facility. Because the emissions data is available from 2007 onward, we can estimate Equation (4) for different years. However, we essentially rely on cross-sectional variation for identification of the credit constraint and management effect because our instruments rely on information from the one-off ES.

Alternatively, we can develop a difference-in-differences design by relying on the tightening of local credit markets after the global financial crisis. We exploit the fact that banks that had funded themselves with short-term and relatively unstable wholesale funding before the crisis had to deleverage more afterwards. In contrast, banks that could count on a stable deposit base were more stable lenders (Iyer, Peydró, da Rocha-Lopes and Schoar, 2013; De Haas and Van Lelyveld, 2014).

As argued before, banks' branch networks were predetermined before the crisis and overlap only partially. This creates a spatially varied pattern of changes in funding conditions, with facilities in

<sup>25</sup>This is akin to a jackknife style approach except that we leave out data on firm  $i$  because we do not have it rather than because we deliberately drop it.

<sup>26</sup>Specifically,  $\mathbf{X}$  includes age, stock exchange listing or delisting, credit market conditions in the vicinity of each parent firm and population size class in the locality.

some localities having access to banks with stable funding whereas other facilities had to rely on branches of banks on a steep deleveraging path (Popov and Udell, 2012; Beck et al., 2018). Hence, with one year of pollution data from before the crisis (2007), we can relate changes in emissions to changes in the immediate financial environment of firms. To do so, we again match each facility with all bank branches within a 15 km radius.<sup>27</sup> We then create a variable that measures the average wholesale funding dependence in 2007, just before the outbreak of the global financial crisis, of these surrounding bank branches. We estimate the following reduced-form model:

$$\begin{aligned} \log(1 + Emissions_{isct}) = & \beta_0 + \beta_1 WSFDependence_{15km,isct} \\ & + \beta_2 WSFDependence_{15km,isct} \times Post2007_t + \beta_3 Post2007_t \quad (5) \\ & + \gamma' \mathbf{X}_{isct} + \xi_c + \zeta_s + \epsilon_{isct}, \end{aligned}$$

where *Emissions* is either the log of (one plus) the total emissions of air pollutants or gases by an industrial facility *i* in sector *s* and country *c* in 2007 and 2008-17. *WSFDependence* is the average wholesale funding dependence in 2007. In the case of facilities that belong to a larger group, the distance is calculated relative to the parent company. *Post2007* is a dummy variable that is 1 in 2008 and later years, and 0 in the base year 2007. The other controls are as per Equation (4), with standard errors clustered by facility.

### 4.3.3 Results

Table 3 presents the estimates of Equation (4). The dependent variable is the  $\log(1 + Emissions)$ .<sup>28</sup> The positive coefficient for regional credit constraints is significant in every year and suggests that credit constraints affect air pollution and gas emissions positively. Note that these predicted credit constraints pick up spatial variation in the earlier tightening of regional lending conditions as banks shored up their Tier 1 capital ratios during 2007-14. It is this reduction in the supply of bank lending during and immediately after the global financial crisis that then leads to lower green investments in the subsequent years and, eventually, to a worse performance in terms of facilities' carbon emissions and other air pollutants. Moreover, the quality of green management in firms surrounding the facility tends to reduce the emission of air pollutants. However, this effect is only

<sup>27</sup>As before, we explored robustness to slightly different distances.

<sup>28</sup>As a robustness check, Table A7 presents similar results with  $\text{Hypersine}(Emissions)$  as the dependent variable.

Table 3: Facility-Level Credit Constraints, Green Management, and Air Pollution

| Dependent variable →        | Air pollutants      |                    |                   | Gas emissions into the air |                    |                    |
|-----------------------------|---------------------|--------------------|-------------------|----------------------------|--------------------|--------------------|
|                             | 2015                | 2016               | 2017              | 2015                       | 2016               | 2017               |
|                             | [1]                 | [2]                | [3]               | [4]                        | [5]                | [6]                |
| Regional credit constraints | 3.832**<br>(1.841)  | 4.041**<br>(1.801) | 3.348*<br>(1.785) | 3.946**<br>(1.847)         | 4.047**<br>(1.808) | 3.541**<br>(1.794) |
| Regional green management   | -1.096**<br>(0.532) | -0.623<br>(0.523)  | -0.478<br>(0.522) | -1.027*<br>(0.534)         | -0.619<br>(0.524)  | -0.409<br>(0.524)  |
| Firm controls               | ✓                   | ✓                  | ✓                 | ✓                          | ✓                  | ✓                  |
| Credit market controls      | ✓                   | ✓                  | ✓                 | ✓                          | ✓                  | ✓                  |
| Country FE                  | ✓                   | ✓                  | ✓                 | ✓                          | ✓                  | ✓                  |
| Sector FE                   | ✓                   | ✓                  | ✓                 | ✓                          | ✓                  | ✓                  |
| Locality size FE            | ✓                   | ✓                  | ✓                 | ✓                          | ✓                  | ✓                  |
| R-squared                   | 0.251               | 0.251              | 0.255             | 0.257                      | 0.260              | 0.260              |
| Observations                | 3,892               | 3,892              | 3,892             | 3,892                      | 3,892              | 3,892              |

*Notes:* This table presents OLS regressions to estimate the relation between, on the one hand, credit constraints and the quality of green management at the subnational regional level and, on the other hand, facility-level air pollution (columns 1-3) and facility-level gas emissions into the air (columns 4-6). All columns use the log ( $x+1$ ) of the dependent variable. The sample consists of all facilities that appear in E-PRTR in each year during 2015-17. For each E-PRTR facility in industry  $i$ , a value for the variables *Regional credit constraints* and *Regional green management* is calculated as averages of the predicted values from Table 2 across all firms in the same subnational region. All regressions include firm-level controls (indicators for listed and delisted firms and the log of firm age); locality-level credit market controls (log average amount of assets of banks in a 15 km radius and the number of bank branches in a 15 km radius) and population size class; and country and sector fixed effects. Table A1 contains all variable definitions and Table A3 provides summary statistics. Bootstrapped standard errors are clustered by facility and shown in parentheses. \*\*\*, \*\* and \* correspond to the 1%, 5%, and 10% level of statistical significance.

statistically significant, and strongest, in 2015. Its sign reflects the spillover effect that a firm's green management practices might have on firms and facilities in the same region, even when from other sectors.

Table 4 reports results from our difference-in-differences specification as described in Equation (5). Both  $\text{Log}(x + 1)$  and the hyperbolic sine of air pollutants and gas emissions are presented as dependent variables. The negative and significant coefficient for the post-2007 dummy variable reflects a secular decline in air pollution and gas emissions. The interaction term between the post-2007 dummy and wholesale funding is positive, large and statistically significant. This means that the decline in emissions and air pollution was smaller in localities where banks had to deleverage more in the wake of the global financial crisis. It also indicates that credit constraints not only hindered firms' green investment, as we demonstrated above, but also, as a result, hampered

Table 4: Local Credit Shocks and Facility-Level Air Pollution

| Dependent variable →   | Air pollutants       |                      | Gas emissions into the air |                      |
|--|----------------------|----------------------|----------------------------|----------------------|
|  | Log (x+1)            | Hyperbolic sine      | Log (x+1)                  | Hyperbolic sine      |
|  | [1]                  | [2]                  | [3]                        | [4]                  |
| Bank dependence on wholesale funding in 2007 (15 km)             | -0.009<br>(0.022)    | -0.017<br>(0.044)    | -0.009<br>(0.023)          | -0.017<br>(0.045)    |
| Post 2007 × Bank dependence on wholesale funding in 2007 (15 km) | 0.013***<br>(0.004)  | 0.027***<br>(0.008)  | 0.014***<br>(0.004)        | 0.028***<br>(0.009)  |
| Post 2007  | -1.311***<br>(0.326) | -2.622***<br>(0.651) | -1.242***<br>(0.344)       | -2.483***<br>(0.688) |
| Firm controls  | ✓                    | ✓                    | ✓                          | ✓                    |
| Credit market controls   | ✓                    | ✓                    | ✓                          | ✓                    |
| Country FE   | ✓                    | ✓                    | ✓                          | ✓                    |
| Sector FE  | ✓                    | ✓                    | ✓                          | ✓                    |
| Locality size FE   | ✓                    | ✓                    | ✓                          | ✓                    |
| R-squared  | 0.288                | 0.288                | 0.291                      | 0.291                |
| Observations   | 3,928                | 3,928                | 3,928                      | 3,928                |

*Notes:* This table presents difference-in-differences regressions to explain the impact of locality-level credit constraints on total facility-level air pollution (columns 1-2) and facility-level gas emissions into the air (columns 3-4). Columns 1 and 3 use the log (x+1) of the dependent variable while columns 2 and 4 use a hyperbolic sine transformation. The sample consists of all facilities that appear in E-PRTR in each year during 2007-17. *Bank dependence on wholesale funding (15 km)* measures the average dependence (in 2007) on wholesale funding of all bank branches located in a circle with a 15 km radius around the industrial facility or, in the case of multi-facility firms, the parent company. *Post 2007* is a dummy variable that is 1 in 2008 and later years and 0 in the base year 2007. All regressions include firm-level controls (indicators for listed and delisted firms and the log of firm age); locality-level credit market controls (log average amount of assets of banks in a 15 km radius and the number of bank branches in a 15 km radius) and population size class; and country and sector fixed effects. Table A1 contains all variable definitions and Table A3 provides summary statistics. Standard errors are clustered by facility and shown in parentheses. \*\*\*, \*\* and \* correspond to the 1%, 5%, and 10% level of statistical significance.

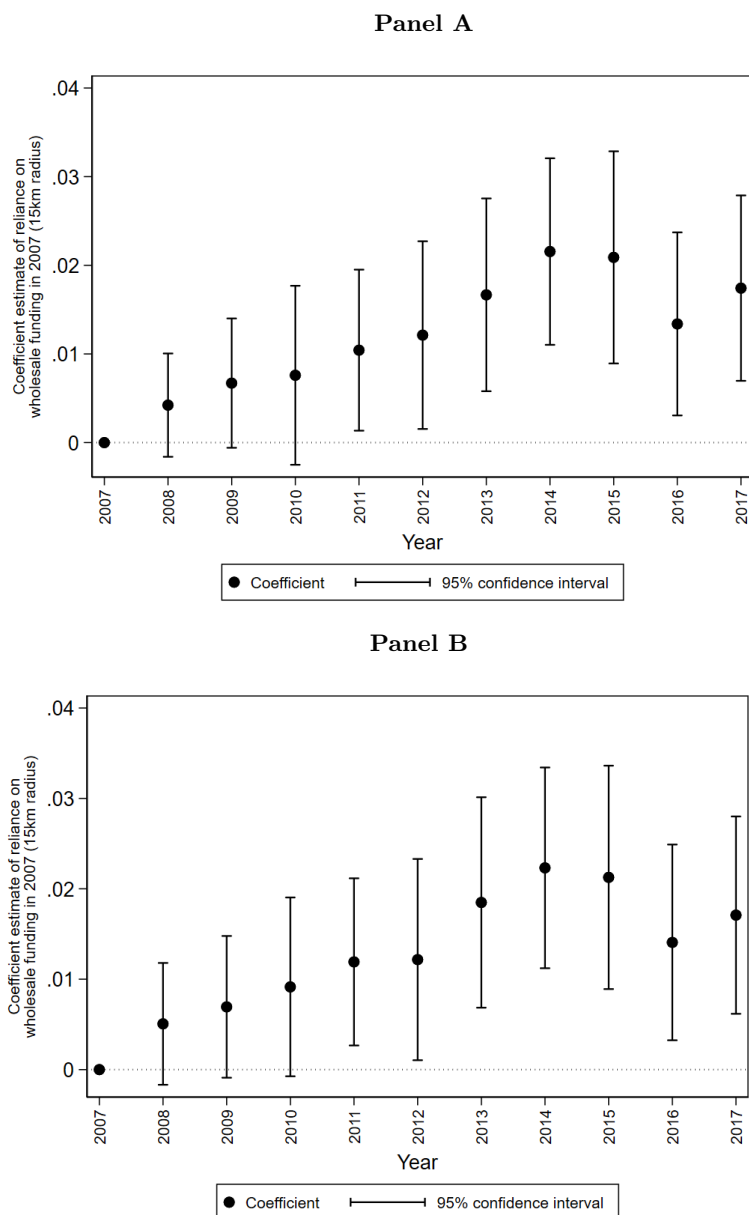
their ability to produce in a less polluting manner. Moreover, the impact of credit constraints is substantial. The estimates indicate that, all else kept constant, total emissions of air pollutants were 15.3 percent higher than they would have been in the absence of credit constraints.

Figure 4 reports credit constraint effects for every individual year in our sample.<sup>29</sup> This reveals that the effect became more pronounced over time. Panel A shows this for air pollution, while Panel B displays the coefficients for gas emissions. In both cases the effect becomes gradually more pronounced. While initially not significantly different from zero, the effects are significant at the 5% level from 2011 onward. This increasingly strong effect is consistent with our proposed

<sup>29</sup>That is, we interact year dummies with the *WSFDependence* variable.

mechanism: it takes time for investments to materialize, and thus for differential access to bank credit to translate into differing levels of air pollution. The difference in annual pollution levels reduces somewhat after around eight years.

Figure 4: Local Credit Shocks and Facility-Level Air Pollution (2007-17)



*Notes:* These charts summarize the coefficient estimates of difference-in-differences regressions to explain the impact of locality-level credit constraints on total air pollution (log kg, Panel A) and total emissions of gas pollutants into the air (log kg, Panel B) at the level of industrial facilities. *Reliance on wholesale funding (15 km)* measures the average dependence (in 2007) on wholesale funding of all bank branches located in a circle with a 15 km radius around the industrial facility or, in the case of multi-facility firms, the parent company. The dots represent coefficient estimates of an interaction term between the reliance on wholesale funding in 2007 and individual year dummies during 2007-17. Regressions control for the firm-level covariates (indicators for listed and delisted firms and the log of firm age); locality-level credit market controls (log average amount of assets of banks in a 15 km radius and the number of bank branches in a 15 km radius) and population size class; and country, sector, and year fixed effects.

## 5 Conclusions

The transition to a low-carbon economy is as challenging as it is urgent. If countries are to fulfill their commitments under the Paris Agreement, substantial investments will be needed over the next three decades to make production structures substantially more energy efficient. The analysis in this paper, based on newly collected data on 11,233 firms across 22 countries, shows how financial constraints continue to hamper firms' implementation of greener technologies and carbon abatement measures. A subsequent analysis of data from the European Pollutant Release and Transfer Register (E-PRTR) reveals the environmental consequences of these financial constraints: a substantially slower decline in the emission of gas and other air pollutants by industrial facilities.

Our results reveal how financial crises can slow down the process of decarbonization of economic production. They should also caution against excessive optimism about the potential green benefits of the current economic slowdown which—like any big recession—has led to reductions in emissions. Our results suggest that such short-term reductions might come at the cost of longer-term increases in emissions if they are associated with more severe credit-market frictions that delay or prevent clean investments.

Our analysis also shows that managerial constraints in the form of environmental management quality tend to hamper green investments. Our results suggest that comparatively low (or no) cost measures—such as developing and implementing an environmental strategy; setting and monitoring environmental targets; and putting a manager in charge of climate change and environmental issues—can lead to increased green investments.

Our results lend support to policy measures that ease access to bank credit specifically for green investments. However, they also suggest that this might be just one element of a broader policy mix to stimulate green investment. Governments and development banks should also consider measures that could strengthen environmental management practices. This may include requirements to measure and report environmental impacts or credit lines that are contingent on the adoption of better environmental management practices by firms.

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# Appendices

Table A1: Variable Definitions and Data Sources

| Variable name                         | Variable definition   | Source |
|---------------------------------------|---|--------|
| <i>Tables 1-2</i>                     |   |        |
| Green investment                      | 1 if firm adopted at least one of the following measures over the last three years: heating and cooling improvements, more climate-friendly energy generation on site, machinery and equipment upgrades, energy management, waste minimisation, recycling and waste management, air pollution and control measures, water management, upgrade of vehicles, improvements to lighting systems, other pollution control measures, measures to enhance energy efficiency; 0 otherwise | ES     |
| Machinery upgrade                     | 1 if firm upgraded machinery and equipment over the last three years; 0 otherwise   | ES     |
| Vehicle upgrade                       | 1 if firm upgraded vehicles over the last three years; 0 otherwise  | ES     |
| Improved heating / cooling / lighting | 1 if firm adopted heating and cooling improvements or improvements to lighting systems over the last three years; 0 otherwise   | ES     |
| Green energy generation               | 1 if firm adopted more climate-friendly energy generation on site over the last three years; 0 otherwise  | ES     |
| Waste and recycling                   | 1 if firm adopted waste minimisation, recycling and waste management over the last three years; 0 otherwise   | ES     |
| Energy / water management             | 1 if firm adopted energy or water management over the last three years; 0 otherwise   | ES     |
| Air / other pollution control         | 1 if firm adopted air pollution or other pollution control measures over the last three years; 0 otherwise  | ES     |
| Energy efficiency measures            | 1 if firm adopted any measures to enhance energy efficiency over the last three years; 0 otherwise  | ES     |
| Credit constrained                    | 1 if firm needed a loan and was discouraged from applying or rejected when it applied; 0 otherwise (including no need for credit or satisfied demand for credit)  | ES     |
| Green management                      | z-score based on four areas of green management practices: strategic objectives related to the environment and climate change, manager with explicit mandate to deal with green issues, environmental targets, monitoring.  | ES     |

Table A1 cont. on next page

Table A1 cont.: Variable Definitions and Data Sources

| <b>Variable name</b>  | <b>Variable definition</b>  | <b>Source</b>                      |
|---|---|------------------------------------|
| Exporter  | 1 if firm directly exported at least 10 per cent of its sales in the last complete fiscal year; 0 otherwise   | ES                                 |
| Listed  | 1 if firm is a shareholding firm with shares traded in the stock market; 0 otherwise  | ES                                 |
| Sole proprietor   | 1 if firm is a sole proprietorship; 0 otherwise   | ES                                 |
| Audited   | 1 if firm had its annual financial statements checked and certified by an external auditor; 0 otherwise   | ES                                 |
| Firm age  | Log of firm age (from when it was registered)   | ES                                 |
| No. bank branches within 15 km radius of the firm                         | Number of bank branches within a 15 km radius around the firm   | BEPS II, Orbis and ES              |
| Average asset size of banks in 15 km radius around the firm in 2007 (log) | Average asset size of banks with branches within a 15 km radius around the firm, weighted by the number of bank branches, logged  | BEPS II, Orbis and ES              |
| Locality size   | Variable based on the number of inhabitants in the firm's locality; categories: city with population over 1 million; over 250,000 to 1 million inhabitants; 50,000 to 250,000 inhabitants; fewer than 50,000 inhabitants  | ES, verified with official sources |
| Credit constraints instrument   | Instrument obtained by averaging the credit constraints of firms in the same country-region cell and excluding firms in the same sector   | ES                                 |
| Change in local average Tier 1 ratio (% points)                           | Difference between the average Tier 1 ratio of banks with branches within a 15 km radius of the firm in 2014 (weighted by the number of bank branches) and the average Tier 1 ratio of banks with branches within a 15 km radius of the firm in 2007 (weighted by the number of bank branches). | BEPS II, Orbis and ES              |
| Green management instrument   | Instrument obtained by averaging the green management score of firms in the same country-region cell and excluding firms in the same sector   | ES                                 |
| Extreme weather events  | Total number of extreme weather events (tornado, hail, wind, precipitation, snow) between 2000-15 in a 200 km radius around the firm, logged  | ESWD v1.60                         |

Table A1 cont. on next page

Table A1 cont.: Variable Definitions and Data Sources

| Variable name   | Variable definition  | Source                                 |
|---|--|--|
| <i>Tables 3-4</i>   |  |  |
| Air pollutants  | Total annual quantity of air pollutants released by the facility in kg; missing values assumed to be 0   | E-PRTR v16                             |
| Gas emissions into the air  | Total annual quantity of greenhouse and other gas emissions released by the facility into the air in kg; missing values assumed to be 0  | E-PRTR v16                             |
| Regional credit constraints   | Averages of the predicted values of credit constraints from Table 2 across all firms in the same subnational region except for those in industry <i>i</i> itself   | ES, BEPS II, Orbis                     |
| Regional green management   | Averages of the predicted values of green management from Table 2 across all firms in the same subnational region except for those in industry <i>i</i> itself   | ES, BEPS II, Orbis                     |
| Listed firm   | 1 if firm is listed, 0 otherwise   | Orbis                                  |
| Delisted firm   | 1 if firm was listed in the past but is no longer listed, 0 otherwise  | Orbis                                  |
| Firm age (log)  | Age of the firm, logged  | Orbis                                  |
| No. bank branches within 15 km radius of the firm                         | Number of bank branches within a 15 km radius around the firm  | E-PRTR v16, BEPS II, Orbis             |
| Average asset size of banks in 15 km radius around the firm in 2007 (log) | Average asset size of banks with branches within a 15 km radius around the firm, weighted by the number of bank branches, logged   | E-PRTR v16, BEPS II, Orbis             |
| Bank dependence on wholesale funding in 2007                              | Average value of banks' net loans over deposits and short-term funding, weighted by the number of bank branches within a 15 km radius around the firm  | E-PRTR v16, BEPS II, Orbis             |
| Locality size   | Variable based on the number of inhabitants in the firm's locality. Categories: city with population over 1 million; over 250,000 to 1 million inhabitants; 50,000 to 250,000 inhabitants; fewer than 50,000 inhabitants | E-PRTR v16, Orbis and official sources |

*Notes:* Sources in this table are as follows: ES refers to the EBRD-WBG-EIB Enterprise Surveys, BEPS II refers to the second round of the Banking Environment and Performance Survey, ESWD to European Severe Weather Database, and E-PRTR refers to the European Pollutant Release and Transfer Register.



Table A2: Sample Breakdown by Country

| Countries              | Number of unique firms and facilities |              |              |
|------------------------|---------------------------------------|--------------|--------------|
|                        | Tables 1-2                            | Table 3      | Table 4      |
| Albania                | 282                                   | 0            | 0            |
| Armenia                | 373                                   | 0            | 0            |
| Azerbaijan             | 197                                   | 0            | 0            |
| Belarus                | 582                                   | 0            | 0            |
| Bosnia and Herzegovina | 274                                   | 0            | 0            |
| Bulgaria               | 638                                   | 154          | 72           |
| Croatia                | 329                                   | 102          | 0            |
| Czech Republic         | 420                                   | 770          | 377          |
| Estonia                | 265                                   | 64           | 35           |
| Georgia                | 415                                   | 0            | 0            |
| Hungary                | 742                                   | 575          | 284          |
| Latvia                 | 245                                   | 31           | 11           |
| Lithuania              | 319                                   | 89           | 39           |
| Moldova                | 271                                   | 0            | 0            |
| North Macedonia        | 296                                   | 0            | 0            |
| Poland                 | 1,173                                 | 1,100        | 689          |
| Romania                | 587                                   | 571          | 244          |
| Serbia                 | 275                                   | 76           | 0            |
| Slovak Republic        | 375                                   | 220          | 113          |
| Slovenia               | 369                                   | 140          | 100          |
| Turkey                 | 1,552                                 | 0            | 0            |
| Ukraine                | 1,254                                 | 0            | 0            |
| <i>Total</i>           | <i>11,233</i>                         | <i>3,892</i> | <i>1,964</i> |

*Source:* EBRD-WBG-EIB Enterprise Surveys.

Table A3: Summary statistics

| <i>Tables 1-2</i>  | N      | Mean   | Median | Std.<br>Dev. | Min    | Max    |
|--|--------|--------|--------|--------------|--------|--------|
|  | [1]    | [2]    | [3]    | [4]          | [5]    | [6]    |
| Green investment   | 11,233 | 0.763  | 1.000  | 0.425        | 0.000  | 1.000  |
| Machinery upgrade  | 11,233 | 0.471  | 0.000  | 0.499        | 0.000  | 1.000  |
| Vehicle upgrade  | 11,233 | 0.342  | 0.000  | 0.474        | 0.000  | 1.000  |
| Improved Heating/cooling/lighting  | 11,233 | 0.555  | 1.000  | 0.497        | 0.000  | 1.000  |
| Green energy generation  | 11,233 | 0.125  | 0.000  | 0.331        | 0.000  | 1.000  |
| Waste and recycling  | 11,233 | 0.398  | 0.000  | 0.489        | 0.000  | 1.000  |
| Energy/water management  | 11,233 | 0.347  | 0.000  | 0.476        | 0.000  | 1.000  |
| Air/other pollution control  | 11,233 | 0.200  | 0.000  | 0.400        | 0.000  | 1.000  |
| Energy efficiency measures   | 11,233 | 0.348  | 0.000  | 0.476        | 0.000  | 1.000  |
| Credit constrained   | 11,233 | 0.226  | 0.000  | 0.418        | 0.000  | 1.000  |
| Green management   | 11,233 | 0.070  | -0.310 | 1.033        | -1.908 | 6.980  |
| Exporter   | 11,233 | 0.254  | 0.000  | 0.436        | 0.000  | 1.000  |
| Publicly listed  | 11,233 | 0.066  | 0.000  | 0.248        | 0.000  | 1.000  |
| Sole proprietorship  | 11,233 | 0.163  | 0.000  | 0.369        | 0.000  | 1.000  |
| Audited  | 11,233 | 0.341  | 0.000  | 0.474        | 0.000  | 1.000  |
| Age (log)  | 11,233 | 2.791  | 2.944  | 0.690        | 0.000  | 5.323  |
| No. bank branches in 15 km radius  | 11,233 | 193    | 59     | 333          | 1      | 2,379  |
| Average asset size of banks in 15 km radius around the establishment in 2007 (log) | 11,233 | 15.220 | 15.230 | 1.536        | 11.010 | 17.700 |
| Credit constraints instrument  | 11,233 | 0.223  | 0.183  | 0.161        | 0.000  | 0.681  |
| Change in local average Tier 1 ratio (% points)                                    | 11,233 | 2.080  | 1.488  | 7.843        | -35.88 | 44.60  |
| Green management instrument  | 11,233 | 0.074  | 0.012  | 0.406        | -0.697 | 1.409  |
| Extreme weather events (log)   | 11,233 | 6.243  | 6.176  | 0.970        | 4.127  | 8.237  |

Table A3 cont.: Summary statistics

| <i>Table 3</i>   | N      | Mean    | Median | Std.<br>Dev. | Min    | Max    |
|--|--------|---------|--------|--------------|--------|--------|
|  | [1]    | [2]     | [3]    | [4]          | [5]    | [6]    |
| Log (air pollutants + 1)   | 11,676 | 6.001   | 0.000  | 6.871        | 0.000  | 24.350 |
| Log (gas emissions into the air + 1)   | 11,676 | 5.887   | 0.000  | 6.902        | 0.000  | 24.350 |
| Air pollutants (kg, hyperbolic sine)   | 11,676 | 11.310  | -0.693 | 13.740       | -0.693 | 48.010 |
| Gas emissions into the air (kg, hyperbolic sine)                             | 11,676 | 11.080  | -0.693 | 13.800       | -0.693 | 48.010 |
| Regional credit constraints  | 11,676 | 0.157   | 0.133  | 0.112        | 0.011  | 0.531  |
| Regional green management  | 11,676 | 0.204   | 0.110  | 0.315        | -0.402 | 0.841  |
| Listed company   | 11,676 | 0.053   | 0.000  | 0.224        | 0.000  | 1.000  |
| Delisted company   | 11,676 | 0.043   | 0.000  | 0.204        | 0.000  | 1.000  |
| Log (company age + 1)  | 11,676 | 3.012   | 3.091  | 0.711        | 0.000  | 5.576  |
| No. bank branches within 15 km radius of the company                         | 11,676 | 174.900 | 54.000 | 277.800      | 1.000  | 1,223  |
| Average asset size of banks in 15 km radius around the company in 2007 (log) | 11,676 | 16.140  | 16.310 | 0.796        | 12.250 | 17.360 |

| <i>Table 4</i>  | N      | Mean    | Median | Std.<br>Dev. | Min    | Max      |
|---|--------|---------|--------|--------------|--------|----------|
|   | [1]    | [2]     | [3]    | [4]          | [5]    | [6]      |
| Log (air pollutants + 1)  | 21,604 | 7.484   | 9.582  | 7.498        | 0      | 24.35    |
| Log (gas emissions into the air + 1)  | 21,604 | 7.293   | 9.540  | 7.585        | 0      | 24.35    |
| Air pollutants (kg, hyperbolic sine)  | 21,604 | 14.28   | 18.47  | 15.00        | -0.693 | 48.01    |
| Gas emissions into the air (kg, hyperbolic sine)                            | 21,604 | 13.89   | 18.39  | 15.17        | -0.693 | 48.01    |
| Listed company (indicator)  | 21,604 | 0.062   | 0.000  | 0.241        | 0.000  | 1.000    |
| Delisted company (indicator)  | 21,604 | 0.051   | 0.000  | 0.221        | 0.000  | 1.000    |
| Log (company age + 1)   | 21,604 | 2.918   | 2.944  | 0.817        | 0.000  | 5.576    |
| No. bank branches within 15km radius of the company                         | 21,604 | 173.900 | 56.000 | 270.800      | 1.000  | 1223.000 |
| Average asset size of banks in 15km radius around the company in 2007 (log) | 21,604 | 16.240  | 16.370 | 0.698        | 14.120 | 17.340   |
| Bank dependence on wholesale funding (15km)                                 | 21,604 | 73.710  | 70.500 | 13.520       | 47.290 | 200.400  |

*Sources:* EBRD-WBG-EIB Enterprise Surveys, Banking Environment and Performance Survey II, Bureau van Dijk's ORBIS database, European Pollutant Release and Transfer Register v16, European Severe Weather Database v1.60 and authors' calculations.

Table A4: Firm-level Credit Constraints, Green Management, and Green Investments - Robustness OLS results

| Dependent variable →   | [1]                          | [2]               | [3]             | [4]                                   | [5]                     | [6]                 | [7]                       | [8]                           | [9]                        |
|--|------------------------------|-------------------|-----------------|---------------------------------------|-------------------------|---------------------|---------------------------|-------------------------------|----------------------------|
|  | Green investment (indicator) | Machinery upgrade | Vehicle upgrade | Improved heating / cooling / lighting | Green energy generation | Waste and recycling | Energy / water management | Air / other pollution control | Energy efficiency measures |
| <b>Panel A: P-values corrected for multiple hypothesis testing</b> |                              |                   |                 |                                       |                         |                     |                           |                               |                            |
| Credit constrained   | -0.0372**                    | -0.0556***        | -0.0623***      | -0.0490**                             | -0.0257*                | -0.0356*            | -0.0322**                 | 0.0008                        | -0.0225                    |
| <i>p</i> -value original model                                     | 0.0031                       | 0.0000            | 0.0000          | 0.0008                                | 0.0152                  | 0.0060              | 0.0042                    | 0.9501                        | 0.0868                     |
| Romano-Wolf FWER <i>p</i> -value                                   | 0.0350                       | 0.0020            | 0.0010          | 0.0160                                | 0.0959                  | 0.0579              | 0.0410                    | 0.9510                        | 0.2318                     |
| Green management   | 0.0852***                    | 0.1078***         | 0.0988***       | 0.1183***                             | 0.0889**                | 0.1240***           | 0.1755***                 | 0.1558***                     | 0.1623***                  |
| <i>p</i> -value original model                                     | 0.0000                       | 0.0000            | 0.0000          | 0.0000                                | 0.0000                  | 0.0000              | 0.0000                    | 0.0000                        | 0.0000                     |
| Romano-Wolf FWER <i>p</i> -value                                   | 0.0010                       | 0.0010            | 0.0010          | 0.0010                                | 0.0010                  | 0.0010              | 0.0010                    | 0.0010                        | 0.0010                     |
| Firm controls  | ✓                            | ✓                 | ✓               | ✓                                     | ✓                       | ✓                   | ✓                         | ✓                             | ✓                          |
| Bank branch controls   | ✓                            | ✓                 | ✓               | ✓                                     | ✓                       | ✓                   | ✓                         | ✓                             | ✓                          |
| Country FE   | ✓                            | ✓                 | ✓               | ✓                                     | ✓                       | ✓                   | ✓                         | ✓                             | ✓                          |
| Sector FE  | ✓                            | ✓                 | ✓               | ✓                                     | ✓                       | ✓                   | ✓                         | ✓                             | ✓                          |
| Locality size FE   | ✓                            | ✓                 | ✓               | ✓                                     | ✓                       | ✓                   | ✓                         | ✓                             | ✓                          |
| Observations   | 11,233                       | 11,233            | 11,233          | 11,233                                | 11,233                  | 11,233              | 11,233                    | 11,233                        | 11,233                     |
| Clusters   | 2,226                        | 2,226             | 2,226           | 2,226                                 | 2,226                   | 2,226               | 2,226                     | 2,226                         | 2,226                      |
| <b>Panel B: Standard errors corrected for spatial correlation</b>  |                              |                   |                 |                                       |                         |                     |                           |                               |                            |
| Credit constrained   | -0.0372**                    | -0.0556***        | -0.0623***      | -0.0490***                            | -0.0257*                | -0.0356**           | -0.0322***                | 0.0008                        | -0.0225                    |
|  | (0.0150)                     | (0.0162)          | (0.0149)        | (0.0171)                              | (0.0132)                | (0.0156)            | (0.0120)                  | (0.0143)                      | (0.0153)                   |
| Green management   | 0.0852***                    | 0.1078***         | 0.0988***       | 0.1183***                             | 0.0889***               | 0.1240***           | 0.1755***                 | 0.1558***                     | 0.1623***                  |
|  | (0.0063)                     | (0.0063)          | (0.0068)        | (0.0064)                              | (0.0081)                | (0.0074)            | (0.0055)                  | (0.0066)                      | (0.0067)                   |
| Firm controls  | ✓                            | ✓                 | ✓               | ✓                                     | ✓                       | ✓                   | ✓                         | ✓                             | ✓                          |
| Bank branch controls   | ✓                            | ✓                 | ✓               | ✓                                     | ✓                       | ✓                   | ✓                         | ✓                             | ✓                          |
| Country FE   | ✓                            | ✓                 | ✓               | ✓                                     | ✓                       | ✓                   | ✓                         | ✓                             | ✓                          |
| Sector FE  | ✓                            | ✓                 | ✓               | ✓                                     | ✓                       | ✓                   | ✓                         | ✓                             | ✓                          |
| Locality size FE   | ✓                            | ✓                 | ✓               | ✓                                     | ✓                       | ✓                   | ✓                         | ✓                             | ✓                          |
| Observations   | 11,233                       | 11,233            | 11,233          | 11,233                                | 11,233                  | 11,233              | 11,233                    | 11,233                        | 11,233                     |
| R-squared  | 0.1432                       | 0.1679            | 0.1569          | 0.1841                                | 0.1271                  | 0.2141              | 0.2515                    | 0.2279                        | 0.2234                     |

*Notes:* This table presents OLS regressions (Panel A, Table 1) to estimate the relation between, on the one hand, firm-level credit constraints and the quality of green management and, on the other hand, firm-level green investments. All regressions include firm-level controls (indicators for exporter status, listed firm, sole proprietorship and audited financial accounts, as well as the log of firm age); locality-level credit market controls (log average amount of assets of banks in a 15 km radius and the number of bank branches in a 15 km radius) and population size class; and country and sector fixed effects. Table A1 contains all variable definitions and Table A3 provides summary statistics. Robust standard errors are clustered by locality and shown in parentheses. Panel A presents Romano-Wolf FWER *p*-values corrected for multiple-hypothesis testing. Panel B presents standard errors corrected for spatial correlation using the *areg* Stata command and following Colella et al. (2019). \*\*\*, \*\*, and \* correspond to the 1%, 5%, and 10% level of statistical significance.

Table A5: Firm-level Credit Constraints, Green Management, and Green Investments - Robustness IV results

| Dependent variable →   | [1]        | [2]        | [3]        | [4]       | [5]        | [6]       | [7]       | [8]       | [9]       |
|--|------------|------------|------------|-----------|------------|-----------|-----------|-----------|-----------|
| <b>Panel A: P-values corrected for multiple hypothesis testing</b> |            |            |            |           |            |           |           |           |           |
| Credit constrained   | -0.5931**  | -0.6705**  | -0.5278*   | -0.5229   | -0.4788*   | -0.271    | -0.2688   | -0.1872   | 0.0280    |
| <i>p</i> -value original model                                     | 0.0003     | 0.0002     | 0.0011     | 0.0058    | 0.0009     | 0.0680    | 0.0371    | 0.1923    | 0.8261    |
| Romano-Wolf FWER <i>p</i> -value                                   | 0.0440     | 0.0350     | 0.0719     | 0.1019    | 0.0719     | 0.3137    | 0.2438    | 0.4985    | 0.8472    |
| Green management   | 0.3143***  | 0.3084***  | 0.2185***  | 0.3245*** | 0.1784**   | 0.3791*** | 0.4312*** | 0.3789*** | 0.4160*** |
| <i>p</i> -value original model                                     | 0.0000     | 0.0000     | 0.0000     | 0.0000    | 0.0006     | 0.0000    | 0.0000    | 0.0000    | 0.0000    |
| Romano-Wolf FWER <i>p</i> -value                                   | 0.0020     | 0.0020     | 0.0020     | 0.0020    | 0.0140     | 0.0010    | 0.0010    | 0.0020    | 0.0010    |
| Firm controls  | ✓          | ✓          | ✓          | ✓         | ✓          | ✓         | ✓         | ✓         | ✓         |
| Bank branch controls   | ✓          | ✓          | ✓          | ✓         | ✓          | ✓         | ✓         | ✓         | ✓         |
| Country FE   | ✓          | ✓          | ✓          | ✓         | ✓          | ✓         | ✓         | ✓         | ✓         |
| Sector FE  | ✓          | ✓          | ✓          | ✓         | ✓          | ✓         | ✓         | ✓         | ✓         |
| Locality size FE   | ✓          | ✓          | ✓          | ✓         | ✓          | ✓         | ✓         | ✓         | ✓         |
| Observations   | 11,233     | 11,233     | 11,233     | 11,233    | 11,233     | 11,233    | 11,233    | 11,233    | 11,233    |
| Clusters   | 2,226      | 2,226      | 2,226      | 2,226     | 2,226      | 2,226     | 2,226     | 2,226     | 2,226     |
| <b>Panel B: Standard errors corrected for spatial correlation</b>  |            |            |            |           |            |           |           |           |           |
| Credit constrained   | -0.5931*** | -0.6705*** | -0.5278*** | -0.5229** | -0.4788*** | -0.2710*  | -0.2688*  | -0.1872   | 0.0280    |
|  | (0.2098)   | (0.2175)   | (0.1824)   | (0.2104)  | (0.1578)   | (0.1600)  | (0.1372)  | (0.1452)  | (0.1826)  |
| Green management   | 0.3143***  | 0.3084***  | 0.2185***  | 0.3245*** | 0.1784***  | 0.3791*** | 0.4312*** | 0.3789*** | 0.4160*** |
|  | (0.0566)   | (0.0771)   | (0.0535)   | (0.0789)  | (0.0539)   | (0.0520)  | (0.0619)  | (0.0659)  | (0.0689)  |
| Firm controls  | ✓          | ✓          | ✓          | ✓         | ✓          | ✓         | ✓         | ✓         | ✓         |
| Bank branch controls   | ✓          | ✓          | ✓          | ✓         | ✓          | ✓         | ✓         | ✓         | ✓         |
| Country FE   | ✓          | ✓          | ✓          | ✓         | ✓          | ✓         | ✓         | ✓         | ✓         |
| Sector FE  | ✓          | ✓          | ✓          | ✓         | ✓          | ✓         | ✓         | ✓         | ✓         |
| Locality size FE   | ✓          | ✓          | ✓          | ✓         | ✓          | ✓         | ✓         | ✓         | ✓         |
| Observations   | 11,233     | 11,233     | 11,233     | 11,233    | 11,233     | 11,233    | 11,233    | 11,233    | 11,233    |

*Notes:* This table presents IV regressions (Panel B, Table 1) to estimate the relation between, on the one hand, firm-level credit constraints and the quality of green management and, on the other hand, firm-level green investments. All regressions include firm-level controls (indicators for exporter status, listed firm, sole proprietorship and audited financial accounts, as well as the log of firm age); locality-level credit market controls (log average size of assets of banks in a 15 km radius and the number of bank branches in a 15 km radius) and population size class; and country and sector fixed effects. Table A1 contains all variable definitions and Table A3 provides summary statistics. Robust standard errors are clustered by locality and shown in parentheses. Panel A presents Romano-Wolf FWER *p*-values corrected for multiple-hypothesis testing. Panel B presents standard errors corrected for spatial correlation using the `acreg` Stata command and following Colella et al. (2019). \*\*\*, \*\* and \* correspond to the 1%, 5%, and 10% level of significance.

Table A6: 2nd Stage IV Diagnostics

| Dependent variable →                     | [1]                          | [2]                    | [3]                    | [4]                                   | [5]                     | [6]                   | [7]                       | [8]                           | [9]                        |
|--|------------------------------|------------------------|------------------------|---------------------------------------|-------------------------|-----------------------|---------------------------|-------------------------------|----------------------------|
|  | Green investment (indicator) | Machinery upgrade      | Vehicle upgrade        | Improved heating / cooling / lighting | Green energy generation | Waste and recycling   | Energy / water management | Air / other pollution control | Energy efficiency measures |
| Credit constrained                       | -0.5931***<br>(0.1657)       | -0.6705***<br>(0.1811) | -0.5278***<br>(0.1620) | -0.5229***<br>(0.1897)                | -0.4788***<br>(0.1440)  | -0.2710*<br>(0.1485)  | -0.2688**<br>(0.1289)     | -0.1872<br>(0.1436)           | 0.0280<br>(0.1275)         |
| Green management                         | 0.3143***<br>(0.0471)        | 0.3084***<br>(0.0578)  | 0.2185***<br>(0.0479)  | 0.3245***<br>(0.0701)                 | 0.1781***<br>(0.0518)   | 0.3791***<br>(0.0479) | 0.4312***<br>(0.0438)     | 0.3789***<br>(0.0598)         | 0.4160***<br>(0.0497)      |
| Firm controls                            | Yes                          | Yes                    | Yes                    | Yes                                   | Yes                     | Yes                   | Yes                       | Yes                           | Yes                        |
| Bank branch controls                     | Yes                          | Yes                    | Yes                    | Yes                                   | Yes                     | Yes                   | Yes                       | Yes                           | Yes                        |
| Country FE                               | Yes                          | Yes                    | Yes                    | Yes                                   | Yes                     | Yes                   | Yes                       | Yes                           | Yes                        |
| Sector FE                                | Yes                          | Yes                    | Yes                    | Yes                                   | Yes                     | Yes                   | Yes                       | Yes                           | Yes                        |
| Locality size FE                         | Yes                          | Yes                    | Yes                    | Yes                                   | Yes                     | Yes                   | Yes                       | Yes                           | Yes                        |
| Observations                             | 11,233                       | 11,233                 | 11,233                 | 11,233                                | 11,233                  | 11,233                | 11,233                    | 11,233                        | 11,233                     |
| Clusters                                 | 2,226                        | 2,226                  | 2,226                  | 2,226                                 | 2,226                   | 2,226                 | 2,226                     | 2,226                         | 2,226                      |
| LM test for underidentification          | 56.9324                      | 56.9324                | 56.9324                | 56.9324                               | 56.9324                 | 56.9324               | 56.9324                   | 56.9324                       | 56.9324                    |
| <i>p</i> -value of underidentification   | 0.0000                       | 0.0000                 | 0.0000                 | 0.0000                                | 0.0000                  | 0.0000                | 0.0000                    | 0.0000                        | 0.0000                     |
| Stock-Wright LM S statistic              | 53.6023                      | 48.5627                | 54.9165                | 52.4523                               | 59.5948                 | 53.6357               | 48.1677                   | 45.2662                       | 43.0998                    |
| Stock-Wright S stat <i>p</i> -value      | 0.0000                       | 0.0000                 | 0.0000                 | 0.0000                                | 0.0000                  | 0.0000                | 0.0000                    | 0.0000                        | 0.0000                     |
| Anderson-Rubin Wald test                 | 17.9608                      | 14.7352                | 11.0143                | 12.2691                               | 9.6714                  | 14.1900               | 21.7349                   | 10.9286                       | 11.5334                    |
| Anderson-Rubin Wald test <i>p</i> -value | 0.0000                       | 0.0000                 | 0.0000                 | 0.0000                                | 0.0000                  | 0.0000                | 0.0000                    | 0.0000                        | 0.0000                     |
| Anderson-Rubin chi2 test                 | 72.2035                      | 59.2361                | 44.2779                | 49.3223                               | 38.8795                 | 57.0447               | 87.3753                   | 43.9337                       | 46.3648                    |
| Anderson-Rubin chi2 test <i>p</i> -value | 0.0000                       | 0.0000                 | 0.0000                 | 0.0000                                | 0.0000                  | 0.0000                | 0.0000                    | 0.0000                        | 0.0000                     |
| F statistic for weak identification      | 32.2442                      | 32.2442                | 32.2442                | 32.2442                               | 32.2442                 | 32.2442               | 32.2442                   | 32.2442                       | 32.2442                    |
| Hansen J statistic                       | 1.7595                       | 0.3842                 | 0.7437                 | 0.8388                                | 7.0125                  | 4.7038                | 1.6099                    | 2.2236                        | 8.1879                     |
| Hansen J <i>p</i> -value                 | 0.4149                       | 0.8252                 | 0.6894                 | 0.6574                                | 0.0300                  | 0.0952                | 0.4471                    | 0.3290                        | 0.016                      |

Notes: This table provides several diagnostic tests related to the instrumentation strategy used in Panel B of Table 1.

Table A7: Facility-Level Credit Constraints, Green Management, and Air Pollution

| Dependent variable →        | Air pollutants          |                    |                   | Gas emissions into the air |                    |                    |
|-----------------------------|-------------------------|--------------------|-------------------|----------------------------|--------------------|--------------------|
|                             | 2015                    | 2016               | 2017              | 2015                       | 2016               | 2017               |
|                             | [1]                     | [2]                | [3]               | [4]                        | [5]                | [6]                |
| Regional credit constraints | 7.664**<br>(3.682)      | 8.082**<br>(3.601) | 6.696*<br>(3.570) | 7.893**<br>(3.693)         | 8.094**<br>(3.615) | 7.082**<br>(3.588) |
| Regional green management   | -<br>2.193**<br>(1.064) | -1.245<br>(1.046)  | -0.957<br>(1.043) | -2.054*<br>(1.068)         | -1.238<br>(1.047)  | -0.818<br>(1.047)  |
| Firm controls               | ✓                       | ✓                  | ✓                 | ✓                          | ✓                  | ✓                  |
| Credit market controls      | ✓                       | ✓                  | ✓                 | ✓                          | ✓                  | ✓                  |
| Country FE                  | ✓                       | ✓                  | ✓                 | ✓                          | ✓                  | ✓                  |
| Sector FE                   | ✓                       | ✓                  | ✓                 | ✓                          | ✓                  | ✓                  |
| Locality size FE            | ✓                       | ✓                  | ✓                 | ✓                          | ✓                  | ✓                  |
| R-squared                   | 0.251                   | 0.251              | 0.255             | 0.257                      | 0.260              | 0.260              |
| Observations                | 3,892                   | 3,892              | 3,892             | 3,892                      | 3,892              | 3,892              |

*Notes:* This table presents OLS regressions to estimate the relation between, on the one hand, credit constraints and the quality of green management at the subnational regional level and, on the other hand, facility-level air pollution (columns 1-3) and facility-level gas emissions into the air (columns 4-6). All columns use a hyperbolic sine transformation of the dependent variable. The sample consists of all facilities that appear in E-PRTR in each year during 2015-17. For each E-PRTR facility in industry  $i$ , a value for the variables *Regional credit constraints* and *Regional green management* is calculated as averages of the predicted values from Table 2 across all firms in the same subnational region except for those in industry  $i$  itself. All regressions include firm-level controls (indicators for listed and delisted firms and the log of firm age); locality-level credit market controls (log average size of assets of banks in a 15 km radius and the number of bank branches in a 15 km radius) and population size class; and country and sector fixed effects. Table A1 contains all variable definitions and Table A3 provides summary statistics. Bootstrapped standard errors are clustered by facility and shown in parentheses. \*\*\*, \*\* and \* correspond to the 1%, 5%, and 10% level of statistical significance.

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