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FINANCE AND GREEN GROWTH

Abstract

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JEL Classification: G10, O4, Q5

Keywords: Financial Development, Financial structure, Carbon Emissions, Innovation

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Finance and Green Growth*

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Abstract

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1 Introduction

The 2015 Paris Climate Conference (COP21) has put finance firmly at the heart of the debate on climate change. The leaders of the G20 stated their intention to scale up green-finance initiatives to fund low-carbon infrastructure and other climate solutions. Key examples include the burgeoning market for green bonds, the establishment of the British Green Investment Bank, and the creation of a green credit department by the largest bank in the world—ICBC in China.

Somewhat paradoxically, the interest in green finance has also laid bare our limited understanding of the relation between regular finance and the environment. To date, no rigorous evidence exists on how finance affects industrial pollution as economies grow. Are expanding banking sectors and stock markets detrimental to the environment as they fuel economic growth and the concomitant emission of pollutants? Or can financial development steer economies towards sustainable growth by favoring "green" sectors over "brown" ones? A better understanding of the link between finance and pollution is important because most of the global transition to a low-carbon economy will need to be funded by the private financial sector if international climate goals are to be met on time (UNEP, 2011). Insights into how banks and stock markets affect carbon emissions can also help policy makers to benchmark the ability of special green-finance initiatives to cut emissions.

To analyze the channels that connect finance, industrial composition, and environmental degradation—as measured by the emission of CO_2—we exploit a 48-country, 16-industry, 26-year panel.[1] To preview our results, we first demonstrate that for given levels of economic and financial development, CO_2 emissions per capita are significantly lower in economies where equity financing is more important relative to bank lending. Subsequent analysis at the industry level shows that industries that pollute more for technological reasons, start to emit relatively less carbon dioxide where and when stock markets expand. Our analysis reveals two distinct channels that underpin these results. First—holding cross-industry differences in technology constant—stock markets tend to reallocate investment towards more carbon-efficient sectors. Second, stock markets facilitate the development of cleaner technologies by

[1] CO_2 emissions are the main source of global warming as they account for over half of all radiative forcing (net solar retention) by the earth (IPCC, 1990; 2007). The monitoring and regulation of anthropogenic CO_2 emissions is therefore at the core of international climate negotiations. CO_2 emissions also proxy for other air pollutants caused by fossil fuels such as methane, carbon monoxide, SO_2, and nitrous oxides.

polluting industries. In particular, we show that deeper stock markets are associated with more green patenting in carbon-intensive industries. This patenting effect is strongest for inventions to increase the energy efficiency of industrial production. In line with this positive role of stock markets for green innovation, our industry-level data show that carbon emissions per unit of value added decline relatively more in carbon-intensive sectors in countries where stock markets account for an increasing share of all corporate funding. Additional analysis shows that neither the reallocation of investment towards more energy-efficient sectors nor the increased energy efficiency in carbon-intense sectors are merely side effects of sectoral variation in R&D-intensity or firms' reliance on tangible assets.

The domestic green benefits of more developed stock markets may be offset by more pollution abroad, for instance because equity-funded firms offshore the most carbon-intensive parts of their production processes to foreign pollution havens. We show that the reduction in emissions by carbon-intensive sectors due to domestic stock market development is indeed accompanied by an increase in carbon embedded in imports of final and intermediary goods of the same sector. This effect is stronger for 'footloose' industries that can more easily outsource part of their production abroad. However, the domestic greening effect dominates the pollution outsourcing effect by a factor of ten. This indicates that stock markets have a genuine cleansing effect on polluting industries and do not simply help such industries to shift carbon-intensive activities to pollution havens.

A concern in interpreting our industry-level panel evidence is the influence of omitted factors that could confound the observed relation between the relative importance of stock markets and the CO_2 emissions of relatively polluting sectors. We deal with this issue in three ways. First, and most importantly, we saturate our regressions with an exhaustive set of interactive fixed effects (country-industry fixed effects as well as unobservable country and industry trends). These fixed effects control for a host of potential confounding factors, including general economic development and changes in environmental regulation. Second, we employ policy shocks to both equity markets and banking sectors as instruments for the size and structure of financial systems across countries and years. Third, we take advantage of the fact that one of the countries in our sample, Belgium, introduced a notional interest deduction (NID) for corporate equity in 2006. This policy shock provides an exogenous source of variation to the cost of equity financing. Using firm-level data from Orbis and the European Emissions Trading System (ETS), we trace how the NID reform caused Belgian firms to increase their equity ratio (by about 5% of the sample mean) and to reduce the carbon intensity of their production. Importantly, these results also hold in a difference-in-differences setting where we compare the treated Belgian firms to a control group of firms in the Netherlands (a neighboring country that did not reform its corporate tax law but was exposed to similar economic shocks). The results also hold when we match Belgian firms to observationally similar firms in the same 2-digit industry from a broader set of neighboring countries and again apply a difference-in-differences framework.

This paper contributes to (and connects) three strands of the literature. First, we inform the debate on economic growth and environmental pollution. Early work on this topic focused on the environmental Kuznets hypothesis, according to which pollution increases at early development stages but declines once a country surpasses a certain income level. Two main mechanisms underlie this hypothesis. First, during the early stages of development, a move from agriculture to manufacturing and heavy industry is associated with both higher incomes and more pollution per capita. After some point, the economy moves towards light industry and services, and this shift goes hand-in-hand with a leveling off or even a reduction in pollution (Hettige, Lucas, and Wheeler, 1992 and Hettige, Mani, and Wheeler, 2000). Second, when economies develop, breakthroughs at the technological frontier (or the adoption of technologies from more advanced countries) may substitute clean for dirty technologies and reduce pollution per unit of value added (within a given sector).

While empirical work provides evidence for a Kuznets curve for a variety of pollutants, the evidence for CO_2 emissions is mixed.[2] Schmalensee, Stoker, and Judson (1998) find an inverse U-curve in the relationship between per capita GDP and CO_2 emissions while Holtz-Eakin and Selden (1995) show that CO_2 emissions increase with per capita GDP but merely stabilize when economies reach a certain income level. Our contribution is to explore the role of finance in shaping the relation between economic growth and carbon emissions. In particular, we assess how a country's financial structure—the relative importance of stock markets versus banks as corporate funding sources—affects the two main channels that underpin the Kuznets hypothesis: a shift towards less-polluting sectors and an innovation-driven reduction in pollution within sectors.

Second, a more recent literature views the link between growth and environmental pollu-

[2]Grossman and Krueger (1995) find a Kuznets curve for the pollution of urban air and river basins. See Dasgupta, Laplante, Wang, and Wheeler (2002) for a literature review on the environmental Kuznets curve.

tion through the lens of endogenous growth theory (Aghion and Howitt, 1998). Acemoglu, Aghion, Bursztyn, and Hemous (2012) and Acemoglu, Akcigit, Hanley, and Kerr (2016) develop endogenous growth models with directed technical change. In these models, sustainable growth depends on temporary carbon taxes and research subsidies that redirect innovation towards clean technologies.[3] A key macro parameter in these models is the elasticity of substitution between clean (energy efficient) and dirty (carbon intense) production.[4] Within a country, this substitution can reflect that industries become cleaner over time or that resources shift towards sectors with a higher share of clean energy inputs. Our contribution is to show how (changes in) the structure of a country's financial system can shape both these drivers of the elasticity of substitution between clean and dirty inputs.

Third, our results contribute to the literature on the relation between financial structure and economic development. A substantial body of empirical evidence has by now established that growing financial systems contribute to economic growth in a causal sense (King and Levine, 1993).[5] Earlier studies suggested that the structure of the financial system—bank-based or market-based—matters little: both credit markets and stock markets contribute positively to economic growth (Levine and Zervos, 1998; Beck and Levine, 2002; Jerzmanowski, 2017). However, more recent research qualifies this finding by showing that the impact of banking on growth declines (and the impact of stock markets increases) as national income rises (Demirgüç-Kunt, Feyen, and Levine, 2013; Gambacorta, Yang, and Tsatsaronis, 2014), potentially explaining growth threshold effects in overbanked economies (Arcand, Berkes, and Panizza, 2015). Our contribution is to show that the structure of the financial system also matters for the degree of environmental degradation that accompanies the process of economic development.

This paper is structured as follows. Section 2 discusses the link between financial structure and carbon emissions. Sections 3 and 4 then describe our empirical methodology and data, respectively. Section 5 presents the empirical results and Section 6 concludes.

[3] Empirically, Aghion, Dechezleprêtre, Hemous, Martin, and Van Reenen (2016) show how higher fuel prices redirect the car industry towards clean innovation (electric and hybrid technologies) and away from dirty technology (internal combustion engines).

[4] Using industry-level data, Papageorgiou, Saam, and Schulte (2017) estimate that this elasticity is relatively high, at just below three, for the aggregate non-energy sector of the economy.

[5] For comprehensive surveys of this literature, see Levine (2005), Beck (2008), and Popov (2018).

2 Stock Markets, Banks, and Carbon Emissions

Financial structure, defined as the relative importance of equity versus credit markets, can have an environmental impact if different forms of finance affect environmental pollution to a different extent or through different channels. The existing literature suggests several reasons why banks and stock markets may differentially affect industrial pollution.

On the banking side, three main arguments have been made. First, banks typically operate with a relatively short horizon (the loan maturity) and may ignore whether funded assets will become less valuable (or even stranded) in the more distant future. Ongena, Delis, and de Greiff (2018) show how banks only recently started to price the climate risk of lending to firms with large fossil fuel reserves. Anecdotal evidence also suggests that in recent years banks became more sensitive to the financial and reputational risks associated with lending to polluting firms (Zeller, 2010). Such a narrow focus on reputational risk and environmental liability may of course not prevent banks with a short-term horizon from lending to less visibly polluting industries, like those emitting large amounts of CO_2.

Second, there is a large body of evidence indicating that bank lending (and debt funding more generally) is ill-suited to finance innovative, high-risk–high-return projects. To the extent that technological innovation is an important mechanism to contain environmental pollution, this implies that banks may be relatively ineffective in reducing such pollution. Several mechanisms can play a role. Banks may be technologically conservative: they fear that funding new (and possibly cleaner) technologies erodes the value of collateral that underlies existing loans that represent older (dirtier) technologies (Minetti, 2011). Banks can also hesitate to finance green technologies if these involve assets that are intangible and firm-specific (Hall and Lerner, 2010) and therefore difficult to collateralize (Carpenter and Petersen, 2002). Asset intangibility and uncertainty are indeed characteristic of many energy technology startups (Nanda, Younge, and Fleming, 2015). Lastly, banks may simply lack the skills to assess early-stage (green) technologies (Ueda, 2004).[6]

Third, even if banks ignore environmental risk due to their short-term horizon (at least until recently), and even if they are badly equipped to finance frontier innovation, their lending may still alleviate firms' financial constraints, including constraints that hold back

[6]In line with this skeptical view of banks as financiers of innovative technologies, Hsu, Tian, and Xu (2014) provide cross-country evidence that industries that depend on external finance and are high-tech intensive are less likely to file patents in countries with more developed credit markets.

investment in pollution abatement. In line with this, Levine, Lin, Wang, and Xi (2018) show how positive credit supply shocks in U.S. counties reduced 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.

What about stock markets? First, mirroring the above arguments, equity may be better suited to finance high-risk–high-return innovations, including new technologies to increase energy efficiency and reduce carbon emissions.[7] Second, if equity investors care about (future) pollution costs, then stock prices will rationally discount cash flows of polluting industries. A key question is therefore to what extent investors take carbon emissions into account when assessing longer-term corporate risk. Hart and Zingales (2017) develop a model predicting that public firms, with their diffuse ownership and limited personal responsibility of each voting investor, display an 'amoral drift' away from pro-social decisions, in contrast to closely held private firms. In line with this, Shive and Forster (2020) find that private firms in the U.S. emit fewer greenhouse gases as compared to otherwise similar public firms.

Yet, a growing body of evidence suggests that investors, especially institutional ones, increasingly do take longer-term climate-change related risk into account and put pressure on companies to reduce carbon emissions. Survey evidence by Krueger, Sautner, and Starks (2020) shows that a large proportion of investment managers believe that climate risk is already affecting their portfolio companies. Almost 40 percent of the surveyed investors are therefore aiming to reduce the carbon footprint of their portfolios, including through active engagement with management.[8] Gibson Brandon and Krueger (2018) find that especially institutional investors with a longer-term horizon hold equity portfolios with a better environmental footprint. Dyck et al. (2019) show likewise that institutional shareholder ownership is positively and causally related to firms' environmental and social performance. Ormazabal et al. (2020) focus on the "Big Three" institutional investors (BlackRock, Vanguard and State Street Global Advisors) and find a strong negative association between the

[7]Brown, Martinsson, and Petersen (2017) show that while credit markets foster growth in industries that rely on external finance for physical capital accumulation, equity markets have a comparative advantage in financing technology-led growth. In line with this, Kim and Weisbach (2008) find that most of the funds that firms raise in public stock issues are invested in R&D.

[8]Oil majors recently gave in to investor pressure to disclose the impact of climate policies on future activities (ExxonMobil) or to set carbon emissions targets (Royal Dutch Shell). Glencore, a coal mining company, announced that in response to investor demands it would cap coal production (Financial Times, 2017; The Economist, 2018; Wall Street Journal, 2019).

ownership of equity by these investors, especially when they hold a significant stake, and firms' subsequent carbon emissions. Mutual funds and other institutional investors may also benefit from pushing companies to reduce carbon emissions because this helps to attract environmentally responsible investment clients (Ceccarelli, Ramelli and Wagner, 2020). In line with this, Hartzmark and Sussman (2019) show how a sudden increase in the transparency of U.S. mutual funds' sustainability ratings led to net inflows (outflows) into high-sustainability (low-sustainability) funds.

Investor concerns about corporate exposure to climate-change risk is also affecting asset prices and firms' funding costs. Ilhan, Sautner, and Vilkov (2020) show for a sample of S&P 500 companies that higher emissions increase tail risk in put options and that this effect is concentrated in high-emission industries. This suggests that stock market participants, in particular institutional investors, take carbon emissions into account when assessing corporate risk. Likewise, Bolton and Kacperczyk (2020) find that stocks of U.S. firms with higher carbon emissions earn higher returns.[9] Moreover, institutional investors appear to shun carbon-intensive companies, although this effect is limited to direct emissions from production and to the most carbon-intense industries.

In sum, whether banks or stock markets are better suited to reducing carbon emissions remains an important open question. The aim of this paper is therefore to provide robust empirical evidence—at the country, industry, and firm level—on the link between a country's financial structure and the amount of carbon dioxide that firms emit.

3 Empirical Methodology and Identification

We first estimate a regression to map financial sector trends into carbon emissions and where countries are the unit of observation. In doing so, we distinguish between the size and the structure of the financial system. We define financial sector size (or *Financial Development, FD*) as the sum of private credit and stock market capitalization divided by the country's

[9] Cheng, Ioannou, and Serafeim (2014) confirm for a cross-country sample of listed firms that increased environmental responsibility improves firms' access to finance. Chava (2014) shows how the environmental profile of a firm affects both the cost of its equity and its debt capital, suggesting that both banks and equity investors take environmental concerns into account. Higher capital costs can be an important channel through which investor concerns affect firm behavior and their pollution intensity. If higher capital costs outweigh the cost of greening the production structure, firms will switch to a more expensive but less polluting technology (Heinkel, Kraus, and Zechner, 2001).

gross domestic product:

$$FD_{c,t} = \frac{Credit_{c,t} + Stock_{c,t}}{GDP_{c,t}} \tag{1}$$

Next, we define *Financial Structure* (FS) as the share of stock market financing out of total financing through credit and stock markets:

$$FS_{c,t} = \frac{Stock_{c,t}}{Credit_{c,t} + Stock_{c,t}} \tag{2}$$

In both cases, $Credit$ is the sum of credit extended to the private sector by deposit money banks and other credit institutions while $Stock$ is the value of all publicly traded shares.

With these proxies at hand, we proceed to estimate the following specification:

$$\frac{CO_{2c,t}}{Population_{c,t}} = \beta_1 FD_{c,t-1} + \beta_2 FS_{c,t-1} + \beta_3 X_{c,t-1} + \varphi_c + \phi_t + \varepsilon_{c,t} \tag{3}$$

Here, $\frac{CO_{2c,t}}{Population_{c,t}}$ denotes total per capita emissions of carbon dioxide in country c during year t. Both *Financial Development* (FD) and *Financial Structure* (FS) are 1-period lagged. $X_{c,t-1}$ is a vector of time-varying country-specific variables, such as the state of environmental regulation, that can account for a sizeable portion of the variation in cross-country CO_2 emissions. Another important factor is economic development, the pollution impact of which can be positive at early stages of development as the economy utilizes the cheapest technologies available, and negative at later stages when the economy innovates to reduce pollution (one of the environmental Kuznets-curve arguments). We account for this by including the logarithm of per capita GDP, both on its own and squared. The phase of the business cycle can also have an impact on pollution. For example, the economy may cleanse itself from obsolete technologies during recessions.[10] To account for this, we include a dummy equal to 1 if the economy experiences negative growth.

[10] See Gali and Hammour (1991) and Caballero and Hammour (1994). Recessions may involve an environmental cleansing effect when inferior-technology companies are also the least energy efficient ones. A recession will then prune these companies and improve the energy efficiency of the average (surviving) firm. Any such positive effects may be counterbalanced, however, if renewable energy investments are put on hold, thus delaying the introduction of cleaner technologies. Indeed, Campello, Graham, and Harvey (2010) show that firms that were financially constrained during the global financial crisis cut spending on technology and capital investments and bypassed attractive investment opportunities.

φ_c is a vector of country dummies that net out the independent impact on carbon emissions of unobservable country-specific time-invariant influences, such as comparative advantage or voters' appetite for regulation. ϕ_t is a vector of year dummies that purge our estimates from the effect of unobservable global trends common to all countries, such as the "Great Moderation", the adoption of a new technology across countries around the same time, or a collapse in the demand for tradeables that reduces transportation intensity. Finally, $\varepsilon_{c,t}$ is an idiosyncratic error term. We cluster the standard errors by country to account for the possibility that they are correlated within a country over time.

Interpreting the results from Model (3) as causal assumes that financial development is unaffected by current or expected per capita carbon emissions, and that carbon intensity and financial development are not affected by a common factor. The latter assumption is questionable. For example, if global demand increases for products by carbon-intensive industries that rely on external finance, CO_2 emissions and *Financial Development* increase simultaneously without there necessarily being a causal link from finance to carbon emissions. Alternatively, a reduction in income taxes can result simultaneously in higher stock market investment and higher consumption, inducing a spurious positive correlation between *Financial Structure* and carbon emissions. We address this point through a Two-Stage Least Squares (2SLS) procedure in which policy changes induce exogenous shocks to financial system size and structure. The first instrument measures pro-competitive bank regulation, based on Abiad et al. (2008). It captures the degree to which domestic banking markets are open to entry by foreign banks; open to entry by new domestic banks; open to branching by existing banks; and open to the emergence of universal banks. The idea behind this instrument is that bank liberalization should increase the size but reduce the equity share of the financial system. The second instrument measures equity market liberalization (Bekaert et al., 2005) and is a dummy equal to one in the years after equity markets open up to investment by foreign investors. The idea is that opening up to foreign portfolio investment should increase the equity share of the domestic financial system. Because both instruments focus specifically on *financial* liberalization events, we expect the exclusion restriction to be met as these shocks only influence carbon emissions through their impact on the size and/or the structure of a country's financial system.

Next, in the main part of our analysis, we estimate the impact of *Financial Development* and *Financial Structure* on carbon emissions at the sector level. More specifically, we assess the relative role of within-country financial development and financial structure for different types of industries, depending on their technological propensity to emit carbon dioxide. The working hypothesis is that shocks to the size and structure of financial systems impact differentially per capita carbon emissions in carbon-intensive relative to carbon-light industries in one and the same country. To test this hypothesis, we employ the following cross-country, cross-industry regression framework:

$$\begin{aligned}\frac{CO_{2c,s,t}}{Population_{c,t}} = \; & \beta_1 FD_{c,t-1} \times Carbon\ intensity_s + \beta_2 FS_{c,t-1} \times Carbon\ intensity_s \\ & + \beta_3 X_{c,s,t-1} + \varphi_{c,s} + \phi_{c,t} + \theta_{s,t} + \varepsilon_{c,s,t}\end{aligned} \tag{4}$$

Here, $\frac{CO_{2c,s,t}}{Population_{c,t}}$ denotes total per capita emissions of carbon dioxide by industry s in country c during year t.[11] As in Model (3), $FD_{c,t-1}$ is the sum of total bank credit to the private sector and the total value of all listed shares, normalized by GDP, in country c during year $t-1$. $FS_{c,t-1}$ is the total value of all listed shares, divided by the sum of total credit to the private sector and the value of all listed shares, in country c during year $t-1$. $Carbon\ intensity_s$ is a time-invariant, sector-specific variable that measures the average carbon dioxide emissions of sector s per unit of value added, in the global sample during the sample period (see Table 1). The underlying assumption is that the global average of a sector's emissions per unit of value added captures the sector's inherent propensity to pollute. In robustness tests, we employ a proxy for $Carbon\ intensity_s$ that captures average carbon dioxide emissions by the respective sector in the United States (over the sample period) and another one based on the industry's global average emissions in any given year.

In the most saturated version of Model (4), we control for $X_{c,s,t-1}$, a vector of interactions between the industry benchmark for carbon intensity and time-varying country-specific factors that capture economic development (GDP per capita), the size of the market (population), and the business cycle (whether the country is in a recession). This controls for the possibility that the association between financial development and carbon emissions is contaminated by concurrent developments in a country's economy. Lastly, we saturate the empirical specification with interactions of country and sector dummies ($\varphi_{c,s}$), interactions of country and year dummies ($\phi_{c,t}$), and interactions of sector and year dummies ($\theta_{s,t}$). $\varphi_{c,s}$

[11] We express the industry-level carbon dioxide emissions in per capita terms to have uniform scaling across countries; make the coefficients comparable to those in the country-level regressions; and to allow the industry effects to sum up to aggregate effects.

nets out all variation that is specific to a sector in a country and does not change over time (e.g., the comparative advantage of agriculture in France). $\phi_{c,t}$ eliminates the impact of unobservable, time-varying factors that are common to all industries within a country (e.g., voters' demand for environmental protection). $\theta_{s,t}$ controls for all variation coming from unobservable, time-varying factors that are specific to an industry and common to all countries (e.g., technological development in air transport).[12]

In the next two steps, we test for the channels via which financial systems exert an impact on carbon emissions. The first channel is one whereby—holding technology constant—financial markets (or some types thereof) reallocate investment away from technologically carbon-intensive towards technologically 'green' industries. This channel manifests itself if energy-efficient sectors grow relatively faster in countries dominated by either banks or stock markets. The second channel is one whereby—holding the industrial structure constant—some forms of finance are better at improving the energy efficiency of technologically 'dirty' industries, bringing them closer to their technological frontier. This channel will result in carbon-intensive sectors becoming greener over time in countries dominated by either banks or stock markets.

We test for the presence of the first channel using the following regression model:

$$\begin{aligned}\Delta Value\ \ added_{c,s,t} = \ & \beta_1 FD_{c,t-1} \times Carbon\ intensity_s + \beta_2 FS_{c,t-1} \times Carbon\ intensity_s \\ & + \beta_3 X_{c,s,t-1} + \varphi_{c,s} + \phi_{c,t} + \theta_{s,t} + \varepsilon_{c,s,t}\end{aligned} \tag{5}$$

where relative to Model (4), the only change is that the dependent variable is now the percentage change in value added between year $t-1$ and year t by industry s in country c. The evolution of this variable over time measures the industry's growth relative to other industries in the country. It can therefore capture the degree of reallocation that takes place in the economy from technologically carbon-intensive towards technologically green

[12] Institutional investors may avoid carbon-intensive sectors (Bolton and Kacperczyk, 2020). Any variation in institutional ownership at the sector-country and year-country level will be absorbed by our fixed effects. Yet, institutional ownership at the country-sector level may also evolve over time and this change may be correlated with our main independent variable of interest, the interaction between financial structure and a sector's carbon intensity. We do not disentangle this potential role of changes in institutional ownership in stock markets (at the country-year-sector level) from the more general impact of changes in financial structure, but acknowledge that this is a potentially important mechanism through which stock market development can affect sectoral carbon emissions.

industries. Earlier work has shown how well-developed stock and credit markets make countries more responsive to global common shocks by allowing firms to better take advantage of time-varying sectoral growth opportunities (Fisman and Love, 2007). Evidence also suggests that financially developed countries increase investment more (less) in growing (declining) industries (Wurgler, 2000).

We test for the presence of the second mechanism using the following regression model:

$$\begin{aligned}\frac{CO_{2c,s,t}}{Value\ \ added_{c,s,t}} = & \ \beta_1 FD_{c,t-1} \times Carbon\ intensity_s + \beta_2 FS_{c,t-1} \times Carbon\ intensity_s \\ & +\beta_3 X_{c,s,t-1} + \varphi_{c,s} + \phi_{c,t} + \theta_{s,t} + \varepsilon_{c,s,t}\end{aligned} \tag{6}$$

where relative to Model (4), the only change is that the dependent variable is now the total emissions of carbon dioxide by industry s in country c during year t, divided by the total value added of industry s in country c during year t. The evolution of this variable over time thus measures the change in an industry's energy efficiency—that is, how dirty the production process is per unit of value added.

Lastly, to gauge whether improvements in carbon efficiency over time are due to own innovation (as opposed to technological adoption), we evaluate the following model:

$$\begin{aligned}\frac{Patents_{c,s,t}}{Population_{c,t}} = & \ \beta_1 FD_{c,t-1} \times Carbon\ intensity_s + \beta_2 FS_{c,t-1} \times Carbon\ intensity_s \\ & +\beta_3 X_{c,s,t-1} + \varphi_{c,s} + \phi_{c,t} + \theta_{s,t} + \varepsilon_{c,s,t}\end{aligned} \tag{7}$$

The dependent variable is one of several measures of green patent production, in industry s in country c during year t, divided by the population in country c in year t. These variables capture the propensity of industries to engage in green innovation. This propensity may be stronger in carbon-intensive industries as well as in countries with a more developed financial system or one dominated by a particular type of finance.

4 Data

This section introduces the four main data sources we use. We first describe the data on carbon emissions, then the industry-level data on value added and green patents, and finally the country-level data on financial development. We also discuss the matching of the industry-level data. Appendix Table A1 contains variable definitions and data sources.

4.1 CO_2 emissions

We obtain data on CO_2 emissions from fuel combustion at the sectoral level from the International Energy Agency (IEA).[13] The original data set contains information for 137 countries over the period 1974–2015. Information on CO_2 emissions is reported both at the aggregate level and for a total of 16 industrial sectors, which are based on NACE Rev. 1.1. These sectors encompass each country's entire economy, and not just the manufacturing sector, which is important given that some of the main CO_2-polluting activities, such as energy supply and land transportation, are of a non-manufacturing nature. The 16 sectors are: (1) Agriculture, hunting, forestry, and fishing; (2) Mining and quarrying; (3) Food products, beverages, and tobacco; (4) Textiles, textile products, leather, and footwear; (5) Wood and products of wood and cork; (6) Pulp, paper, paper products, printing, and publishing; (7) Chemical, rubber, plastics, and fuel products; (8) Other non-metallic mineral products; (9) Basic metals; (10) Fabricated metal products, machinery, and equipment; (11) Transport equipment; (12) Electricity, gas, and water supply; (13) Construction; (14) Land transport – transport via pipelines; (15) Water transport; and (16) Air transport.

We next produce a data set of countries that each have a fair representation of industries with non-missing CO_2 data. We drop countries that have fewer than half of the sectors with at least 10 years of CO_2 emissions data. This results in a final data set of 48 countries with at least 8 sectors with at least 10 years of CO_2 emissions data. We combine the country-level and the industry-level data on CO_2 emissions with data on each country's population, which allows us to construct the dependent variables in Models (3), (4), and (7).

4.2 Industry value added

To calculate the dependent variables in Models (5) and (6), we need industry data on value added. We obtain these from two sources. The first one is the United Nations Industrial Development Organization (UNIDO) data set, which contains data on value added in manufacturing (21 industries) for all countries in the IEA data set. The second one is the OECD's STAN Database for Structural Analysis which provides data on value added for all sectors in the economy, but it only covers the 28 OECD countries in our final data set. We can therefore calculate proxies for CO_2 emissions per unit of value added, for value added growth,

[13] 80% of anthropogenic CO_2 emissions are due to the combustion of fossil fuels (Pepper et al., 1992).

and for each sector's share of total output in the country, for two separate data sets. One contains all 48 countries with data on CO_2, as well as all manufacturing sectors, while the other comprises 28 of the 48 countries, as well as all sectors in the economy. The main tests in the paper are based on the former data set with a view to maximizing country coverage, but we also include tests based on the latter data set to maximize sector coverage. We winsorize the data on value added growth at a maximum of 100% growth and decline. To make value added by the same industry comparable across countries, we convert all nominal output into US$ and then deflate it to create a time series of real industrial output.

4.3 Green patents

To evaluate Model (7), we use the largest international patent database—the Patent Statistical database (PATSTAT) of the European Patent Office (EPO)—to calculate the number of green patents across countries, sectors, and years. Because of an average delay in data processing in PATSTAT of 3.5 years, our patent data end in 2015. We follow the methodological guidelines of the OECD Patent Statistics Manual and take the year of the priority filing as the reference year. If a patent does not have a priority filling, the reference year is the year of the application filling. This ensures that we closely track the timing of inventive performance. We take the country of residence of the inventor as the reference country. If a patent has multiple inventors from different countries, we use fractional counts: each country is attributed a corresponding share of the patent. Every patent indicator is based on data from a single patent office and we use the United States as the primary patent office.[14]

PATSTAT classifies each patent according to the International Patent Classification (IPC). We round this classification to 4-character IPC codes and use the concordance table of Lybbert and Zolas (2014) to convert these codes into ISIC 2-digit sectors.[15] We then use these data to construct three patenting variables. The first one, 'Green patents', counts all patents granted to a particular country, sector, and year and that belong to the EPO

[14]In unreported robustness checks, we calculate patent indicators using the EPO as the primary office. The correlation coefficients between the US and European indicators range between 0.75 and 0.81.

[15]PATSTAT also classifies patents according to NACE 2. A drawback of this classification is that it only covers manufacturing. Given that our scope is broader, we do not use this as our baseline approach but only in robustness checks. To ensure comparability between both approaches, we convert NACE 2 into ISIC 3.1. The correlation coefficients between both indicator types vary between 0.93 and 0.98.

Y02/Y04S climate change mitigation technology (CCMT) tagging scheme.[16] CCMTs include all technological inventions to reduce the amount of greenhouse gas emitted when producing or consuming energy. The scheme is the most reliable method for identifying green patents and has become the standard in studies on green innovation (Popp, 2019). The second variable, 'Green patents (excluding transportation and waste)', counts all granted CCMT patents except for those with the tag Y02T (Climate change mitigation technologies related to transportation) or Y02W (Climate change mitigation technologies related to solid and liquid waste treatment). The third variable, 'Green patents (industrial production)', only counts CCMT patents that belong to the arguably most important category of patents (Y02P) for our purposes: patents related to inventions to increase the energy efficiency of the industrial production or processing of goods.

4.4 Country-level data

Our measures of financial system size and structure, FD and FS, are calculated using two country-specific data series. The first one is the value of total credit by financial intermediaries to the private sector (lines 22d and 42d in the IMF International Financial Statistics) normalized by GDP. These data exclude credit by central banks, credit to the public sector, and cross claims of one group of intermediaries on another. They count credit from all financial institutions rather than only deposit money banks. The data come from Beck et al. (2016) and are available for all countries in the data set.[17] The second country-specific data series is the value of all stocks, normalized by GDP. This is a measure of the total value of traded stock, not of the intensity with which trading occurs. These data too come from Beck et al. (2016) and are available for all countries as well. The correlation between FD and FS in the sample is 0.19, suggesting that while the two variables are not excessively correlated, it is important to study their impact on carbon emissions simultaneously

Chart 1 plots the annual sample average of FD and FS between 1974 and 2015. During these four decades, the overall size of financial systems more than tripled (relative to gross domestic product). Chart 1 also shows that the relative importance of stock markets more

[16] We disregard empty sector-year-country cells, so that we effectively focus on the intensive margin of green innovation.

[17] In unreported tests, we document that the results of the paper go through (and are indeed statistically stronger) if we only use the corporate-lending segment of private credit, for those countries for which these data are available.

than doubled during this period. That is, stock markets tend to catch up with credit markets at later stages of development. One issue is that both data series are patchy before 1990, especially for Central and Eastern European countries. We therefore drop these observations so that our final data set comprises 48 countries observed between 1990 and 2015.[18]

We also use data on real per capita GDP, population, and recessions (defined as an instance of negative GDP growth) from the World Development Indicators. Lastly, we use the OECD Environmental Policy Stringency Index (EPS), a country-specific and internationally comparable measure of the stringency of environmental policy. It captures the degree to which environmental policies put an explicit or implicit price on polluting or environmentally harmful behavior and ranges between 0 (not stringent) and 6 (very stringent).[19]

4.5 Concordance and summary statistics

Our data are available in different industrial classifications. The original IEA data on carbon dioxide emissions are classified across 16 industrial sectors, using IEA's classification. The UNIDO and STAN data on value added are classified in 2-digit industrial classes using the ISIC classification. This calls for a concordance procedure to match the disaggregated ISIC sectors with the broader IEA sectors. The matching results in a total of 16 industrial sectors with data on both carbon dioxide emissions and industrial output. While some sectors are uniquely matched between IEA and UNIDO/STAN, others result from the merging of ISIC classes. For example, ISIC 15 "Food products and beverages" and ISIC 16 "Tobacco products" are merged into ISIC 15–16 "Food products, beverages, and tobacco", to be matched to the corresponding IEA industry class.

Appendix Table A2 summarizes the data. At the country level, we use aggregate CO_2 emissions (in metric tons), divided by population. The average country emits 6.78 metric tons of CO_2 per capita each year. The financial variables show that in the average country, the sum of private credit and stock market capitalization exceeds gross domestic product. However, there is a large dispersion, with FD as small as 0.03 in Azerbaijan in 1999, and as large as 4.16 in Switzerland in 2007. The same holds for FS: while the share of stock markets in the total financial system is on average 0.39, it is only one-tenth of a percent in Bulgaria in 1997, but 0.82 in Finland in 2000. The data on GDP per capita indicate that the

[18]See Online Appendix Table OA1 for a list of these countries.
[19]See Botta and Kozluk (2014) for more details.

data set contains a good mix of developing countries, emerging markets, and industrialized economies. The median country has a GDP per capita of $14,051 and a population of 14.4 million. On average, a country is in a recession once every five years.

The industry-level data from UNIDO show that the median industry emits 0.071 metric tons of carbon dioxide per capita per year, and 0.269 metric ton per US$ thousand of value added. Over the sample period, the median industry grows by 0.1% per year and makes up about 0.6% of total manufacturing. These values are relatively consistent across the UNIDO and STAN data sets. However, the median STAN industry records larger per capita emissions than the median UNIDO industry because the four heaviest polluters—ISIC 40 and 41 "Electricity, gas, and water supply," ISIC 60 "Land transport – transport via pipelines," ISIC 61 "Water transport," and ISIC 62 "Air transport"—are not manufacturing industries. In terms of green patents, the average country-industry produces around 0.2 such patents per 1 million people in both samples.

Table 1 presents the concordance key to map 62 ISIC classes into 16 IEA ones, including 9 manufacturing sectors. It also summarizes, by sector, our main industrial benchmark, 'Carbon intensity', calculated as the average emissions of carbon dioxide per unit of value added by all firms in the respective sector across the world and over the whole sample period.

5 Empirical Results

This section investigates the relation between finance and carbon emissions at the country level (Section 5.1), industry level (Section 5.2), and firm-level (Section 5.3). Section 5.4 presents robustness tests.

5.1 Finance and pollution: Aggregate results

Table 2 reports results, using aggregate data, on the link between finance and carbon emissions. We estimate three versions of Model (3). The first one is an OLS model on the full sample. The second one applies OLS to a sample of 28 OECD countries, so that we can control for environmental regulation. Third, we run a 2SLS model on the full sample, using banking liberalization and equity-market liberalization events as instruments. Because not all data are available for each country-year, the number of observations is reduced to at most

1,074 (out of a possible 1,248).

In column (1), we regress per capita carbon emissions on FD and FS, the other country controls, and country and year dummies. We fail to reject the null hypothesis that financial system size is uncorrelated with per capita carbon emissions. At the same time, controlling for the size of financial systems, per capita carbon emissions are lower in countries where firms get more of their funding from stock markets. The point estimate is significant at the 5% level. Column (2) uses the sub-sample of 28 OECD countries, so that we can control for the stringency of environmental regulation. The same pattern obtains in the data. While the overall size of financial systems is not associated with carbon emissions, when we control for this size, more equity-based economies emit fewer carbon emissions per capita. The data also confirm that more stringent environmental regulation is significantly and negatively correlated with aggregate per capita emissions, all else equal.

In both regressions, we account for the fact that financial development correlates with general economic development, and so the former may pick up the effect of higher incomes on the demand for pollution. We therefore add GDP per capita and the square thereof. In the full sample, the Kuznetz-curve effect survives controlling for financial system size and structure: per capita CO_2 emissions increase and then decrease with economic development. The specification indicates that carbon emissions start declining at an annual income of around \$65,463 which is the 95$^{\text{th}}$ percentile in our country-level income distribution.

We include two other controls, both of which have the expected sign. First, more populous countries emit fewer carbon emissions per capita, suggesting a negative pollution premium to market size. Second, recessions are associated with lower per capita CO_2 emissions. There are two explanations for this. First, output declines during a recession, reducing overall pollution too. Second, firms may use downturns to purge themselves from obsolete (and more carbon-intensive) technologies (Caballero and Hammour, 1994).

We next move to our 2SLS results. Columns (3) and (4) report the first-stage. Both instruments are significantly correlated with financial sector size and structure. By making it easier for banks to enter and branch out, bank liberalization events increase the size of financial systems. By allowing inward portfolio investment, equity market liberalization events increase the share of equity financing. The relation with the overall size of the financial system is negative, suggesting that equity liberalization tends to slow down banking sector growth (controlling for the strictness of bank regulation). The first-stage Wald statistics, reported as F-statistics, are consistent with the critical value for the IV regression to have no more than 10% of the bias of the OLS estimate (Stock and Yogo, 2005).

Column (5) provides the second-stage 2SLS results. Even when inducing exogenous shocks to FD and FS, the earlier patterns hold. Financial development on its own is uncorrelated with carbon emissions. But, importantly, for a given level of financial and economic development, a country's economy generates fewer carbon emissions per capita if it receives more of its funding from stock markets. The absolute value of the point estimate increases substantially in the 2SLS model, which suggests that unobservable factors that correlate positively with the equity share of overall finance also do so with per capita emissions.

Numerically, the point estimate in column (5) suggests that increasing the share of equity financing by 1 percentage point, while holding the size of the financial system constant, reduces aggregate per capita carbon emissions by 0.077 metric tons. What are the aggregate implications of this? We note that for several countries that are not financial centers and have large banking sectors, such as Australia, Canada, Finland, and the Netherlands, FS is approximately 0.5 throughout the sample period. Suppose that we take all countries below this threshold and lift them to $FS = 0.5$, and we leave every country with $FS > 0.5$ unchanged. For about 80% of the countries in the data set, this would imply an average increase in FS of 0.2 (from an average of around 0.3). Doing so would reduce per capita pollution by around 1.54 metric tons. Given average per capita emissions of 6.8 (Appendix Table A2), this would reduce current aggregate per capita emissions by about 22.6%. This is more than half of the 40% reduction in emissions that countries committed to achieve by 2030 in the context of the Paris Agreement.

5.2 Finance and pollution: Industry-level results

5.2.1 Per capita carbon emissions

We next turn to sector-level data. We start by constructing a proxy for each industry's natural propensity to pollute that is exogenous to pollution in each particular industry-country. Our main proxy is industry-specific average CO_2 emissions per unit of value added, calculated across all countries and years in the sample (Table 1). The assumption is that a long-term global average better reflects the technological capabilities of an industry than its performance in an individual country. In later robustness tests, we allow this benchmark to change over time to account for the possibility that the technological frontier evolves. We also take inspiration from Rajan and Zingales (1998) and calculate each industry's average CO_2 emissions per unit of value added in the United States. The assumption in this case is that an industry's pollution intensity in a country with few regulatory impediments and with deep and liquid financial markets reflects its inherent propensity to pollute.

In Table 3, we evaluate Model (4) to test whether the difference in carbon emissions by technologically more versus less carbon-intensive sectors becomes smaller in countries with financial systems that expand and/or become more skewed towards equity. Crucially, all regressions in Table 3 (and thereafter) are saturated with country-sector dummies, country-year dummies, and sector-year dummies. This ensures that the statistical associations we measure in the data are not contaminated by unobservable factors that are specific to a sector in a country and that do not change over time; by unobservable time-varying factors that are common to all industries within a country; and to unobservable, time-varying factors that are specific to an industry and common to all countries. We cluster standard errors at the country-sector level.

Table 3 confirms the findings from the aggregate tests in Table 2. Column (1) shows that carbon-intensive sectors do not generate relatively higher CO_2 emissions per capita in countries with growing financial sectors. However, in column (2) we find that carbon-intensive sectors produce relatively fewer per capita CO_2 emissions in countries with relatively rapidly expanding stock markets. This effect is significant at the 5% statistical level. We also note that sectors that produce a larger share of overall value added, pollute more per capita than smaller sectors.

These patterns hold when we include FD and FS together in column (3). Overall financial sector size again does not matter for CO_2 emissions. Yet, controlling for financial development, an increase in the equity dependence of an economy generates a larger decline in CO_2 emissions in carbon-intensive industries. Column (4) reruns the specification in the preceding column while accounting for the potential endogeneity in financial sector size and structure. We again use the indices of banking liberalization and equity market liberalization events to induce exogenous variation in the two main characteristics—size and structure—of the financial system.

The results in column (4) strongly suggest that our earlier findings are not driven by reverse causality whereby trends in carbon emissions increase an economy's relative use of equity finance, or by omitted variable bias whereby an unobservable factor causes a simultaneous decline in carbon emissions and an increase in the equity reliance of the economy. We continue to find that in countries with expanding equity markets (relative to banking sectors) carbon-intensive sectors generate fewer carbon emissions per capita. This relationship is economically meaningful too. Take a country at the 25^{th} percentile of FS (Germany) and one at the 75^{th} percentile (Australia). The interaction coefficient of pollution intensity and FS in column (4) (-0.0925) means that giving Australia's financial structure to Germany, while keeping the size of its financial system constant, would reduce CO_2 emissions by 0.14 metric tons in the most relative to the least polluting industry.

5.2.2 Channels

Our main finding so far is that per capita carbon emissions decline—more so in technologically carbon-intensive sectors—as the relative importance of equity funding grows. This raises the question via which channels equity translates into lower carbon emissions? There are two main potential channels. The first one is cross-industry reallocation whereby—holding technology constant—stock markets reallocate investment towards greener sectors. The second one is within-industry technological innovation whereby—holding industrial structure constant—industries develop and implement greener technologies when access to equity improves. We now test whether any of the two, or both, channels are operational.

Cross-industry reallocation. In Table 4, we test for the first channel using Model (5). The dependent variable is the growth in value added in an industry in a particular country and year. All regressions are again saturated with country-sector dummies, country-year dummies, and sector-year dummies. A negative coefficient on the interaction term of interest would imply that financial development reallocates investment away from carbon-intensive sectors. This test is conceptually similar to Wurgler (2000) who finds that in countries with deeper financial systems, investment is higher in booming than in declining sectors.

Column (1) shows that technologically carbon-intensive sectors do not grow at a different rate, relative to greener sectors, in countries with larger financial systems. In column (2), we find that carbon-intensive sectors grow more slowly (or, conversely, that green industries grow faster) in countries with expanding stock markets. This effect is significant at the 10% statistical level. We document the same patterns when we control for the size and structure of financial systems jointly (column (3)) and when using IV instead of OLS (column (4)). According to all specifications, larger sectors grow more slowly, a result in line with theories of growth convergence.

We conclude that our evidence supports the conjecture that—holding cross-sector differences in technology constant—stock markets promote a reallocation of investment towards greener (in the carbon-emissions sense) sectors. This partially explains the negative association between financial structure and industry-level CO_2 emissions per capita (Table 3).

Within-industry efficiency improvement. In Table 5, we test the second channel by estimating Model (6). The dependent variable is sector-level annual CO_2 emissions per unit of value added and, once again, all regressions are saturated with country-sector dummies, country-year dummies, and sector-year dummies. In this case, a negative coefficient on the interaction term of interest would imply that financial development results in a technological improvement within an environmentally dirty industry, regardless of its level of overall growth. Yet, column (1) returns no evidence that within-sector carbon efficiency is affected by changes in the size of the financial system. This aligns with our previous evidence where we found no statistical association between the size of a country's financial system and per capita carbon emissions in relatively polluting versus green sectors.

We next look at the independent role of financial structure for carbon emissions per unit of value added. Column (2) indicates that stock market development plays an important role in within-sector efficiency. In particular, carbon emissions per unit of value added decline relatively more in carbon-intensive sectors, in countries where stock market funding accounts for an increasing share of overall funding (holding overall funding constant). This effect is significant at the 1% statistical level. This pattern also obtains when we include the size and structure of financial systems simultaneously (column (3)) and when we account for the potential endogeneity in financial sector size and structure (column (4)). Indeed, the absolute value of the point estimate increases relative to the OLS case, indicating that unobservable factors that correlate positively with the equity share of overall finance also correlate positively with carbon intensity. CO_2 emissions per unit of value added would decrease significantly if a country was to convert some of its bank funding into equity financing. Going back to our earlier thought experiment, the interaction coefficient of pollution intensity and FS (-9.36) indicates that giving Germany (a country at the 25^{th} percentile of FS) the financial structure of Australia (at the 75$^{\text{th}}$ percentile of FS), while keeping the size of its financial system constant, would reduce CO_2 emissions by 2.8 metric tons per US$ 1 million of value added in the most, relative to the least, polluting industry.

Table 5 suggests that stock markets facilitate the development and/or adoption of greener technologies in carbon-intensive sectors. This evidence thus helps explain the role that stock markets play in reducing per capita carbon emissions over time, as documented in Table 3.

5.2.3 Finance and green innovation

We find that CO_2 emissions per unit of value added decline with stock market development, especially in carbon-intensive industries. An intuitive interpretation is that this reflects the propensity of carbon-intensive industries to become more carbon-efficient in countries where more financing comes from equity markets. Such an effect could come from two directions: either companies adopt already existing green technology[20] or they develop such technologies from scratch.[21] We now provide direct evidence for the latter conjecture by using data on industrial patenting (see Section 4.3) to estimate Model (7). We report OLS and 2SLS results in Panels A and B of Table 6 and again test for the role of FD and FS jointly.

Both panels indicate that carbon-intensive sectors do not have a different propensity to patent green technologies (compared with greener sectors) in countries with deepening financial systems. This holds for all three green patent definitions. However, we do find that the number of green patents increases faster in carbon-intensive sectors in countries with deepening stock markets (column (1) in both panels). We find the same when excluding green patents related to transportation and waste (column (2) in both panels). Strikingly, when we focus on the 'greenest' patents, those intended to increase energy efficiency in the production or processing of goods, we again find that an increasing share of equity funding is strongly associated with an increase in these patents. This effect is significant at the 1% level (column (3) in both panels) and is economically meaningful, too. The 2SLS

[20] Schumpeterian growth models suggest that financial constraints may prevent firms in less-developed countries from exploiting R&D carried out in countries closer to the technological frontier (Aghion, Howitt, and Mayer-Foulkes, 2005).

[21] 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.

coefficient of 0.6024 in column (3) of Panel B indicates that moving from the 25$^{\text{th}}$ to the 75$^{\text{th}}$ percentile of financial structure is associated with an increase in green patents generated by an industry at the 75$^{\text{th}}$ percentile of carbon intensity—relative to one at the 25$^{\text{th}}$ percentile of pollution intensity—of 0.14 patents per million (three times the sample mean). These results complement those of Hsu, Tian and Xu (2014), who show that industries relying on external finance and are high-tech intensive are more (less) likely to file patents in countries with deeper equity (credit) markets. We show that stock markets also play an important role in enabling carbon-intensive industries to make their production processes more energy efficient through green innovation.[22]

5.2.4 OECD sample

One may query whether our results are driven by a particular sample choice. Our findings so far are based on the UNIDO sample which features more countries (48) but fewer sectors (9 manufacturing ones).[23] The UNIDO sample contains many developing countries and emerging markets and may thus produce empirical regularities that are driven by the manufacturing industry in countries with relatively low economic and financial development.

We now replicate our main tests in the OECD sample, using data from STAN. This allows us to run our tests on a sample of fewer countries (28) but more sectors (16), encompassing the whole economy with the exception of services. This is potentially important because the heaviest polluters in terms of carbon emissions per unit of value added are not part of manufacturing (Table 1). Including them ensures that our results are not driven by a special relationship between finance and carbon emissions in the manufacturing sector.

With this strategy in hand, we replicate the most saturated versions of Models (4)–(6), the ones with country-sector dummies, country-year dummies, and sector-year dummies—in the OECD sample. Table 7 reports OLS and 2SLS results in the odd and even columns, respectively. We still find that deeper stock markets are associated with a reduction in per

[22] Financial development could also affect industry-level pollution through within-industry shifts across products with different pollution intensities. Shapiro and Walker (2018) show that such within-industry reallocation has not been a significant driver of the sharp reduction in US manufacturing pollution since the 1990s. Instead, this reduction mainly reflects lower pollution per unit of value added within narrowly defined product categories. Our results are in line with this and highlight the role of stock markets in enabling green innovation.

[23] It is worth noting that together with primary industry, the manufacturing sector accounts for almost 40% of worldwide greenhouse gas emissions (Martin, de Preux, and Wagner, 2014).

capita pollution levels (columns (1) and (2)) and that this result is fully driven by an increase in within-industry efficiency (columns (5) and (6)). We do not find a differential impact of deeper stock markets on growth in carbon-intensive versus greener sectors (columns (3) and (4)). Table 7 thus suggests that the negative relationship between stock market development and carbon emissions is by and large not a feature of a sample dominated by lower-income countries or by economies at early stages of financial development.

5.2.5 Mechanisms

Our results so far raise a natural question about the deeper mechanisms at play. They suggest that financial structure affects aggregate carbon emissions via two distinct channels. When financial systems become more skewed towards equity markets, green sectors grow relatively faster and, second, carbon-intensive sectors become more energy efficient, partly due to increased green innovation and patenting. What are the deeper economic forces underpinning these two channels? There is no ex-ante theory about why financial systems—or segments thereof—should affect *directly* the relative performance of carbon-intensive sectors. At the same time, there are a number of theories that could explain our results even in the absence of such a direct effect.

One possibility is that energy-efficient sectors are more innovation intensive than carbon-intensive sectors, and stock markets tend to be better at funding innovation than banks (Kim and Weisbach, 2008; Brown, Martinsson, and Petersen, 2017). For example, as discussed in Section 2, banks may lack the skills to evaluate early-stage technologies (Ueda, 2004) or operate with a time horizon that is incompatible with the funding of long-term R&D. If this is the case, then controlling for a sector's propensity to innovate could explain away the statistical association between financial structure and a reallocation from carbon-intensive towards more energy-efficient sectors.

Another possibility is that carbon-intensive firms own more tangible assets while energy-efficient firms depend more on intangible assets. Banks may then refuse to finance green projects because intangible assets are hard to collateralize (Carpenter and Petersen, 2002; Hall and Lerner, 2010). Equity markets, on the other hand, may be better suited to finance green firms with intangible assets. If this mechanism is driving our results, then a sector's asset tangibility is another factor that can explain the statistical association between financial structure and reallocation towards relatively energy-efficient sectors.

Third, it is possible that stock markets dominate banks in ways that are related more directly to climate risk. In particular, environmental disasters expose firms to potential litigation costs, which is why stock markets tend to be more sensitive to the financing of firms that perform badly in environmental terms (Klassen and McLaughlin, 1996). Large-scale ecological accidents, such as the Bhopal disaster or the Exxon Valdez oil spill, are associated with severe litigation risk (Salinger, 1992). When it comes to future litigation risk, shareholders have skin in the game while creditors are exempt. As a consequence, equity investors may have an incentive to either stay away from carbon-intensive sectors or, conditional on investing in them, to push for a 'greening' of their production technologies in order to reduce future litigation risk. If this is the case, then controlling for the likelihood of future litigation could moot the association between financial structure and the energy-efficiency improvement in carbon-intensive sectors.

To test for whether these mechanisms are at play, we augment our principal regression framework with the interaction of FD and FS with three alternative industry benchmarks. The first one is *R&D intensity*. In the spirit of Rajan and Zingales (1998), this proxy takes the industry-median value of R&D investment over total assets, for large mature companies in Compustat (data come from Laeven, Klapper, and Rajan, 2006). The second benchmark is *Asset tangibility*, measured as the ratio of an industry's tangible assets to total assets (the data, also derived from large mature companies, come from Braun, 2003). The third benchmark is *Litigation risk*. This variable is constructed as the total environmental penalties and fines paid by a sector in the U.S. over the period 2000–2014 (following both administrative and judicial legal cases) divided by the sector's value added over the same period. The penalty data come from the Environmental Protection Agency (EPA)'s Enforcement and Compliance History Online (ECHO) data set. Online Appendix Table A10 reports industry-level correlations between carbon intensity, R&D intensity, asset tangibility, and litigation risk (Table 1 provides sector averages). The statistics suggest that all of the mechanisms discussed above could be at play. Carbon-intensive sectors are less R&D-intensive (correlation of -0.37), more asset-tangible (0.40), and also more litigation-prone (0.75).

We investigate the empirical relevance of these mechanisms in Table 8 and do so separately for the two channels at play: between-sector reallocation and within-sector improvements in energy efficiency. In Panel A, we test for the possibility that the relative expansion of green sectors in countries with deepening stock markets is explained by such sectors being more

R&D-intensive, less asset-tangible, and less litigation-prone. We augment Model (5) with interactions of FD and FS with the three benchmarks just discussed, introducing them one by one. Odd (even) columns present our OLS (IV) results.

We find that, as expected, R&D-intensive sectors grow faster in countries with deepening stock markets (columns (1) and (2)). We also find that sectors rich in tangible assets expand faster in economies that rely more on bank financing (columns (3) and (4)). These results are entirely in line with the intuition discussed. Importantly, in both cases the impact of financial structure on growth in energy-efficient relative to carbon-intensive sectors remains in the 2SLS specifications and even becomes stronger (columns (2) and (4)). This suggests that the reallocation of investment towards relatively energy-efficient sectors in countries with deepening stock markets is not merely a side effect of these sectors also being more innovative and less rich in tangible assets. At the same time, we find that litigation risk does not explain cross-sector reallocation (columns (5) and (6)).

In Panel B, we test whether carbon-intensive sectors also being less R&D-intensive, more asset-tangible, and more litigation-prone, explains the increase in energy efficiency in such sectors in countries with deepening stock markets. We do not find that carbon emissions per unit of value added decline relatively more in R&D-intensive sectors as stock markets develop (columns (1) and (2)). The same is true when we control for the possibility that equity-markets induce innovation in asset-intangible sectors (columns (3) and (4)). At the same time, across all four specifications we again continue to find that stock market development leads to a cleaning of carbon-intense industries relative to more energy-efficient ones.

Importantly, stock-market deepening also reduces carbon emissions per unit of value added in litigation-prone sectors in the 2SLS specification (column (6)). Moreover, this weakens somewhat the statistical association between financial structure and the reduction in the gap in energy efficiency between relatively polluting and relatively clean sectors. The technological 'greening' of carbon-intensive sectors as stock markets develop is therefore to some degree also explained by equity investors being concerned about litigation risk. These results go in the same direction as a number of recent findings in the literature. In particular, Fernando, Sharfman, and Uysal (2017) find that institutional investors tend to avoid stocks with high environmental risk exposure, while Akey and Appel (2020) show that increased liability protection leads to higher toxic emissions as a result of lower investment in abatement technologies. At the same time, even in this regression, financial structure continues to be strongly and negatively correlated with carbon emissions per unit of value added in carbon-intensive sectors. We therefore conclude that neither R&D-intensity, asset tangibility, nor litigation risk can fully explain the results documented earlier in Table 5. Our findings thus leave a role for alternative mechanisms that are more difficult to test, such as individual investors having different social objectives than banks, for example.

5.2.6 Finance, imports, and carbon leakage

An important issue to address is that the decline in domestic carbon emissions due to stock market development might be offset by the outsourcing of carbon-intensive activities to other countries, including so-called pollution havens (Eskeland and Harrison, 2003; Aichele and Felbermayr, 2015). This would result in a concomitant increase in carbon embedded in imports of intermediate inputs or final consumer goods. Stock market funding is ultimately provided by investors with their own social objectives (Bolton, Li, Ravina, and Rosenthal, 2020) and investors may be more sensitive to firms that perform badly in environmental terms. One unintended consequence may be that firms close domestic operations, but open foreign ones, under the assumption that poor environmental performance away from home is more acceptable (or less observable) to investors. If so, then the decline in pollution domestically would be neutralized by a proportionate increase in pollution elsewhere (carbon leakage), making for a null effect from a global point of view.[24]

To test this hypothesis, we download detailed data from the World Input-Output Database on bilateral imports and exports. We then calculate the amount of carbon emissions embedded in the import of goods for each country-sector-year in the following way. First, we determine what shares of output in a country-sector-year is exported versus sold domestically, and we split the associated CO_2 proportionately. We then determine what share of total exports by a particular sector in country i was imported by country j, and we assign to country j a proportionate share of the overall CO_2 associated with these exports. Next, we sum over all WIOD countries i that export to country j to get the full amount of CO_2 associated with the import in country j of goods (of a particular sector) produced abroad.

[24] A related concern is that stock market development involves substantial within-country cross-sector spillovers through, for example, purchased materials and outsourced activities (so-called scope 3 emissions). While addressing the role of upstream and downstream spillovers is beyond the scope of this paper, we are less concerned about such indirect emissions because of the clear negative aggregate relationship between financial structure and country-level emissions shown in Table 2.

We also determine the final user in country j of these imported goods, and assign each a proportionate share of the associated CO_2 emissions abroad. There are five final-user categories: households; the same sector; other sectors; gross fixed capital formation (GFCF); and the government. In the case of the same sector and other sectors, these are typically purchases of intermediate inputs—for instance, purchases of car parts produced in Indonesia for the production of cars in Germany. In the case of households and the government, these are typically purchases of final goods (e.g., cars). Lastly, in the case of GFCF, these are (for example) cars and car parts imported by German firms to be used as investment goods rather than intermediate inputs. For each of these categories, we calculate per capita carbon emissions, to make the analysis comparable to Table 3.

Previous evidence suggests that outsourcing to pollution havens may be particularly likely for 'footloose' sectors with a lower cost of relocating operations abroad (Ederington, Levinson, and Minier, 2005). This suggests that carbon emissions associated with the production of imported goods will be higher in such footloose sectors. We acquire data from Ederington, Levinson, and Minier (2005) on the costs of relocating production abroad, and aggregate it to match our sector classification.[25] The combination of these new data allows us to test whether in countries with a growing share of equity financing, carbon embedded in imports increases in case of carbon-intensive sectors, especially if the industry can relatively easily outsource (parts of) its production.

Table 9 reports estimates from a modified Model (4) where the dependent variable is per capita CO_2 emissions associated with the production of imported goods (in total and for the five user categories). Column (1) shows that in countries where equity markets gain in relative importance, imports from carbon-intensive sectors go up. This means that part of the decline in domestic carbon emissions due to increased equity financing is neutralized by an increase in carbon emitted during the production of imports. However, the magnitude of the point estimate is one-half of the one in Table 3, column (3), and overall imports are only around one-fifth of domestic production. The increase in carbon emissions associated with the production of imported goods is therefore only around one-tenth of the reduction in domestic carbon emissions due to the relative growth of equity markets. The analysis across

[25] We classify sectors by their product market transportation costs. Industries where such costs are high are less likely to relocate abroad because the distance between production and consumers is then too costly to overcome. The classification is based on industry fixed effect coefficients from a regression of transport costs on distance and distance squared. See Appendix A of Ederington et al. (2005) for details.

final users reveals further interesting patterns. Goods purchased by households account for around 5% of the overall increase in CO_2 embedded in imported goods (column (2)). Intermediate goods purchased by the same sector (column (3)) and by other sectors (column (4)) account for the remaining 95%, in a roughly equal proportion. There is no increase in carbon embedded in imports of either capital goods (GFCF) or government purchases.

In Online Appendix Table OA2, we distinguish between sectors for which production is difficult to outsource due to high transportation costs (Panel A) and sectors that can outsource more easily (Panel B). As expected, the overall effect on carbon emissions associated with the foreign production of imported goods is much stronger for footloose sectors (Panel B, column (1)) than for immobile ones (Panel A, column (1)). That is, when stock market development leads to a domestic reduction in per capita carbon emissions in a relatively polluting industry, then this greening effect is offset more (but still far from completely) in the case of sectors whose products can be easily sourced abroad.

Interestingly, the import of consumer goods and of intermediates play intuitively different roles. The relatively small contribution of households to the increase in carbon emissions abroad that we documented for the full sample in Table 9 is much stronger for relatively immobile industries (Panel A, column (2)). Instead, the contribution of outsourcing by domestic industrial sectors is much stronger in the case of relatively footloose industries (Panel B, columns (3) and (4)). These results are consistent with the idea that the more footloose a sector is, the more it outsources the production of intermediary goods abroad. For immobile sectors we instead observe that a domestic greening is accompanied by an increase in households buying final consumer goods abroad (as well as some firms buying investment goods abroad, column (5) in Panel A).

Overall, our estimates indicate that the reduction in carbon emissions in carbon-intensive sectors due to domestic stock market development is accompanied by an increased reliance of these sectors on the production of intermediary goods abroad (and to a much smaller extent an increase in household consumption of imports). This holds in particular for more footloose sectors. Yet, in terms of magnitudes, the increase in carbon embedded in sectoral imports remains dominated by a greening of the domestic economy by a factor of ten. In all, our findings are therefore in line with Levinson (2009) and Shapiro and Walker (2018) who show that the cleanup of US manufacturing since the late 1980s mainly reflects technological progress and only to a very limited extent the shifting of polluting industries overseas.

5.3 Finance and pollution: Firm-level results

We have not yet documented the link between the type of finance used and environmental performance at the firm level. To support the evidence on the within-industry greening effect of stock markets, it must be the case that when firms move towards more equity financing, they tend to invest more in pollution-reducing technologies and generate fewer carbon emissions per unit of value added. Demonstrating this chain of events is difficult because firms' choice of funding sources is typically endogenous, making the causal link from equity to lower carbon emissions tenuous.

To address this issue, we use a new firm-level data set and a plausibly exogenous policy change that reduced the cost of equity funding to firms. Specifically, we exploit the 2006 introduction of a tax shield for equity in Belgium that allowed firms to deduct from their taxable income an interest calculated on the basis of their equity. This notional interest deduction (NID) or allowance for corporate equity (ACE) reduced the relative tax advantage of debt funding and made equity funding relatively cheaper for firms.[26] Existing evidence indicates that this policy change indeed significantly increased the share of equity in Belgian firms' funding structure (Schepens, 2016 and Hebous and Ruf, 2017).

We use a sample of Belgian non-financial corporations that we observe before and after the introduction of the NID. We collect information on all Belgian firms that report annual emissions under the EU Emissions Trading System (ETS). More specifically, we use firm-level data on metric tons of carbon dioxide equivalent, which describes for a given mixture and amount of emitted greenhouse gas, the amount of CO_2 that would have the same global warming potential. From Orbis we obtain data to calculate annual equity ratios, defined as shareholder funds as a percentage of total current plus non-current liabilities. We have non-missing information on both emissions and financials for 159 Belgian firms.

We compare these Belgian firms to two control groups. First, we use 101 ETS-reporting Dutch corporations. The Netherlands is a neighboring country with a similar economy and history[27], but it did not introduce a tax shield on equity in 2006 or later. This control group helps ensure that we do not capture a global (or regional) move toward more equity funding

[26]The NID allows firms to deduct from their taxable income a notional charge that equals the product of the book value of equity and a benchmark interest rate (the 10-year government bond yield). The Belgian NID is "hard" in the sense that the allowance is calculated over the total book value of equity instead of newly issued equity only (as in a "soft" NID).

[27]Both countries were part of the United Kingdom of the Netherlands until 1839.

unrelated to the Belgian reform.

Second, we use as a control group all ETS-reporting firms in the Netherlands, France, Germany and Luxembourg. These are all of Belgium's neighboring countries, closely economically integrated and sharing the same currency. This larger control group allows us to match each treated Belgian firm with a similar control firm before applying our difference-in-difference estimator (Heckman, Hidehiko, and Todd, 1997). We match strictly within 2-digit industries and further refine the match using nearest-neighbor propensity score matching. The following variables enter the propensity score model: tangibility (tangible assets/total assets); profitability (EBITDA/total assets); size (log of total assets); and a dummy for negative operating revenues. All firm characteristics refer to 2004, two years before the Belgian reform came into force.

With these data in hand, we can answer two questions. First, did Belgian firms use more equity after the introduction of the NID in 2006? And second, did Belgian firms reduce their carbon emissions after 2006 and, if so, did they do so relative to control firms in neighboring countries? To answer these questions, we first compare the panel of Belgian firms before and after the introduction of the NID. In a second step, we then compare their development with that of both control groups in a difference-in-differences framework. To mimic our previous analysis, we calculate sector-specific carbon intensities as the median carbon emissions by sales or by assets for all 33 countries for which firm-level CO_2 data are available from the ETS. We do this for all 24 sectors available in Orbis. The regressions include firm fixed effects, as well as year fixed effects where appropriate.

We report the results in Table 10. Column (1) of Panel A documents a significant increase in the share of equity funding after the introduction of the NID, confirming the existing literature.[28] On average, after 2006, Belgian firms used 0.64 percentage points more equity (an increase of 5% of the sample mean). This increase in the share of equity in firms' capital structure is significant at the 5% statistical level. Columns (2) and (3) further indicate that after 2006, Belgian firms in relatively polluting industries experienced a reduction in their carbon equivalent emissions per sales and per assets, respectively. Both effects are significant at the 1% statistical level, and represent a 20% reduction in the difference in emissions

[28]The observation period for columns (1) in all three panels is a symmetric window 1995–2018 around the 2006 NID introduction in Belgium. For columns (2)-(3) a shorter period is used (2005–2018) since ETS reporting on carbon emissions only started in 2005.

between an industry at the 25th and one at the 75th percentile of emissions intensity.

Panel B provides difference-in-differences results using the Dutch ETS-reporting firms as controls. We find that as a result of the NID introduction, Belgian firms became less leveraged over time, also when compared to Dutch neighboring firms (column (1)). While the data indicate a downward trend in firm leverage in the Netherlands as well, the post-2006 drop in leverage among Belgian firms is about 60% larger. The results in columns (2) and (3) confirm that after 2006, Belgian firms in relatively polluting industries reduced their carbon equivalent emissions per sales and per assets, also when compared to Dutch firms.

Panel C reports difference-in-differences results using matched firms from all neighboring countries as a control group. The results are striking in that they show how Belgian firms significantly increased their use of equity after 2006, also when compared to observationally similar firms in adjacent countries (column (1)). Moreover, while the carbon intensity of ETS firms in relatively polluting industries in these comparison countries increased post-2006, this increase is much smaller among the Belgian firms (columns (2)-(3)).[29]

In short, the results in Table 10 confirm at the firm-level what we documented at the industry level: a higher reliance on equity funding, due to an exogenous shift in firms' incentives to fund themselves with equity, results in fewer carbon equivalent emissions, plausibly due to the implementation of greener technologies.

5.4 Robustness tests

One potential concern with our empirical specification is that we assume that the impact of shocks to financial sector size and structure is relatively contemporaneous (1-year lag). Changes in overall financing and in the equity share thereof may nevertheless take more time to fully propagate through the economy. To account for this, we now impose a structure that aggregates the data over 5-year periods (1990–1993, 1994–1998, 1999–2003, 2004–2008, 2009–2013). We then test for the impact of shocks to financial sectors during one 5-year period on carbon emissions and sector growth during the next 5-year period. Online Appendix Table OA3 reports the estimates from these alternative tests. The specifications control for the time-varying size of each sector as a share of the economy and for country-sector dummies, country-period dummies, and sector-period dummies. We find strong support for the

[29]Results are robust to clustering the standard errors at either the firm or the country level.

three stylized facts that we already documented: in countries with deepening stock markets, and relative to technologically greener industries, carbon-intensive industries generate fewer carbon emissions per capita (column (1)), grow more slowly (column (2)), and generate fewer emissions per unit of value added (column (3)). These effects are statistically significant at least at the 10% level, and at least at the 5% level in two of the three tests.

In Online Appendix Table OA4 we include both components of FD—the volume of bank credit and the value of traded stocks—separately in the regression. Column (1) suggests that an increase in stock market size a negative effect on CO_2 emissions at the industry level. The latter is driven by a reduction in relative growth rates in carbon-intensive sectors (column (2)) and by a reduction in carbon emissions per unit of value added in carbon-intensive sectors (column (3)), confirming the main results of the paper.

Next, our baseline results in Tables 3–5 are confirmed when we control for how dependent on external finance a sector is (Online Appendix Table OA5) and when we employ alternative benchmarks for carbon intensity, calculated using US data or contemporaneous sector-specific global averages (Online Appendix Table OA6). Furthermore, we document that our main results hold up well when we include the depth of corporate bond markets (Online Appendix Table OA7) or the size of private equity investment (Online Appendix Table OA8) in the calculation of FD and FS. The latter likely reflects that private equity, such as venture capital and angel investments, is often instrumental for generating early-stage innovation (Kortum and Lerner, 2000). Lastly, the main results also survive when we control for country-industry-specific fuel subsidies (Online Appendix Table OA9). Fuel subsidies may blunt firms' incentives to make their production technology more energy efficient, even when firms can access stock markets to finance such green investments.

6 Conclusions

The 2018 Sveriges Riksbank Nobel Prize in Economic Sciences was awarded to William Nordhaus for integrating climate change into long-run macroeconomic analysis. Economists, both theorists and empiricists, are increasingly analyzing the interdependent relationships between economic growth and global warming. As yet, many questions remain unanswered and economic research lags behind the proliferation of climate policies. The rapid growth of green finance initiatives is a case in point and contrasts sharply with the paucity of evidence on the link between conventional finance and carbon emissions.

To quantify this role, we study the relation between financial development and structure, on the one hand, and CO_2 emissions, on the other hand, in a large panel of countries and sectors over the period 1990–2015. We find that for a given level of economic development and environmental protection, financial sector size has no impact on CO_2 emissions, but that a financial structure tilted towards equity financing reduces per capita emissions significantly. When further analyzing the role of financial structure for sectors that generate more carbon emissions per unit of value added, due to intrinsic technological reasons, we find that such industries emit relatively less carbon in countries with deepening stock markets.

This first set of results can be interpreted in light of the Kuznets-curve argument that industrial pollution follows an inverse U-shape over the development cycle. Our results imply that this pattern of per capita pollution over time is intimately related to the sequential development of different types of financial markets. As stock markets tend to deepen at later stages of development than credit markets, our findings show that the evolution of financial structure directly contributes to the concave relationship between economic development and environmental quality as documented in the literature (e.g. Grossman and Krueger, 1995).

We next study the channels that underpin these country- and sector-level results. We find strong evidence for the conjecture that stock markets facilitate the adoption of cleaner technologies in polluting industries. Further analysis of sectoral patenting data confirms that deeper stock markets are associated with more green innovation in carbon-intensive sectors. We also document weaker evidence that—holding cross-industry differences in technology constant—stock markets help reallocate investment towards more energy-efficient sectors. These empirical regularities still obtain in the data when we use policy interventions in equity and credit markets to instrument for financial market size and structure. Moreover, we also show that the beneficial effect of stock market development in terms of lower carbon emissions is only to a very limited extent offset by higher imports of 'dirty' intermediate or final consumer goods. Lastly, we confirm our main results at the firm level by using data on carbon emissions from the European Emissions Trading System and by exploiting a Belgian policy shock that suddenly increased firms' use of equity funding.

In sum, we show that stock-market based financial systems are tightly associated with fewer greenhouse gas emissions. Why? There is increasing evidence that investors value environmentally sustainable behavior by firms (see Section 2). Such investors can reduce their carbon footprint in two ways: by engaging with investee firms with the goal of reducing their carbon emissions and by divesting from carbon-intensive stocks. The two channels that underpin our results (cross-sectoral reallocation and within-sector increases in energy efficiency) are in line with these active and passive roles of equity investors. Moreover, our results on underlying mechanisms indicate that neither the reallocation of investment towards more energy-efficient sectors nor the increased energy efficiency in carbon-intense sectors are merely side effects of sectoral variation in R&D-intensity or firms' reliance on tangible assets.

Overall, our findings indicate that countries with a bank-based financial system that aim to green their economy, such as through the promotion of green bonds or other green-finance initiatives, could consider stimulating the development of conventional equity markets as well. This holds especially for middle-income countries where carbon dioxide emissions have increased more or less linearly during the development process. There, according to our findings, stock markets could play an important role in making future growth greener, in particular by stimulating innovation that leads to cleaner production processes within industries. An important way to facilitate the deepening of stock markets in such countries is to improve the legal protection of (minority) shareholders (Pagano and Volpin, 2006).

In parallel, countries can try to counterbalance the tendency of credit markets to finance relatively carbon-intensive industries. Examples include the green guidelines that China and Brazil recently introduced to encourage banks to improve their environmental performance and to lend more to firms that are part of the low-carbon economy. From an industry perspective, adherence to the so-called Carbon Principles, Climate Principles, and Equator Principles should also contribute to a greening of bank lending.[30] Strict adherence to these principles can also make governmental climate change policies more effective by accelerating capital reallocation and investment towards low-carbon technologies.

Lastly, countries that want to limit the negative environmental externalities stemming from a financial system that is overly reliant on bank lending (and debt more generally) can

[30]The Carbon Principles are guidelines to assess the climate change risks of financing electric power projects. The Climate Principles comprise a similar but broader framework. Lastly, the Equator Principles are a risk management framework to assess and manage environmental and social risk in large projects. Equator Principle banks commit not to lend to borrowers that do not comply with their environmental and social policies and procedures, and to require borrowers with greenhouse gas emissions above a certain threshold to implement measures to reduce such emissions.

reduce tax-code favoritism towards debt (such as the deductibility of interest payments and double taxation of dividends in the U.S.). An example is the notional interest deduction that Belgium introduced in 2006 and that we analyzed in this paper. Similarly, as part of the European Commission's work on the Capital Markets Union, a common corporate tax base has been proposed to address the current debt bias in corporate taxation. A so-called Allowance for Growth and Investment will give firms equivalent tax benefits for equity and debt. Our results suggest that, to the extent that such policies indeed move economies towards more equity-funded investments, they will also have important environmental benefits by making low-carbon technologies easier to finance.

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Table 1: Sectoral benchmarks

ISIC code	Sector name	Carbon intensity	R&D intensity	Asset tangibility	Litigation risk
01-05	Agriculture, hunting, forestry, and fishing	0.233	0.002	0.350	0.004
10-14	Mining and quarrying	0.129	0.000	0.350	0.044
15-16	Food products, beverages, and tobacco	0.167	0.009	0.329	0.032
17-19	Textiles, textile products, leather, and footwear	0.107	0.013	0.203	0.075
20	Wood and products of wood and cork	0.094	0.075	0.380	0.121
21-22	Pulp, paper, paper products, printing, and publishing	0.195	0.009	0.429	0.034
23-25	Chemical, rubber, plastics, and fuel products	0.438	0.010	0.304	0.062
26	Other non-metallic mineral products	1.066	0.013	0.275	0.192
27	Basic metals	1.641	0.012	0.421	0.147
28-33	Fabricated metal products, machinery, and equipment	0.033	0.103	0.207	0.015
34-35	Transport equipment	0.056	0.020	0.255	0.030
40-41	Electricity, gas, and water supply	4.257	0.000	0.350	0.000
45	Construction	0.033	0.000	0.124	0.001
60	Land transport transport via pipelines	3.019	0.000	0.667	0.016
61	Water transport	7.244	0.000	0.758	0.002
62	Air transport	3.012	0.000	0.557	0.001

Notes: This table summarizes, by sector, the main benchmarks used in the paper. 'Carbon intensity' denotes the average value, over the entire sample period, of each sector's annual CO_2 emissions per value added in the global sample. 'R&D intensity' denotes the industry-median value of R&D investment over total assets for mature listed firms, from Compustat North America. 'Asset tangibility' denotes the share of tangible assets out of total assets for mature listed firms, from Compustat North America. 'Litigation risk' denotes the total penalties paid by a sector in the U.S. over the period 2000-2014 (following both administrative and judicial legal cases) as a share of the sector's value added over the same period, from the Environmental Protection Agency (EPA)'s Enforcement and Compliance History Online (ECHO) data set (data on penalties) and WIOD (data on value added).

Table 2: Financial development and aggregate pollution

	OLS		2SLS		
			First stage		Second stage
			FD	FS	
	(1)	(2)	(3)	(4)	(5)
Pro-competitive bank regulation			0.0534**	0.0124	
			(0.0245)	(0.0093)	
Equity market liberalization			-0.1565***	0.0890***	
			(0.0596)	(0.0226)	
FD	0.0333	-0.1422			-2.6861
	(0.1362)	(0.1448)			(1.6154)
FS	-0.7336**	-0.7308**			-7.6905**
	(0.3090)	(0.3506)			(3.4790)
Log GDP per capita	6.2162**	4.8670**	-0.7151*	0.6876***	7.2392**
	(2.2053)	(2.3677)	(0.4596)	(0.1747)	(3.0981)
Log GDP per capita squared	-0.2038*	-0.0559	0.0545**	-0.0369***	-0.2291
	(0.1282)	(0.1363)	(0.0259)	(0.0098)	(0.1740)
Population (million)	-4.8021***	-4.5707**	0.7337	-0.3836*	-5.5421**
	(1.7754)	(2.0272)	(0.5353)	(0.2035)	(2.7483)
Recession	-0.2060**	-0.1992**	0.0068	-0.0509***	-0.5646**
	(0.0741)	(0.0975)	(0.0246)	(0.0094)	(0.2123)
Environmental Protection Index		-0.2993***			
		(0.0787)			
Country dummies	Yes	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes
F-statistics			6.96	8.77	
No. Observations	1,074	608	911	911	911
R-squared	0.97	0.98	0.91	0.69	0.93

Notes: This table reports estimates from OLS (columns (1)-(2)) and 2SLS (columns (3)-(5)) regressions. The dependent variable in columns (1)-(2) and (5) is 'CO_2 emissions per capita' which denotes aggregate emissions of carbon dioxide, in tons, per capita. In column (5), 'FD' and 'FS' are instrumented using equity market liberalization events from Bekaert et al. (2005), and an index of pro-competitive banking regulation from Abiad et al. (2008). The sample period is 1990-2015. All regressions include fixed effects as specified. Robust standard errors are included in parentheses, where ***, **, and * indicate significance at the 1, 5, and 10 percent statistical level, respectively.

Table 3: Finance and sector-level carbon emissions per capita

	CO_2 emissions per capita			
	(1)	(2)	(3)	(4)
FD × Carbon intensity	0.0309		0.0313	-0.0086
	(0.0324)		(0.0313)	(0.0214)
FS × Carbon intensity		-0.1438**	-0.1445**	-0.0925**
		(0.0699)	(0.0696)	(0.0383)
Sector share	5.6874*	5.5531*	5.5384*	1.2086***
	(3.5362)	(3.4913)	(3.4751)	(0.4607)
Country × Sector dummies	Yes	Yes	Yes	Yes
Country × Year dummies	Yes	Yes	Yes	Yes
Sector × Year dummies	Yes	Yes	Yes	Yes
No. Observations	6,477	6,477	6,477	6,477
R-squared	0.77	0.77	0.77	0.77

Notes: The table reports estimates from OLS (columns (1)-(3)) and 2SLS (column (4)) regressions. The instruments used in column (4) are the same as in columns (3)-(4) of Table 2. The dependent variable is 'CO_2 emissions per capita' which denotes sector-specific annual emissions of carbon dioxide, in tons, per capita. 'Sector share' denotes the 1-period lagged share in value added of the sector out of the whole economy. Sector-specific data come from IEA and UNIDO. The sample period is 1990-2015. All regressions include fixed effects as specified. Standard errors clustered at the country-sector level are included in parentheses, where ***, **, and * indicate significance at the 1, 5, and 10 percent statistical level, respectively.

Table 4: Finance and cross-sector reallocation

	Finance and growth in value added			
	(1)	(2)	(3)	(4)
FD × Carbon intensity	-0.0169		-0.0168	-0.0182
	(0.0150)		(0.0149)	(0.0278)
FS × Carbon intensity		-0.0654*	-0.0653*	-0.0964*
		(0.0411)	(0.0403)	(0.0635)
Sector share	-14.2969***	-14.4169***	-14.4059***	-13.8634***
	(2.2614)	(2.2494)	(2.2410)	(2.4227)
Country × Sector dummies	Yes	Yes	Yes	Yes
Country × Year dummies	Yes	Yes	Yes	Yes
Sector × Year dummies	Yes	Yes	Yes	Yes
No. Observations	6,229	6,229	6,229	6,197
R-squared	0.56	0.56	0.56	0.51

Notes: The table reports estimates from OLS (columns (1)-(3)) and 2SLS (column (4)) regressions. The instruments used in column (4) are the same as in columns (3)-(4) of Table 2. The dependent variable is 'Growth in value added' which denotes annual sector-specific growth in value added. 'Sector share' denotes the 1-period lagged share in value added of the sector out of the whole economy. Sector-specific data come from IEA and UNIDO. The sample period is 1990-2015. All regressions include fixed effects as specified. Standard errors clustered at the country-sector level are included in parentheses, where ***, **, and * indicate significance at the 1, 5, and 10 percent statistical level, respectively.

Table 5: Finance and sector-level carbon emissions per unit of output

	CO_2 emissions per value added			
	(1)	(2)	(3)	(4)
FD × Carbon intensity	-0.2053		-0.2147	0.5785
	(0.4363)		(0.3964)	(0.5295)
FS × Carbon intensity		-4.2575***	-4.2608***	-7.8935***
		(1.0591)	(1.0593)	(3.1528)
Sector share	8.0868	1.1471	1.3156	-1.0666
	(13.8427)	(13.4502)	(13.6336)	(11.0649)
Country × Sector dummies	Yes	Yes	Yes	Yes
Country × Year dummies	Yes	Yes	Yes	Yes
Sector × Year dummies	Yes	Yes	Yes	Yes
No. Observations	6,112	6,112	6,112	6,112
R-squared	0.82	0.82	0.82	0.78

Notes: The table reports estimates from OLS (columns (1)-(3)) and 2SLS (column (4)) regressions. The instruments used in column (4) are the same as in columns (3)-(4) of Table 2. The dependent variable is 'CO_2 emissions per value added' which denotes sector-specific annual emissions of carbon dioxide, in tons, per unit of value added. 'Sector share' denotes the 1-period lagged share in value added of the sector out of the whole economy. Sector-specific data come from IEA and UNIDO. The sample period is 1990-2015. All regressions include fixed effects as specified. Standard errors clustered at the country-sector level are included in parentheses, where ***, **, and * indicate significance at the 1, 5, and 10 percent statistical level, respectively.

Table 6: Finance and green innovation

Panel A. OLS

	Green patents per capita	Green patents per capita (excl. transport and waste)	Green patents per capita (industrial production)
	(1)	(2)	(3)
FD × Carbon intensity	-0.4124	-0.4728	-0.0650
	(0.4473)	(0.4745)	(0.1210)
FS × Carbon intensity	1.6225*	1.8070**	0.7476***
	(0.9056)	(0.9333)	(0.2568)
Sector share	-8.8971	2.1508	-6.2458*
	(25.6923)	(22.2149)	(6.1878)
Country × Sector dummies	Yes	Yes	Yes
Country × Year dummies	Yes	Yes	Yes
Sector × Year dummies	Yes	Yes	Yes
No. Observations	2,593	2,218	1,791
R-squared	0.85	0.82	0.83

Panel B. 2SLS

	Green patents per capita	Green patents per capita (excl. transport and waste)	Green patents per capita (industrial production)
	(1)	(2)	(3)
FD × Carbon intensity	0.1025	0.2425	-0.0257
	(0.3300)	(0.3419)	(0.1151)
FS × Carbon intensity	2.9008**	3.0861***	0.6024***
	(1.4960)	(1.0636)	(0.2378)
Sector share	-16.8799	-11.5871	-12.0305
	(23.8312)	(19.8725)	(6.0693)
Country × Sector dummies	Yes	Yes	Yes
Country × Year dummies	Yes	Yes	Yes
Sector × Year dummies	Yes	Yes	Yes
No. Observations	2,597	2,228	1,799
R-squared	0.84	0.82	0.83

Notes: The table reports estimates from OLS regressions (Panel A) and 2SLS regressions (Panel B). The dependent variable is the number of green patents in a country-sector-year, per 1 mln. population (column (1)); the number of patents in the most climate-change-intensive technologies in a country-sector-year, per 1 mln. population, excluding patents related to transportation and to wastewater treatment and waste management (column (2)); and the number of patents intended to increase the energy efficiency of industrial production processes in a country-sector-year, per 1 mln. population (column (3)). Sector-specific data come from IEA and UNIDO. The sample period is 1990-2015. All regressions include fixed effects as specified. Standard errors clustered at the country-sector level are included in parentheses, where ***, **, and * indicate significance at the 1, 5, and 10 percent statistical level, respectively.

Table 7: Finance and sector-level carbon emissions: OECD countries

	CO_2 emissions per capita		Growth in value added		CO_2 emissions per value added	
	OLS	2SLS	OLS	2SLS	OLS	2SLS
	(1)	(2)	(3)	(4)	(5)	(6)
FD × Carbon intensity	-0.0059	-0.0151	0.0080	0.0125	-0.0993	0.2213*
	(0.0171)	(0.0269)	(0.0102)	(0.0143)	(0.1203)	(0.1276)
FS × Carbon intensity	-0.1760***	-0.0920**	-0.0120	0.0436	-1.6519***	-5.5866***
	(0.0550)	(0.0448)	(0.0400)	(0.0804)	(0.3522)	(1.2686)
Sector share	0.5653	0.4912	-4.7391***	-3.9138***	-0.3212	0.7121
	(0.4325)	(0.3319)	(0.9607)	(0.6807)	(1.0936)	(1.3691)
Country × Sector dummies	Yes	Yes	Yes	Yes	Yes	Yes
Country × Year dummies	Yes	Yes	Yes	Yes	Yes	Yes
Sector × Year dummies	Yes	Yes	Yes	Yes	Yes	Yes
No. Observations	3,368	3,368	3,132	3,132	3,210	3,210
R-squared	0.94	0.94	0.62	0.60	0.88	0.86

Notes: The table reports estimates from OLS regressions (columns (1), (3), and (5)), and 2SLS regressions (columns (2), (4), and (6)). The dependent variable is the sector's annual emissions of carbon dioxide, in tons, per capita (columns (1) and (2)); the sector's annual growth in value added (columns (3) and (4)); and the sector's annual emissions of carbon dioxide, in tons, per unit of value added (columns (5) and (6)). Sector-specific data for 33 OECD countries come from IEA and STAN. The sample period is 1990-2015. All regressions include fixed effects as specified. Standard errors clustered at the country-sector level are included in parentheses, where ***, **, and * indicate significance at the 1, 5, and 10 percent statistical level, respectively.

Table 8: Finance and sector-level carbon emissions: Mechanisms

Panel A: Finance and cross-sector reallocation

	Growth in value added					
	OLS	2SLS	OLS	2SLS	OLS	2SLS
	(1)	(2)	(3)	(4)	(5)	(6)
FD × Carbon intensity	-0.0236	0.0239	-0.0176	0.0199	-0.0202	0.0245
	(0.0167)	(0.0227)	(0.0160)	(0.0195)	(0.0161)	(0.0230)
FS × Carbon intensity	-0.0277	-0.2143***	-0.0287	-0.1941***	-0.0520	-0.2221***
	(0.0426)	(0.0706)	(0.0415)	(0.0656)	(0.0478)	(0.0714)
FD × R&D intensity	0.0883	0.2592				
	(0.3081)	(0.2872)				
FS × R&D intensity	1.5319*	1.5280*				
	(0.9830)	(0.9514)				
FD × Asset tangibility			-0.1497	-0.2005**		
			(0.0992)	(0.0970)		
FS × Asset tangibility			-0.5415**	-0.5305*		
			(0.2814)	(0.2890)		
FD × Litigation risk					-0.4078	-0.8844
					(0.6896)	(0.6596)
FS × Litigation risk					-0.1600	-0.5983
					(1.9890)	(1.7979)
Sector share	-15.9120***	-15.9932***	-16.0505***	-16.0440***	-15.6056***	-15.5767***
	(2.5874)	(2.5830)	(2.7105)	(2.7160)	(2.6870)	(2.7267)
Country × Sector dummies	Yes	Yes	Yes	Yes	Yes	Yes
Country × Year dummies	Yes	Yes	Yes	Yes	Yes	Yes
Sector × Year dummies	Yes	Yes	Yes	Yes	Yes	Yes
No. Observations	5,419	5,419	5,279	5,279	5,419	5,419
R-squared	0.55	0.55	0.55	0.55	0.55	0.55

Panel B: Finance and within-sector efficiency

	CO_2 emissions per value added					
	OLS	2SLS	OLS	2SLS	OLS	2SLS
	(1)	(2)	(3)	(4)	(5)	(6)
FD × Carbon intensity	-0.2553	0.1905	-0.2215	0.2533	-0.3555	-0.1470
	(0.4457)	(0.4343)	(0.3907)	(0.3695)	(0.3457)	(0.4416)
FS × Carbon intensity	-4.6483**	-6.8401**	-4.6597***	-5.8566**	-4.1536***	-6.5611**
	(1.1381)	(3.2183)	(1.1063)	(2.8407)	(1.0153)	(3.1625)
FD × R&D intensity	-0.9123	1.1560				
	(2.4821)	(2.1349)				
FS × R&D intensity	-13.6212	11.3799				
	(8.3795)	(8.8244)				
FD × Asset tangibility			0.2449	-0.4274		
			(1.3751)	(2.0364)		
FS × Asset tangibility			-2.2926	-10.8363*		
			(4.4549)	(5.7454)		
FD × Litigation risk					10.0498	1.6725
					(12.7883)	(17.6392)
FS × Litigation risk					-22.4192	-91.9465**
					(36.5820)	(43.4210)
Sector share	-1.8204	-2.9763	-9.9761	-6.4004	-3.8441	1.9620
	(13.5724)	(13.6293)	(13.4704)	(13.0582)	(13.2811)	(14.6006)
Country × Sector dummies	Yes	Yes	Yes	Yes	Yes	Yes
Country × Year dummies	Yes	Yes	Yes	Yes	Yes	Yes
Sector × Year dummies	Yes	Yes	Yes	Yes	Yes	Yes
No. Observations	5,335	5,335	5,048	5,048	5,335	5,335
R-squared	0.80	0.80	0.82	0.81	0.80	0.80

Notes: The table reports estimates from OLS (columns (1), (3), and (5)) and 2SLS (columns (2), (4), and (6)) regressions. The dependent variable is 'Growth in value added' which denotes annual sector-specific growth in value added (Panel A) and 'CO_2 emissions per value added' which denotes the sector's annual emissions of carbon dioxide, in tons, per unit of value added (Panel B). 'Sector share' denotes the 1-period lagged share in value added of the sector out of the whole economy. All regressions include fixed effects as specified. Standard errors clustered at the country-sector level are included in parentheses, where ***, **, and * indicate significance at the 1, 5, and 10 percent statistical level, respectively.

Table 9: Finance, imports, and carbon leakage

	CO_2 emissions per capita from imports					
	Total	Households	Sector, same	Sector, other	GFCF	Government
	(1)	(2)	(3)	(4)	(5)	(6)
FD × Carbon intensity	0.0083	0.0009	0.0069	0.0003	0.0001	0.0000
	(0.0151)	(0.0008)	(0.0125)	(0.003)	(0.0005)	(0.0000)
FS × Carbon intensity	0.0613***	0.0029**	0.0274***	0.0304***	0.0007	0.0000
	(0.0182)	(0.0015)	(0.0108)	(0.0087)	(0.0013)	(0.0000)
Sector share	0.0009**	0.0000	0.0007*	0.0002	0.0001***	0.0000
	(0.0005)	(0.0001)	(0.0004)	(0.0001)	(0.0000)	(0.0000)
Country × Sector dummies	Yes	Yes	Yes	Yes	Yes	Yes
Country × Year dummies	Yes	Yes	Yes	Yes	Yes	Yes
Sector × Year dummies	Yes	Yes	Yes	Yes	Yes	Yes
No. Observations	3,167	3,167	3,167	3,167	3,167	3,167
R-squared	0.98	0.97	0.97	0.98	0.97	0.92

Notes: The table reports estimates from OLS regressions. The dependent variable is the total emissions of carbon dioxide associated with foreign-produced goods purchased by the total economy (column (1)), by households (column (2)), by the same industry (column (3)), by other industries (column (4)), purchased for gross fixed capital formation (column (5)), or purchased by the government (column (6)), in tons, per capita. Import data come from WIOD and sector-specific data from IEA and UNIDO. The sample includes all sectors and is for the period 1995-2009. All regressions include fixed effects as specified. Standard errors clustered at the country-sector level are included in parentheses, where ***, **, and * indicate significance at the 1, 5, and 10 percent statistical level, respectively.

Table 10: Finance and pollution: Firm-level evidence

Panel A. Belgium

	Equity ratio	CO_2 emissions per sales	CO_2 emissions per assets
	(1)	(2)	(3)
Post 2006	0.0989***		
	(0.0058)		
Post 2006 × Carbon intensity		-0.0011***	-0.0001***
		(0.0002)	(0.0000)
Firm fixed effects	Yes	Yes	Yes
Year dummies	No	Yes	Yes
No. Observations	3,240	1,773	1,821
No. Firms	159	159	159
R-squared	0.55	0.66	0.80

Panel B. Difference-in-Differences (Belgium vs. the Netherlands)

	Equity ratio	CO_2 emissions per sales	CO_2 emissions per assets
	(1)	(2)	(3)
Post 2006	0.0615***		
	(0.0084)		
Post 2006 × Belgium	0.0374***		
	(0.0103)		
Post 2006 × Carbon intensity		0.0000	-0.0001
		(0.0002)	(0.0001)
Post 2006 × Carbon intensity × Belgium		-0.0011***	-0.0001*
		(0.0002)	(0.0000)
Firm fixed effects	Yes	Yes	Yes
Country × Year dummies	No	Yes	Yes
No. Observations	5,020	2,356	2,676
No. Firms	260	260	260
R-squared	0.56	0.66	0.83

Panel C. Difference-in-Differences (Matched sample: Belgium, France, Germany, Luxembourg, and the Netherlands)

	Equity ratio	CO_2 emissions per sales	CO_2 emissions per assets
	(1)	(2)	(3)
Post 2006	0.0061		
	(0.0066)		
Post 2006 × Belgium	0.0938***		
	(0.0090)		
Post 2006 × Carbon intensity		0.1292***	0.1466***
		(0.0460)	(0.0336)
Post 2006 × Carbon intensity × Belgium		-0.1093**	-0.1373***
		(0.0515)	(0.0429)
Firm fixed effects	Yes	Yes	Yes
Country × Year dummies	No	Yes	Yes
No. Observations	5,809	3,165	3,287
No. Firms	296	296	296
R-squared	0.58	0.93	0.93

Notes: This table reports estimates from OLS regressions (Panel A); difference-in-differences regressions (Panel B); and difference-in-differences regressions combined with nearest neighbor matching (Panel C). The dependent variables are the ratio of the firm's shareholder funds to total current plus non-current liabilities (column (1)); the firm's emissions of carbon dioxide equivalent, in tons, divided by total sales (column (2)); and the firm's emissions of carbon dioxide equivalent, in tons, divided by total assets (column (3)). Belgium introduced an allowance for corporate equity (ACE) in 2006. 'Post' is a dummy variable equal to one in 2007 and thereafter. 'Carbon intensity' denotes the sector average, over the entire period 2005-2018, of firms' CO_2 equivalent emissions per sales (column (2)) or per assets (column (3)), for the 33 countries for which firm-level CO_2 equivalent data are available from the ETS. Data on equity ratios, sales, and assets come from Orbis. The sample period is 19952018 (column (1)) and 20052018 (columns (2)-(3)). All regressions include fixed effects as specified. Standard errors are included in parentheses, where ***, **, and * indicate significance at the 1, 5, and 10 percent statistical level, respectively.

Appendix

Table A1: Variable definitions and sources

Variable	Definition	Data source
CO_2 emissions per capita	Aggregate or sector-specific emissions of carbon dioxide, in tons, divided by the country's population.	UNIDO; OECD
Financial development (FD)	Sum of private-sector credit and value of all listed stocks, divided by the country's GDP, 1-period lagged.	Beck et al. (2019)
FD with bonds	Sum of credit to the private sector, the value of all listed stocks, and the value of all issued private corporate bonds, divided by the country's GDP, 1-period lagged.	Beck et al. (2019)
Financial structure (FS)	Value of all listed stocks, divided by the sum of credit to the private sector and the value of all listed stocks, 1-period lagged.	Beck et al. (2019)
FS with bonds	Sum of the value of all listed stocks divided by the sum of credit to the private sector, the value of all listed stocks, and the value of all issued private corporate bonds 1-period lagged.	Beck et al. (2019)
GDP per capita	Country's per capita GDP.	WDI
Population	Country's population, in millions of inhabitants.	WDI
Recession	Dummy variable equal to 1 if the country experiences negative GDP growth.	WDI
Environmental protection index	Index that measures the stringency of environmental protection taking values from 0 (not stringent) to 6 (very stringent).	OECD; Botta and Kozluk (2014)
Pro-competitive bank regulation	Index of how pro-bank entry regulation is. Values of 4 or 5 indicate fully liberalized; 3 indicates largely liberalized; 2 or 1 indicates partially repressed and 0 indicates fully repressed.	Abiad et al. (2008)
Equity market liberalization	Dummy variable equal to 1 if the country's stock market is open to foreign portfolio investment.	Bekaert et al. (2005)
Growth in value added	Sector-specific growth in value added.	UNIDO; OECD
CO_2 emissions per value added	Aggregate or sector-specific emissions of carbon dioxide, in tons, divided by the sector's value added (in thousand dollars).	UNIDO; OECD
Imported CO_2 emissions per capita	Sector-specific carbon dioxide embedded in imports, in tons, divided by the country's population.	WIOD

Continued on next page.

Table A1 cont.: Variable definitions and sources

Variable	Definition	Data source
Green patents per capita	Number of green patents in a country-sector-year, per 1 million population.	UNIDO; OECD; PATSTAT
Green patents per capita (excl. transport and waste)	Number of patents in the most climate-change-intensive technologies in a country-sector-year, per 1 million population, excluding patents related to transportation and to waste water treatment and waste management.	UNIDO; OECD; PATSTAT
Green patents per capita (industrial production)	Number of patents related to inventions to increase the energy efficiency of industrial production or processing of goods in a country-sector-year, per 1 million population.	UNIDO; OECD; PATSTAT
Sector share	Share in value added of the sector out of the whole economy.	UNIDO; OECD
Carbon intensity	Average value, over the entire sample period, of a sector's CO_2 emissions per value added in the global sample.	IEA; UNIDO; STAN
Carbon intensity (contemporaneous)	Average value, for each year, of each sector's CO_2 emissions per value added, for all countries in the sample.	IEA; UNIDO; STAN
Carbon intensity (US)	Average value, over the entire sample period, of each sector's CO_2 emissions per value added in the US.	IEA; UNIDO; STAN
R&D intensity	Industry-median value of R&D investment over total assets for mature listed firms, from Compustat North America.	Laeven et al. (2006)
Asset tangibility	Share of tangible assets out of total assets for mature listed firms, from Compustat North America.	Braun (2003)
Litigation risk	Total penalties paid by a sector in the U.S. during 2000-2014 (following both administrative and judicial legal cases) as a share of the sector's value added over the same period.	EPA and ECHO; WIOD
Stock/GDP	One-period lagged ratio of the value of all listed stocks to the country's GDP.	Beck et al. (2016)
Credit/GDP	One-period lagged ratio of credit to the private sector to the country's GDP.	Beck et al. (2016)
External dependence	Share of capital investment financed with sources other than retained earnings, for Compustat firms during 1990–2000.	Compustat
Fuel subsidies	Difference between the observed price of fuel and the benchmark price of fuel for a particular country-sector.	IMF Energy Subsidies Template
Equity ratio	Shareholder funds/current plus non-current liabilities (in %).	Orbis
CO_2 emissions per sales	Firms' emissions of carbon dioxide, in tons, divided by total sales.	ETS; Orbis
CO_2 emissions per assets	Firms' emissions of carbon dioxide, in tons, divided by total assets.	ETS; Orbis

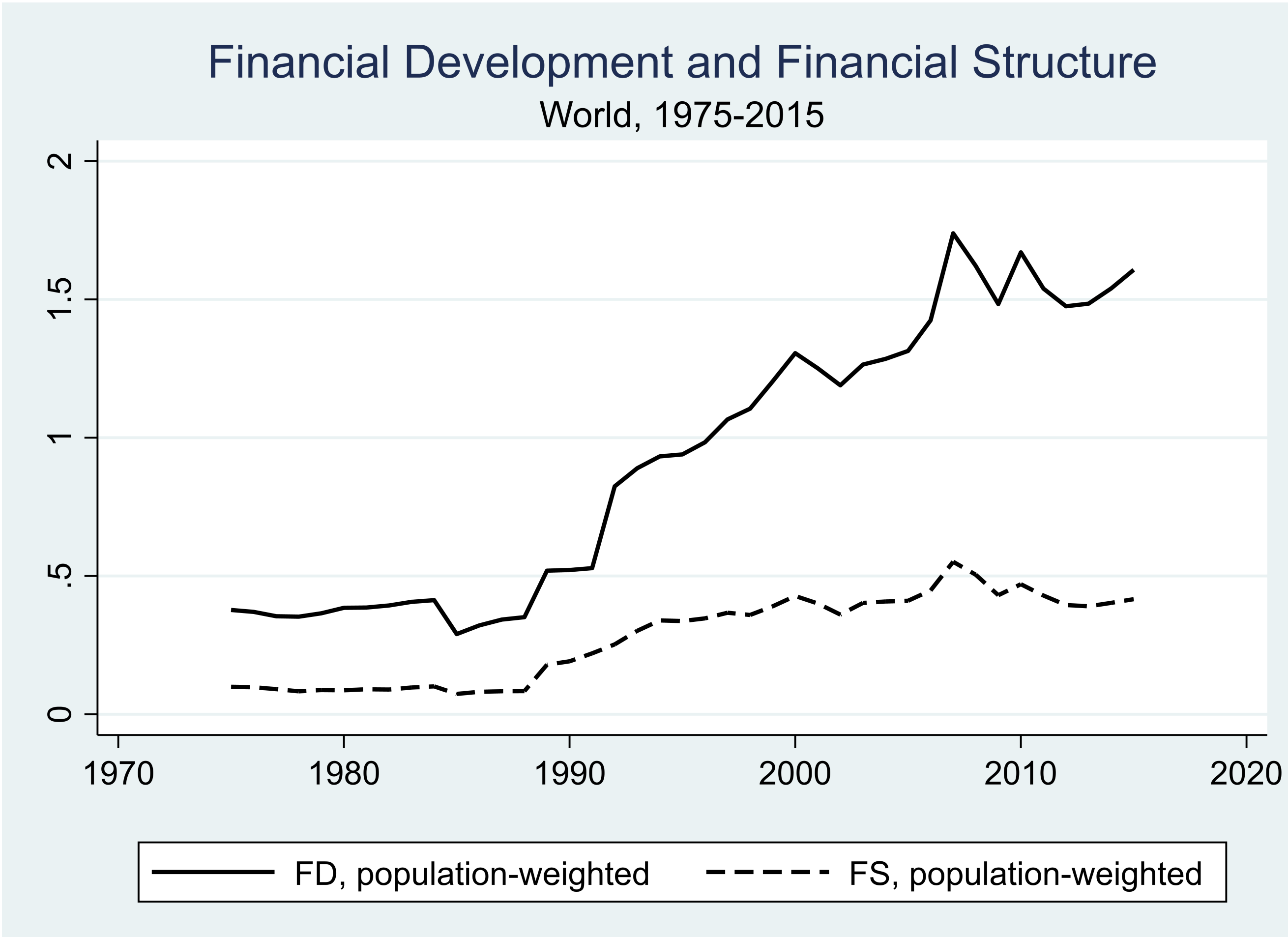
Notes: This table provides definitions and data sources for all variables used in the paper. UNIDO: United Nations Industrial Development Organization. OECD: Organisation for Economic Co-operation and Development. WDI: World Development Indicators. IEA: International Energy Agency. PATSTAT: European Patent Office (EPO) Worldwide Patent Statistical Database. STAN: STAN Data set for Structural Analysis (OECD). EPA and ECHO: Environmental Protection Agency (EPA)'s Enforcement and Compliance History Online (ECHO) data set. WIOD: World Input-Output Database. ETS: EU Emissions Trading System. Orbis: Orbis - Bureau van Dijk.

Table A2: Summary statistics

Variable	Mean	Median	St. dev.	Min	Max
Country-level					
CO_2 emissions per capita	6.784	6.008	4.908	0.098	32.404
Financial development (FD)	1.242	1.111	0.814	0.028	4.159
Financial structure (FS)	0.390	0.393	0.161	0.001	0.823
GDP per capita	23.322	14.051	21.821	0.553	135.553
Population	0.078	0.014	0.223	0.001	1.357
Recession	0.246	0.000	0.412	0.000	1.000
Environmental protection index	1.612	1.480	0.917	0.210	4.130
Pro-competitive bank regulation	2.689	3.000	0.652	0.000	3.000
Equity market liberalization	0.857	1.000	0.350	0.000	1.000
Sector-level (UNIDO)					
CO_2 emissions per capita	0.436	0.071	1.160	0.000	15.479
Growth in value added	-0.004	0.001	0.179	-1.000	1.000
CO_2 emissions per value added	1.457	0.269	5.148	0.000	196.941
Green patents per capita	0.153	0.000	0.947	0.000	32.858
Green patents per capita (excl. transport and waste)	0.112	0.000	0.735	0.000	28.013
Green patents per capita (industrial production)	0.044	0.000	0.243	0.000	8.354
Sector share	0.019	0.006	0.059	0.001	0.912
Sector-level (OECD)					
CO_2 emissions per capita	0.579	0.112	1.378	0.000	15.478
Growth in value added	0.002	0.006	0.119	-1.000	1.000
CO_2 emissions per value added	1.498	0.214	5.020	0.000	216.825
Green patents per capita	0.216	0.000	0.977	0.000	21.130
Green patents per capita (excl. transport and waste)	0.165	0.000	0.825	0.000	20.850
Green patents per capita (industrial production)	0.066	0.000	0.274	0.000	6.252
Sector share	0.020	0.014	0.022	0.001	0.282
Firm-level (Orbis and ETS)					
Equity ratio	0.395	0.381	0.256	0.000	1.000
CO_2 emissions per sales	0.009	0.007	0.013	0.000	0.129
CO_2 emissions per assets	0.012	0.009	0.014	0.000	0.098

Notes: This table summarizes the data used in the paper. Summary statistics for country-, sector- and firm-level CO_2 emissions are expressed in metric tons (1000 kg). At the country- and sector-level, these variables are measured in kilotons (1^6 kg) in the regression analyses. Appendix Table A1 contains all variable definitions.

Chart 1: Global financial development and financial structure over time



Notes: The chart plots population-weighted global 'Financial development' and 'Financial structure' between 1975 and 2015.

Online Appendix

Table OA1: Main variables by country (1990-2015 averages)

Country	FD	FS	CO_2 per capita
Argentina	0.278	0.466	3.541
Australia	1.825	0.483	15.682
Austria	1.141	0.194	7.535
Azerbaijan	0.028	0.023	3.812
Belgium	1.167	0.462	10.769
Brazil	0.768	0.414	1.468
Bulgaria	0.486	0.149	6.142
Canada	2.374	0.491	15.848
Chile	1.653	0.559	2.681
China	1.389	0.226	3.247
Colombia	0.590	0.414	1.309
Costa Rica	0.360	0.229	1.092
Croatia	0.788	0.344	3.946
Czech Republic	0.658	0.282	11.643
Denmark	1.589	0.369	10.396
Estonia	0.826	0.301	12.256
Finland	1.510	0.475	10.693
France	1.487	0.400	6.296
Germany	1.362	0.276	11.188
Greece	1.006	0.359	6.556
Hungary	0.578	0.301	6.104
India	0.810	0.561	0.734
Ireland	1.561	0.346	8.835
Italy	1.004	0.298	6.689
Japan	2.560	0.292	8.402
Kazakhstan	0.435	0.349	11.404
Lithuania	0.448	0.381	4.159
Luxembourg	2.262	0.596	25.911
Mexico	0.492	0.553	3.349
Morocco	0.840	0.399	0.954
Netherlands	1.858	0.426	9.950
New Zealand	1.412	0.277	6.638
North Macedonia	0.342	0.166	4.345
Norway	1.181	0.296	7.018
Philippines	0.856	0.584	0.740
Poland	0.523	0.341	9.292
Portugal	1.363	0.224	3.926
Russia	0.607	0.516	10.908
Slovenia	0.691	0.263	7.307
Spain	2.031	0.447	5.622
Sweden	1.865	0.440	6.072
Switzerland	3.294	0.523	5.889
Thailand	1.471	0.327	1.892
Turkey	0.471	0.476	2.582
Ukraine	0.543	0.327	7.237
United Kingdom	2.500	0.473	9.165
United States	2.685	0.405	19.189
Zambia	0.201	0.586	0.332

Table OA2: Finance, imports, and carbon leakage: Low versus high mobility sectors

Panel A. Low-mobility (high-transport-cost) sectors

	CO_2 emissions per capita from imports					
	Total	Households	Sector, same	Sector, other	GFCF	Government
	(1)	(2)	(3)	(4)	(5)	(6)
FD × Carbon intensity	0.0048	0.0013	-0.0027	0.0061	0.0001	0.0000
	(0.0067)	(0.0021)	(0.0018)	(0.0043)	(0.0001)	(0.0000)
FS × Carbon intensity	0.0316**	0.0092***	0.0059	0.0159	0.0005**	0.0000
	(0.0147)	(0.0037)	(0.0041)	(0.0106)	(0.0002)	(0.0000)
Sector share	0.0005*	-0.0001	0.0001	0.0006**	0.0001***	0.0000
	(0.0003)	(0.0001)	(0.0001)	(0.0003)	(0.0000)	(0.0000)
Country × Sector dummies	Yes	Yes	Yes	Yes	Yes	Yes
Country × Year dummies	Yes	Yes	Yes	Yes	Yes	Yes
Sector × Year dummies	Yes	Yes	Yes	Yes	Yes	Yes
No. Observations	1,624	1,624	1,624	1,624	1,624	1,624
R-squared	0.99	0.98	0.98	0.99	0.93	0.95

Panel B. High-mobility (low-transport-cost) sectors

	CO_2 emissions per capita from imports					
	Total	Households	Sector, same	Sector, other	GFCF	Government
	(1)	(2)	(3)	(4)	(5)	(6)
FD × Carbon intensity	0.0062	0.0003	0.0075	-0.002	0.0003	0.0000**
	(0.0153)	(0.0006)	(0.0122)	(0.0036)	(0.0004)	(0.0000)
FS × Carbon intensity	0.0676***	-0.0001	0.0324***	0.0350***	0.0003	0.0000
	(0.0216)	(0.0015)	(0.0120)	(0.0107)	(0.0014)	(0.0000)
Sector share	0.0004	0.0000	0.0004	-0.0001	0.0001**	0.0000
	(0.0005)	(0.0001)	(0.0003)	(0.0002)	(0.0000)	(0.0000)
Country × Sector dummies	Yes	Yes	Yes	Yes	Yes	Yes
Country × Year dummies	Yes	Yes	Yes	Yes	Yes	Yes
Sector × Year dummies	Yes	Yes	Yes	Yes	Yes	Yes
No. Observations	1,540	1,540	1,540	1,540	1,540	1,540
R-squared	0.98	0.97	0.97	0.98	0.97	0.92

Notes: The table reports estimates from OLS regressions. The dependent variable is the total emissions of carbon dioxide associated with foreign-produced goods purchased by the total economy (column (1)), by households (column (2)), by the same industry (column (3)), by other industries (column (4)), purchased for gross fixed capital formation (column (5)), or purchased by the government (column (6)), in tons, per capita. Import data come from WIOD and sector-specific data from IEA and UNIDO. The sample period is 1995-2009. The sample includes sectors with above-median transport costs (low footloose sectors) (Panel A) and sectors with below-median transport costs (footloose sectors) (Panel B). All regressions include fixed effects as specified. Standard errors clustered at the country-sector level are included in parentheses, where ***, **, and * indicate significance at the 1, 5, and 10 percent statistical level, respectively.

Table OA3: Finance and sector-level carbon emissions: 5-year averages

	CO_2 emissions per capita	Growth in value added	CO_2 emissions per value added
	(1)	(2)	(3)
FD × Carbon intensity	-0.0160	-0.0021	0.3228
	(0.0206)	(0.0157)	(0.2881)
FS × Carbon intensity	-0.0888*	-0.1064**	-5.2172***
	(0.0569)	(0.0533)	(1.6036)
Sector share	2.2444**	-3.2582**	18.2842
	(1.0420)	(1.3758)	(14.7835)
Country × Sector dummies	Yes	Yes	Yes
Country × Period dummies	Yes	Yes	Yes
Sector × Period dummies	Yes	Yes	Yes
No. Observations	1,228	1,148	1,215
R-squared	0.89	0.72	0.91

Notes: The table reports estimates from OLS regressions. The dependent variable is the sector's annual emissions of carbon dioxide, in kilotons, per capita (column (1)); the sector's annual growth in value added (column (2)); and the sector's annual emissions of carbon dioxide, in tons, per unit of value added (column (3)). 'Sector share' denotes the 1-period lagged share in value added of the sector out of the whole economy. All variables are averages over non-overlapping 5-year intervals (1990-1994, 1995-1999, 2000-2004, 2005-2009, 2010-2015). Sector-specific data come from IEA and UNIDO. The sample period is 1990-2013. All regressions include fixed effects as specified. Standard errors clustered at the country-period level are included in parentheses, where ***, **, and * denote significance at the 1, 5, and 10 percent statistical level, respectively.

Table OA4: Credit markets, stock markets, and sector-level carbon emissions

	CO_2 emissions per capita	Growth in value added	CO_2 emissions per value added
	(1)	(2)	(3)
Credit/GDP × Carbon intensity	0.1384	0.0096	0.5415
	(0.0914)	(0.0180)	(0.5229)
Stocks/GDP × Carbon intensity	-0.0820*	-0.0452**	-0.9819***
	(0.0469)	(0.0212)	(0.4136)
Sector share	3.8725	-14.4746***	7.3110
	(2.7110)	(2.2423)	(14.6099)
Country × Sector dummies	Yes	Yes	Yes
Country × Year dummies	Yes	Yes	Yes
Sector × Year dummies	Yes	Yes	Yes
No. Observations	6,563	6,079	6,192
R-squared	0.78	0.56	0.91

Notes: The table reports estimates from OLS regressions. The dependent variable is the sector's annual emissions of carbon dioxide, in kilotons, per capita (column (1)); the sector's annual growth in value added (column (2)); and the sector's annual emissions of carbon dioxide, in tons, per unit of value added (column (3)). 'Sector share' denotes the 1-period lagged share in value added of the sector out of the whole economy. Sector-specific data come from IEA and UNIDO. The sample period is 1990-2015. All regressions include fixed effects as specified. Standard errors clustered at the country-sector level are included in parentheses, where ***, **, and * denote significance at the 1, 5, and 10 percent statistical level, respectively.

Table OA5: Finance and sector-level carbon emissions: External finance dependence

	CO_2 emissions per capita	Growth in value added	CO_2 emissions per value added
	(1)	(2)	(3)
FD × Carbon intensity	0.0448	-0.0186	-0.1486
	(0.0398)	(0.0167)	(0.4548)
FS × Carbon intensity	-0.1861**	-0.0786*	-4.5625***
	(0.0873)	(0.0439)	(1.1387)
FD × External dependence	0.0676	-0.0087	0.3407
	(0.0686)	(0.0234)	(0.5426)
FS × External dependence	-0.2114	-0.0680	-1.5325
	(0.1577)	(0.0639)	(1.9049)
Sector share	5.5940*	-14.3814***	1.9919
	(3.4984)	(2.2458)	(13.6135)
Country × Sector dummies	Yes	Yes	Yes
Country × Year dummies	Yes	Yes	Yes
Sector × Year dummies	Yes	Yes	Yes
No. Observations	6,477	6,229	6,112
R-squared	0.77	0.56	0.82

Notes: The table reports estimates from OLS regressions. The dependent variable is the sector's emissions of carbon dioxide, in tons, per capita (column (1)); the sector's annual growth in value added (column (2)); and the sector's emissions of carbon dioxide, in tons, per unit of value added (column (3)). 'Sector share' denotes the 1-period lagged share in value added of the sector out of the whole economy. Sector-specific data come from IEA and UNIDO. The sample period is 1990-2015. All regressions include fixed effects as specified. Standard errors clustered at the country-sector level are included in parentheses, where ***, **, and * indicate significance at the 1, 5, and 10 percent statistical level, respectively.

Table OA6: Alternative benchmarks for carbon intensity

	CO_2 emissions per capita		Growth in value added		CO_2 emissions per value added	
	(1)	(2)	(3)	(4)	(5)	(6)
FD × Carbon intensity (Contemporaneous)	0.0093		-0.0016		-0.2232**	
	(0.0091)		(0.0037)		(0.1099)	
FS × Carbon intensity (Contemporaneous)	-0.0199*		-0.0096		-1.1231***	
	(0.0117)		(0.0117)		(0.3121)	
FD × Carbon intensity (US)		0.0365		-0.0180		-0.7824*
		(0.0280)		(0.0160)		(0.4171)
FS × Carbon intensity (US)		-0.1678**		-0.0752*		-4.4933***
		(0.0785)		(0.0489)		(1.2281)
Sector share	5.6141*	5.8057*	-14.3529***	-14.9500***	3.3124	2.2164
	(3.5149)	(3.6193)	(2.2558)	(2.2551)	(13.7739)	(14.1506)
Country × Sector dummies	Yes	Yes	Yes	Yes	Yes	Yes
Country × Year dummies	Yes	Yes	Yes	Yes	Yes	Yes
Sector × Year dummies	Yes	Yes	Yes	Yes	Yes	Yes
No. Observations	6,477	6,290	6,229	6,068	6,112	5,951
R-squared	0.77	0.77	0.56	0.56	0.82	0.82

Notes: The table reports estimates from OLS regressions. The dependent variable is the sector's annual emissions of carbon dioxide, in tons, per capita (columns (1)-(2)); the sector's annual growth in value added (columns (3)-(4)); and the sector's annual emissions of carbon dioxide, in tons, per unit of value added (columns (5)-(6)). Sector-specific data come from IEA and UNIDO. The sample period is 1990-2015. All regressions include fixed effects as specified. Standard errors clustered at the country-sector level are included in parentheses, where ***, **, and * indicate significance at the 1, 5, and 10 percent statistical level, respectively.

Table OA7: Finance and sector-level carbon emissions: Including corporate bonds

	CO_2 emissions per capita	Growth in value added	CO_2 emissions per value added
	(1)	(2)	(3)
FD with bonds × Carbon intensity	0.0609	-0.0114	-0.3022
	(0.0449)	(0.0109)	(0.2407)
FS with bonds × Carbon intensity	-0.2180**	-0.0608*	-4.1620***
	(0.1067)	(0.0424)	(1.0997)
Sector share	5.3765*	-14.3664***	3.0156
	(3.3586)	(2.2467)	(13.4660)
Country × Sector dummies	Yes	Yes	Yes
Country × Year dummies	Yes	Yes	Yes
Sector × Year dummies	Yes	Yes	Yes
No. Observations	6,477	6,229	6,112
R-squared	0.77	0.56	0.82

Notes: The table reports estimates from OLS regressions. The dependent variable is the sectors annual emissions of carbon dioxide, in tons, per capita (column (1)); the sector's annual growth in value added (column (2)); and the sectors annual emissions of carbon dioxide, in tons, per unit of value added (column (3)). 'FS' denotes the sum of the value of all listed stocks divided by the sum of credit to the private sector, the value of all listed stocks, and the value of all issued private corporate bonds, 1-period lagged. 'Sector share' denotes the 1-period lagged share in value added of the sector out of the whole economy. Sector-specific data come from IEA and UNIDO and data on corporate bonds from Beck at al. (2019). The sample period is 1990-2015. All regressions include fixed effects as specified. Standard errors clustered at the country-year level are included in parentheses, where ***, **, and * denote significance at the 1, 5, and 10 percent statistical level, respectively.

Table OA8: Finance and sector-level carbon emissions: Including private equity

	CO_2 emissions per capita	Growth in value added	CO_2 emissions per value added
	(1)	(2)	(3)
FD × Carbon intensity	0.0514	0.0063	-0.4776
	(0.0433)	(0.0171)	(0.6563)
FS × Carbon intensity	-0.2174**	-0.0232	-5.9141***
	(0.0947)	(0.0581)	(1.7080)
Sector share	16.9155*	-12.5589***	3.6895
	(10.6717)	(2.2024)	(18.1962)
Country × Sector dummies	Yes	Yes	Yes
Country × Year dummies	Yes	Yes	Yes
Sector × Year dummies	Yes	Yes	Yes
No. Observations	3,688	3,548	3,593
R-squared	0.76	0.57	0.74

Notes: The table reports estimates from OLS regressions. The dependent variable is the sector's annual emissions of carbon dioxide, in tons, per capita (column (1)); the sector's annual growth in value added (column (2)); and the sector's annual emissions of carbon dioxide, in tons, per unit of value added (column (3)). Sector-specific data come from IEA and UNIDO and data on private equity from the European Venture Capital Association. The sample period is 1990-2015. All regressions include fixed effects as specified. Standard errors clustered at the country-sector level are included in parentheses, where ***, **, and * indicate significance at the 1, 5, and 10 percent statistical level, respectively.

Table OA9: Finance and sector-level carbon emissions: Controlling for fuel subsidies

	CO_2 emissions per capita	Growth in value added	CO_2 emissions per value added
	(1)	(2)	(3)
FD × Carbon intensity	0.0278	-0.0160	-0.1688
	(0.0307)	(0.0149)	(0.3999)
FS × Carbon intensity	-0.1503**	-0.0605*	-3.9049***
	(0.0777)	(0.0424)	(1.1052)
FD × Fuel subsidies	0.5756**	-0.4921	-0.6325
	(0.2722)	(0.3645)	(8.5471)
FS × Fuel subsidies	0.2418	0.3190	-42.7516**
	(0.7594)	(0.7432)	(18.2014)
Sector share	5.7019*	-14.6130***	-0.5884
	(3.6422)	(2.3108)	(13.4153)
Country × Sector dummies	Yes	Yes	Yes
Country × Year dummies	Yes	Yes	Yes
Sector × Year dummies	Yes	Yes	Yes
No. Observations	6,167	6,079	5,806
R-squared	0.77	0.56	0.84

Notes: The table reports estimates from OLS regressions. The dependent variable is the sector's annual emissions of carbon dioxide, in tons, per capita (column (1)); the sector's annual growth in value added (column (2)); and the sector's annual emissions of carbon dioxide, in kilotons, per unit of value added (column (3)). Sector-specific data come from IEA, IMF, and UNIDO. The sample period is 1990-2015. All regressions include fixed effects as specified. Standard errors clustered at the country-year level are included in parentheses, where ***, **, and * indicate significance at the 1, 5, and 10 percent statistical level, respectively.

Table OA10: Sector benchmark correlations

	Carbon intensity	R&D intensity	Asset tangibility	Litigation risk
Carbon intensity	1.00			
R&D intensity	-0.37	1.00		
Asset tangibility	0.40	-0.26	1.00	
Litigation risk	0.75	-0.18	0.24	1.00

Notes: This table reports correlations between sector-level carbon intensity, R&D intensity, asset tangibility, and litigation risk.