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Finance and carbon emissions

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Abstract

We study the relation between the structure of financial systems and carbon emissions in a large panel of countries and industries over the period 1990-2013. We find that for given levels of economic and financial development and environmental regulation, CO_2 emissions per capita are lower in economies that are relatively more equity-funded. Industry-level analysis reveals two distinct channels. First, stock markets reallocate investment towards less polluting sectors. Second, they also push carbon-intensive sectors to develop and implement greener technologies. In line with this second effect, we show that carbon-intensive sectors produce more green patents as stock markets deepen. We also document an increase in carbon emissions associated with the production of imported goods equal to around one-tenth of the reduction in domestic carbon emissions.

JEL classification: G10, O4, Q5.

Keywords: Financial development, financial structure, carbon emissions, innovation.

Non-technical summary

The discussion about the link between financial and economic activity on the one hand, and climate change on the other, has markedly intensified in recent years. The 2015 Paris Climate Conference called for green-finance initiatives to fund low-carbon infrastructure and other climate solutions. Earlier this year, a group of academic economists and former Chairs of the Federal Reserve Board and of the Council of Economic Advisers issued a statement calling for immediate national action to tackle global climate change through a carbon tax. And the 2018 Sveriges Riksbank Nobel Prize in Economic Sciences was awarded to William Nordhaus for his work on integrating climate change into long-run macroeconomic analysis.

Central Banks around the world have also begun discussing the implications of climate change for monetary policy, with some—such as the Bank of England—elevating Central Bank response to fundamental (including environmental) change to a main research priorities. This discussion typically focuses on the impact of climate change, as well as of policies designed to tackle it, on financial stability and on the nature, persistence, and magnitude of economic shocks that monetary policy needs to identify. At the same time, little attention is devoted to understanding better how financial market activity contributes to climate change through its impact on the real economy. This is important because different types of financial markets can have different effects on economic activity, and by extension on the industrial pollutants that sit at the heart of anthropogenic climate change.

In this paper, we analyze the mechanisms that connect finance, industrial composition, and environmental degradation—as measured by the emission of CO_2—in a 48-country, 16-industry, 24-year panel. We find that for given levels of economic and financial development, carbon emissions per capita are significantly lower in economies where equity financing is more important relative to bank lending. Industry-level analysis confirms that industries that pollute more for technological reasons, start to produce relatively less carbon dioxide per capita where and when stock markets expand. The 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 adoption of cleaner technologies in polluting industries, leading to a decline in carbon emissions per unit of value added. Auxiliary sectoral evidence confirms that deeper stock markets are associated with more green innovation and patenting in traditionally carbon-intensive industries. These empirical regularities are robust to controlling for a host of potential confounding factors, including general economic development, country-industry fixed effects, and unobservable country and industry trends, and they still obtain when we make use of policy changes that induce exogenous shocks to a country's financial structure. Interestingly, we also find that higher funding through corporate bonds does not have a greening effect on the economy, suggesting that when it comes to green innovation, the right definition of financial structure is not one based on a distinction between banks and markets, but one based on a distinction between debt and equity.

At the same time, we find that the reduction in carbon emissions, due to domestic stock market development, in carbon intensive sectors is accompanied by an increase in carbon emissions associated with the production of both final and of intermediary goods abroad, suggesting a role for the outsourcing of dirty technologies in explaining our results. However, the domestic-greening effect dominates the pollution-outsourcing effect by a factor of ten. This suggests that equity markets have a genuine cleansing effect on polluting industries and do not simply help such industries to outsource carbon-intensive activities to pollution havens.

Our findings indicate that equity-based financial systems are tightly associated with better environmental quality. A back-of-the-envelope calculation suggests that shifting the financial structure of all countries in the world to at least 50-percent equity financing would result in a reduction in current aggregate per capita carbon emissions of around 11.5 percent, or around a quarter of the 40% reduction in emissions which countries committed to achieve by 2030 in the context of the Paris Agreement. Thus, countries with a bank-based financial system that are currently aiming to green their economy through the promotion of green bonds or other green-finance initiatives, could consider stimulating the development of conventional equity markets as well. An environmental objective could also strengthen the case for a Capital Market Union in Europe to deliver sustainable, equity-based growth. In this context, initiatives such as reviewing the tax shield on debt and removing obstacles to (cross-border) investment in public and private equity, by individual as well as institutional investors, can ultimately have an important second-round effect on the environment.

1 Introduction

The 2015 Paris Climate Conference (COP21) has put finance firmly at the heart of the debate on environmental degradation. The leaders of the G20 stated their intention to scale up so-called green-finance initiatives to fund low-carbon infrastructure and other climate solutions. A key example is the burgeoning market for green bonds to finance projects that save energy, reduce carbon emissions, or curtail pollution more generally. Other green-finance initiatives include the establishment of the British Green Investment Bank, which specializes in projects related to environmental preservation, and the creation of a green-credit department by the largest bank in the world—ICBC in China. Similar initiatives are being developed by many other industrialized and developing countries.

Somewhat paradoxically, the interest in green finance has also laid bare our limited understanding of the relation between regular finance and environmental pollution. To date, no rigorous empirical evidence exists on whether and how finance affects industrial pollution as economies grow. Are well-developed banking sectors and stock markets detrimental to the environment as they fuel growth and the concomitant emission of pollutants? Or can financial development steer economies towards more sustainable growth by favoring clean industries over dirty ones? Developing 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 reduce such emissions.

To analyze the mechanisms that connect finance, industrial composition and environmental degradation—as measured by the emission of CO_2—we exploit a 48-country, 16-industry, 24-year panel.[1] To preview our results, we find 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. Industry-level analysis confirms that industries that pollute more for technological reasons, start to produce relatively less carbon dioxide where and when stock markets expand. Our analysis reveals two distinct channels that underpin these results.

[1] CO_2 emissions are widely considered to be 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.

First—holding cross-industry differences in technology constant—stock markets tend to reallocate investment towards more carbon-efficient sectors. Second, stock markets facilitate the adoption of cleaner technologies in polluting industries. Auxiliary sectoral evidence confirms that deeper stock markets are associated with more green innovation and patenting in traditionally carbon-intensive industries. Lastly, we find that the reduction in carbon emissions, due to domestic stock market development, in carbon intensive sectors is accompanied by an increase in carbon emissions associated with the production of both final and of intermediary goods abroad, suggesting a role for the outsourcing of dirty technologies in explaning our results. However, the domestic-greening effect dominates the pollution-outsourcing effect by a factor of ten. This suggests that stock markets have a genuine cleansing effect on polluting industries and do not simply help such industries to outsource carbon-intensive activities to pollution havens. These empirical regularities are robust to controlling for a host of potential confounding factors, including general economic development, country-industry fixed effects, and unobservable country and industry trends.

This paper contributes to (and connects) two strands of the literature. First, we inform the debate on economic development and environmental pollution. This literature has focused mostly on the environmental Kuznets hypothesis, according to which pollution increases at early stages of development but declines once a country surpasses a certain income level. Two main mechanisms underlie this hypothesis (Levinson, 2009). 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, however, the structure of 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.[2] 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 output (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.[3] 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

[2]Hettige, Lucas and Wheeler (1992) and Hettige, Mani and Wheeler (2000) find that the sectoral composition of an economy gets cleaner when a country reaches middle-income status and moves towards less-polluting services.

[3]Grossman and Krueger (1995) find a Kuznets curve for urban air pollution and the contamination of river basins. For a review of empirical research on the environmental Kuznets curve, see Dasgupta, Laplante, Wang and Wheeler (2002).

(1995) show that CO_2 emissions go up 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. Empirical evidence on the diffusion of low-carbon technologies is still lacking (Burke et al., 2016) and our findings shed light on the role of finance in this regard. More specifically, we assess how a country's financial structure—the relative importance of stock markets versus banks as corporate funding sources—affect the two main mechanisms that underpin the Kuznets hypothesis: a shift towards less-polluting sectors and an innovation-driven reduction in pollution within sectors. A move towards greener technologies can require substantial investments and therefore be conditional on the availability of external finance. In line with this, Howell (2017) provides quasi-experimental evidence showing that small firms that receive grant funding from the U.S. Small Business Innovation Research Program (compared with a control group of similar unsuccessfull applicants) generate more revenue and patent more. Importantly, these effects are largest for financially constrained firms and those in sectors related to clean energy and energy efficiency. Moreover, Schumpeterian growth models suggest that financial constraints may prevent firms in less-developed countries from exploiting such R&D carried out in countries close to the technological frontier (Aghion, Howitt and Mayer-Foulkes, 2005). Financial development can then facilitate the absorption of state-of-the art technologies and help mitigate environmental pollution in poorer countries as well.

Second, our results also contribute to the literature on the relationship 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.[4] While earlier findings suggest that the structure of the financial system—bank-based or market-based—matters little for economic growth (Beck and Levine, 2002), more recent research qualifies this finding by showing that the impact of banking on growth declines (and the impact of securities markets on growth increases) as national income rises (Demirgüç-Kunt, Feyen and Levine, 2013; Gambacorta, Yang and Tsatsaronis, 2014). 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.

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

The rest of the paper is structured as follows. Section 2 sets out the main arguments as to why banks and stock markets can have a different impact on industrial pollution. Sections 3 and 4 then describe our empirical methodology and data, respectively. Section 5 presents the empirical results and Section 6 concludes with a discussion of our main findings.

2 Stock Markets, Banks, and Carbon Emissions

Financial structure, or the relative importance of credit versus stock markets, may have an environmental impact if different forms of finance affect industrial pollution to a different extent or through different channels. The existing literature suggests several reasons as to why banks or stock markets may be relatively (in)effective in limiting environmental pollution.[5]

A first strand of the literature is critical about the ability of banks to finance innovative projects. To the extent that technological innovation is an important mechanism to contain environmental pollution, this literature therefore suggests that banks are relatively ineffective in reducing pollution. Several mechanisms may be at play. First, banks may be technologically conservative: they fear that funding new (and possibly cleaner) technologies erodes the value of collateral that underlies existing loans, which represent older (dirtier) technologies (Minetti, 2011). Second, banks can hesitate to finance green technologies if the related innovation involves assets that are intangible, firm-specific, and linked to human capital (Hall and Lerner, 2010). Such assets are difficult to redeploy and therefore hard to collateralize (Carpenter and Petersen, 2002). Asset intangibility and uncertainty are especially problematic for energy technology startups (Nanda, Younge, and Fleming, 2015). Third, banks may lack the skills to assess early-stage (green) technologies (Ueda, 2004). 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 better developed credit markets. Fourth, banks may have a shorter time horizon (the loan maturity) than equity investors and hence be less interested in whether funded assets will become less valuable (or stranded) in the more distant

[5] Bénabou and Tirole (2010) put forward three views as to why firms engage in environmentally sustainable behavior: (i) because it maximizes long-term shareholder value ('doing well by doing good'); (ii) because stakeholders—including financiers—delegate philanthropic activities to firms ('delegated philanthropy') which may or may not enhance firm value; and (iii) because managers (over)invest in sustainability projects for self-serving reasons to the detriment of firm value ('insider initiated philanthropy').

future. Ongena, Delis and de Greiff (2018) show that banks only recently (after 2015) started to price the climate risk of lending to firms with large fossil fuel reserves.

Other contributions are more optimistic about the role of banks in limiting pollution. Levine, Lin, Wang and Xi (2018) show how positive credit supply shocks in US counties, due to the increased fracking of shale oil in other counties, reduce local air pollution. At the firm level, the authors confirm that a relaxation of credit constraints is linked to a decline in emitted toxic air pollutants. In a similar vein, Goetz (2018) finds that financially constrained firms reduced toxic emissions when their capital cost decreased as a result of the US Maturity Extension Program. Dasgupta, Laplante, Wang and Wheeler (2002) show that banks may refuse to lend to a firm if they worry about environmental liability. Screening by banks can then help weed out the (visibly) most polluting enterprises. Recent anecdotal evidence (Zeller, 2010) suggests that banks may indeed have started to scrutinize the dirtiest industries more as they fear the financial and reputational repercussions of lending to them, for instance because depositors discipline banks that visibly cause environmental damage (Homanen, 2019). Such a narrow focus on reputational risk and environmental liability would of course not preclude banks with a short-term horizon from lending to less visibly polluting industries, such as those producing large amounts of greenhouse gases.

Compared to banks, stock markets may be better suited to finance (green) innovations that are characterized by both high risks and high potential returns.[6] Equity investors may also care more about future pollution so that stock prices rationally discount future cash flows of polluting industries.[7] Empirical evidence shows that stock markets indeed punish firms that perform badly in environmental terms (such as after environmental accidents) (Salinger, 1992; Krueger, 2015) and reward those that do well (Klassen and McLaughlin, 1996; Ferrell, Lang and Renneboog, 2016). More specifically related to carbon emissions, Ilhan, Sautner and Vilkov (2019) show for a sample of S&P 500 companies that higher emissions increase downside risk, as measured by tail risk in put options, and that this effect is concentrated in high-emission industries. This suggests that stock

[6] Brown, Martinsson and Petersen (2017) show that while credit markets mainly 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 a majority of the funds that firms raise in public stock issues is invested in R&D.

[7] For instance, 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 large coal mining company, announced that it would cap coal production in response to investor demands (Financial Times, 2017; The Economist, 2018; Wall Street Journal, 2019).

market participants, in particular institutional investors[8], take carbon emissions into account when assessing corporate risk. Indeed, Trinks et al. (2017) show for a cross-country firm-level data set that low-emitting firms benefit from lower costs of equity, especially in carbon-intensive industries.[9]

On the other hand, however, a stock-market listing may lead to short-termism and distorted investment decisions if firm managers believe that equity investors do not properly value long-term projects (Narayanan, 1985; Asker, Farre-Mensa and Ljungqvist, 2015).[10] Stock markets may then blunt managers' incentives to reduce the long-term environmental impact of firms. Hart and Zingales (2017) develop a model which predicts that public firms, with their diffuse ownership and resulting low level of personal responsibility felt by each voting investor, will tend to incur an "amoral drift" away from prosocial decisions, while closely held private firms make prosocial decisions more often. In line with this prediction, Shive and Forster (2019) find that private firms in the U.S. emit less greenhouse gases as compared to otherwise similar public firms. Private firms are also less likely to incur fines related to environmental regulation.

In sum, the existing work on banks versus stock markets as drivers of industrial pollution is scattered and inconclusive. Whether banks or stock markets are better suited to reducing environmental pollution remains an open question. The aim of this paper is therefore to provide robust empirical evidence, at both the country and the industry level, on the link between a country's financial structure and the amount of carbon dioxide its industries 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

[8] Gibson Brandon and Krueger (2018) find that especially institutional investors with a longer-term horizon tend to hold equity portfolios with a better environmental footprint. Such active institutional investors may submit shareholder proposals and vote against management in case they are concerned about environmental issues (Krueger, Sautner and Starks, 2018). Dyck et al. (2019) show for a cross-country data set that institutional shareholder ownership is positively and causally related to firms' environmental and social performance, although there is strong heterogeneity depending on the country of origination of the institutional investors.

[9] Cheng, Ioannou and Serafeim (2014) confirm for a cross-country sample of listed firms that increased environmental responsibility increases 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).

[10] Hong, Li and Xu (2019) show, for instance, that stock markets do not anticipate the effects of predictably worsening droughts on agricultural firms until after they have materialized.

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 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. To account for this, we include a dummy equal to 1 if the economy is experiencing negative growth.[11]

[11] Caballero and Hammour (1994) provide a vintage model in which production units that embody the latest technology are continuously being produced as innovation proceeds. At the same time, outdated units with inferior technology are continuously being destroyed. During a recession, outdated units are most likely to turn unprofitable and to be scrapped. (A related idea is the "pit-stop" view of recessions, according to which recessions stimulate productivity-improving activities because of their temporarily low opportunity costs (Gali and Hammour, 1991)). We argue that recessions may also involve an environmental cleansing effect as inferior-technology companies are typically also the least energy efficient ones. A recession will then prune these companies and hence improve the

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 in the data set, 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 in equation (3) by country to account for the possibility that they are correlated within a country over time.

Interpreting the results from Model (3) as causal rests on the assumption 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 particularly questionable. For example, if the global demand for products produced by carbon-intensive industries that rely on external finance increases, 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 in 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 type of shocks are the equity market liberalization events from Bekaert et al. (2005). This variable is a dummy equal to one in the years after domestic financial markets become open to investment by foreign equity investors. The idea behind this instrument is that opening up to foreign portfolio investment should increase both the size and the equity share of the domestic financial system. The second instrument is the extent of bank liberalization, based on Abiad et al. (2008). This measure captures the degree to which domestic banking markets are: 1) open to entry by foreign banks; 2) open to entry by new domestic banks; 3) open to branching by existing banks; and 4) open to the emergence of universal banks. The idea behind this instrument is that bank liberalization should increase the

energy efficiency of the average (surviving) firm. Any such positive effects may be partly 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.

size but reduce the equity share of the domestic financial system.

In the second part of our analysis, we proceed to 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. As in Model (3), $FD_{c,t-1}$ is the sum of total credit extended to the private sector by deposit money banks and other credit institutions, 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 extended to the private sector by deposit money banks and other credit institutions, and the total 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 2). The underlying assumption is that the global average of a sector's emissions per unit of output 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 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 ($\theta_{s,t}$). $\varphi_{c,s}$ 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).

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 will manifest itself in 'green' sectors growing relatively faster in countries dominated by either banks or stock markets. The second mechanism 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 mechanism using the following regression model:

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

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 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 from a global sample 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 denotes 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 output.

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

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

Here the dependent variable is the total number of patents, or alternatively a measure of the intensity of 'green' patent production, in industry s in country c during year t, divided by the population in country c in year t. This variable captures the propensity of industries to engage in overall as well as 'green' innovation. This propensity may or may not 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 dioxide emissions, then the industry-level data on output 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 all variables 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).[12] The original data set contains information for 137 countries over the period 1974–2013. 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 excludes 89 countries so that the final data set consists 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

[12] Eighty percent of anthropogenic CO_2 emissions are due to the combustion of fossil fuels (Pepper et al., 1992).

per unit of value added, for value added growth, and for each sector's share of total output in the country, for two separate data sets. Both cover the period 1974–2013, and 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, in order to maximize sectoral coverage. We winsorize the data on value added growth at a maximum of 100 percent growth and decline. In order to make value added by the same industry comparable across countries, we convert all nominal output into USD and then deflate it to create a time series of real industrial output.

4.3 Green patents

To evaluate Model (7), we use the Patent Statistical database (PATSTAT) of the European Patent Office (EPO) to calculate the number of green patents across countries, sectors, and years. PATSTAT is the largest international patent database. Because of an average delay in data delivery and processing in PATSTAT of 3.5 years, our patent data end in 2013. To create our patent variables, we follow the methodological guidelines of the OECD Patent Statistics Manual. First, we take the year of the application as the reference year unless a priority patent was submitted in another country. In the latter case, the reference year is the year of the original priority filing. This ensures that we closely track the actual timing of inventive performance. Second, we take the country of residence of the inventors as the reference country. If a patent has multiple inventors from different countries, we use fractional counts (i.e., every country is attributed a corresponding share of the patent). Third, every patent indicator is based on data from a single patent office and we use the United States as the primary patent office.[13]

PATSTAT classifies each patent according to the International Patent Classification (IPC). We round this very detailed classification to 4-character IPC codes and use the concordance table of Lybbert and Zolas (2014) to convert IPC 4-character sectors into ISIC 2-digit sectors.[14] We then

[13] In unreported robustness checks, we calculate patent indicators based on EPO data. The correlation coefficients between US and EPO based indicators range between 0.75 and 0.81.

[14] PATSTAT also classifies patents according to NACE 2. A drawback of this classification is that it only covers manufacturing. Given that the scope of our analysis 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 types of indicators vary between 0.93 and 0.98.

calculate the sum of all green patents in a particular country, sector, and year. The resulting variable, *Green patents*, measures all granted patents that belong to the EPO Y02/Y04S climate change mitigation technology (CCMT) tagging scheme. CCMTs include technologies to reduce the amount of greenhouse gas emitted into the atmosphere when producing or consuming energy. The Y02/Y04S scheme is the most reliable method for identifying green patents and has become the standard in studies on green innovation (see also Popp, 2019). We count all granted patents that belong to the EPO Y02/Y04S CCMT tagging scheme. This includes Y02P patents, which concern innovations to make industrial production more energy efficient, such as green technologies related to the efficient use of energy and flexible manufacturing systems. The other categories included are green inventions related to buildings and home appliances (Y02B), alternative (none fossil) energy sources (Y02E), and smart grids (Y04S). Lastly, we also count patents in Y02T (climate change mitigation technologies related to transportation) and Y02W (climate change mitigation technologies related to solid and liquid waste treatment).

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. The second country-specific data series is the value of all traded stocks in the economy, 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.

Chart 1 plots the annual sample average of FD and FS between 1974 and 2013. It shows that over the course of 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 than doubled during this period. One issue is that both data series are patchy before 1990, especially for many Central and Eastern European countries. We therefore drop these observations so that our final data set comprises 48 countries observed between 1990 and 2013.[15]

In addition to these two variables, we use data on real per capita GDP, on population, and on recessions (defined here as an instance of negative GDP growth) from the World Development Indicators. Lastly, we use the OECD Environmental Policy Stringency Index (EPS), which is 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).[16]

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.

Table 1 summarizes the data. At the country level, we use aggregate CO_2 emissions (in tons), divided by the country's population. The average country emits 6.91 metric tons of CO_2 per capita. The summary of the financial variables shows that in the average country, the sum of private credit and stock market capitalization exceeds the 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 out of total financial intermediation 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 make it clear that the data set contains a good mix of developing countries, emerging markets, and industrialized economies. The median country in the data set has a GDP per capita of $13,033 and a population of 14.9 million. On average, a country is in a

[15] See Appendix Table A2 for a list of all countries included in the analysis.
[16] See Botta and Kozluk (2014) for more details.

recession once every five years.

The industry-level data from UNIDO show that the median industry emits 0.07 metric tons of carbon dioxide per capita per year, and 0.004 metric ton per million USD of value added. Over the sample period, the median industry grows by 1 percent per year and makes up about 0.6 percent 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 0.1 such patents per 1 million people in the global sample, and 0.16 per 1 million people in the OECD sample.

Table 2 presents the concordance key to match 62 ISIC classes into the 16 IEA ones, including 9 manufacturing sectors. It also summarizes, by sector, the main industrial benchmark in the paper, 'Carbon intensity', calculated as the average emissions of carbon dioxide per unit of output by all firms in the respective sector across the world and over the whole sample period.

5 Empirical Results

This section comprises three subsections. Section 5.1 investigates the link between financial sector size and structure, on the one hand, and aggregate pollution, on the other hand. Section 5.2 then estimates the link between finance and industry-level pollution, distinguishing between carbon-intensive and 'green' industries. It also assesses how much between-industry reallocation and within-industry efficiency improvements explain the association between finance and carbon emissions. This subsection also presents several robustness tests. Lastly, Section 5.3 tests whether the cleansing role of stock markets in rich countries reflects the outsourcing of pollution to emerging markets.

5.1 Finance and pollution: Aggregate results

Table 3 reports our baseline results for the relation between finance and carbon dioxide emissions, using aggregate data. We estimate three versions of Model (3) for the full period 1990-2013. The first version is an OLS model on the full sample. The second one is also an OLS model but using a sample of OECD countries only. This allows us to reliably control for the independent effect of environmental regulation. The third one is a 2SLS model on both the full sample and the OECD sample, using equity market liberalization events and the extent of banking sector liberalization as instruments for financial sector size and structure. This addresses concerns about omitted variable bias by inducing exogenous shocks to the size and structure of financial sectors. Because data on financial systems, carbon emissions, and country controls are not available for each country-year, the number of observations is reduced to at most 1,010 (out of a possible 1,152).

Columns (1) and (2) report the first-stage regressions of FD and FS on the two instruments. In both cases, the instruments are significantly correlated with both financial sector size and structure, and the point estimates have the expected sign. By allowing inward flows of international portfolio investment, equity market liberalization events increase both the overall size of the financial sector and the share of equity financing. We also find that by making it easier for domestic and/or foreign banks to enter and to branch out, bank liberalization events increase the overall size of financial systems but reduce the share of equity financing. The value of the first-stage Wald statistics, reported as F-statistics, is strictly higher than the critical value for the IV regression to have no more than 10 percent of the bias of the OLS estimate (Stock and Yogo, 2005).

In column (3), we regress country-level per capita carbon emissions on both FD and FS, on the rest of the country controls, and on country and year dummies. The data fail to reject the null hypothesis that the overall size of financial systems is not significantly correlated with per capita carbon emissions. At the same time, the data strongly suggest that, 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 1-percent statistical level.

In column (4), we run the same regression on the sub-sample of 28 OECD countries, which allows us to include controls for the stringency of environmental regulation. The exact same pattern as before 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 comprehensive environmental regulation has a statistically significant negative impact on aggregate per capita carbon emissions, all else equal.

In both regressions, we also account for the fact that financial development is correlated with general economic development, and so the former may simply pick up the effect of a general increase in wealth on the demand for pollution. We therefore add both GDP per capita and the square thereof to the regression. We find that in the full sample, the Kuznetz-curve effect survives controlling for financial system size and structure: per capita CO_2 emissions first increase and then decrease with economic development. More specifically, this specification indicates that carbon emissions start to decline at an annual income of around $44,606 which is the 85^{th} percentile in our country-level income distribution. This is in line with earlier estimates by Holtz-Eakin and Selden (1995) who find a peak in CO_2 emissions at a per capita GDP of around $35,000.

We also include two other controls, both of which have the expected sign. First, countries with larger populations tend to generate fewer carbon emissions per capita. This suggests that there is a negative pollution premium to market size. Second, recessions are associated with lower per capita CO_2 emissions. There are two potential explanations for this effect. First, overall output goes down during a recession, reducing overall pollution too. Second, firms may also use the downturn to purge themselves from obsolete (and likely more carbon-intensive) technologies (Schumpeter, 1912; Caballero and Hammour, 1994).

We next move to our headline, 2SLS results. In columns (5) and (6), we repeat the tests from columns (3) and (4), but this time use equity liberalization events and the index of bank deregulation as instruments for the size and structure of financial systems. We find that even when inducing exogenous shocks to FD and FS, the same patterns remain visible in the data. For one, financial development on its own has no impact on carbon emissions. Importantly, for a given level of financial development, economic development, and environmental protection, a country's economy generates fewer carbon emissions per capita if it receives relatively more of its funding from stock markets. The absolute value of the point estimate increases in the 2SLS model, which suggests that unobservable factors that correlate positively with the equity share of overall finance also correlate positively with per capita carbon emissions.

Numerically, the point estimate from the regression on the full sample (column (5)) suggests that increasing the share of equity financing by 1 percentage point, while holding the overall size of the financial system constant, reduces aggregate per capita carbon emissions by 0.05 metric tons. What are the aggregate implications of this? In other words, how much less aggregate carbon emissions would there be right now if countries in our sample relied more on equity funding? We notice that for a number of 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 percent 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 aggregate pollution by around 0.8 metric tons. Given average per capita emissions of 6.9 (Table 1), this exercise would result in a reduction in current aggregate per capita emissions of around 11.5 percent. This represents more than a quarter of the 40% reduction in emissions which countries committed to achieve by 2030 in the context of the Paris Agreement.

Our empirical tests demonstrate that financial structure contributes to the inverse-U shape of the environmental Kuznets curve. Because stock markets only catch up with credit markets at later stages of development (see Chart 1), our results imply that the pattern of per capita pollution over time is intimately related to the sequential development of different types of financial markets. We thus conclude that the evolution of financial structure helps explain the non-linear relationship between economic development and environmental quality that has been documented in the literature (e.g., Grossman and Krueger, 1995).

5.2 Finance and pollution: Industry-level results

5.2.1 Per capita carbon emissions

We next turn to evaluating evidence based on an analysis of 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. The main proxy we use is the industry-specific average CO_2 emissions per unit of output, calculated across all countries and years in the sample (see Table 2). 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 for this benchmark to change over time, in order to account for the possibility that the technological frontier is moving over time. We also take inspiration from Rajan and Zingales (1998) and calculate each industry's average CO_2 emissions per unit of output 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 and is unaffected by regulatory arrangements or by credit constraints.

In Table 4, 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 4 (and thereafter) are saturated with interactions of country-sector dummies, country-year dummies, and sector-year dummies. Their inclusion 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.

The evidence in Table 4 confirms the findings from the aggregate tests in Table 3. The estimates in column (1) strongly suggest 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 percent statistical level. We also note that in both cases, sectors that constitute a larger share of the overall economy—in terms of 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. Importantly, 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. This relationship is economically meaningful. 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 (3) (-0.1287) means that giving Germany Australia's financial structure, while keeping the size of its financial system constant, would reduce CO_2 emissions by 0.2 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 dioxide emissions decline—more so in technologically carbon-intensive sectors—as the equity dependence of the economy grows. This naturally 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 relatively greener sectors. The second channel is within-industry technological innovation whereby—holding the industrial structure constant—industries over time develop and implement greener technologies when their access to equity finance improves. In what follows, we test whether any of the two, or both, channels are indeed operational.

Cross-industry reallocation. In Table 5, we test the first channel by estimating Model (5). The dependent variable is the growth in value added in a particular industry in a particular country during a particular year. As before, all regressions are saturated with interactions of country-sector dummies, country-year dummies, and sector-year dummies. A negative coefficient on the interaction term of interest would imply that financial development results in a reallocation of investment away from carbon-intensive sectors. This test is conceptually similar to Wurgler (2000) who finds that in countries with deeper financial markets, 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 percent statistical level. Once we control for the size and structure of financial systems jointly (column (3)), we continue to document the same patterns. Financial system size does not correlate with relative industrial growth, but controlling for size, relative growth is faster in green sectors in countries with deeper stock markets. The latter effect remains significant at the 10 percent statistical level. Note also that in all specifications, we find that 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 pollution per capita that we documented in Table 4.

Within-industry efficiency improvement. In Table 6, we test the second channel by estimating Model (6). The dependent variable is CO_2 emissions per unit of value added and, once again, all regressions are saturated with interactions of 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.

In column (1), we find no evidence that within-sector carbon efficiency is affected by changes in the overall size of the financial system as a share of GDP. This confirms our previous evidence where we found no statistical association between carbon emissions per capita and financial sector size, in carbon-intensive versus green sectors.

We next look at the independent role of financial structure for carbon emissions per unit of output. Column (2) suggests 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-percent statistical level. The magnitude of the point estimates implies that 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. More specifically, and going back to our earlier thought experiment, the interaction coefficient of pollution intensity and FS (-4.33) indicates that giving Germany (a country at the 25^{th} percentile of FS) the financial structure of Australia (at the 75^{th} percentile of FS), while keeping the size of its financial system constant, would reduce CO_2 emissions per unit of value added by 1.54 metric tons per USD 1 million of value added in the most, relative to the least, polluting industry. This pattern continues to obtain when we control for the size and structure of financial systems simultaneously (column (3)).

Table 6 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 4.

5.2.3 2SLS evidence

We now re-run the main specifications from Tables 4, 5 and 6 while accounting for the potential endogeneity in financial sector size and structure. In Table 7, we replicate the empirical specification that tests for the simultaneous impact of FD and FS on carbon emissions per capita (column (1)), sector growth (column (2)), and carbon emissions per unit of output (column (3)). These specifications also control for the time-varying size of each sector as a share of the overall economy, as well as for interactions of country-sector dummies, country-year dummies, and sector-year dummies. Importantly, in all three cases we use equity market liberalization events from Bekaert et al. (2005) and the index of banking liberalization from Abiad et al. (2008) to induce exogenous shocks to the two main characteristics of the financial system.

The evidence in Table 7 strongly suggests that our findings in Tables 4–6 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 induces a simultaneous decline in carbon emissions and an increase in the equity reliance of the economy. In particular, we continue to find that in countries with expanding equity markets (relative to banking sectors) carbon-intensive sectors generate fewer carbon emissions per capita (column (1)); grow more slowly (column (2)); and emit less carbon emissions per unit of output (column (3)). Here as well, the absolute value of the point estimate increases relative to the OLS case, which suggests that unobservable factors which correlate positively with the equity share of overall finance also correlate positively with carbon activity.

5.2.4 Finance and green innovation

In the previous sections, we found that CO_2 emissions per unit of output decline with stock market development, relatively more so in carbon-intensive industries. The intuitive interpretation of this result is that it reflects the propensity of carbon-intensive industries to become more carbon-efficient in countries where more of their financing comes from equity markets. Such an effect could come from two different directions: either existing companies adopt already existing green technology, or they develop new green technologies from scratch.

We now aim to provide direct evidence for the latter conjecture. To do so, we first incorporate in our analysis data on industrial patenting. We use a comprehensive global data set on patents, PATSTAT, which reports patents according to the International Patent Classification (IPC). For the countries and industries in our sample, we calculate four separate variables. The first one, 'Total patents', measures all patents granted to an industry in a country, regardless of the patent's underlying technological contribution. The second one, 'Green patents', counts all granted patents that belong to the EPO Y02/Y04S climate change mitigation technology (CCMT) tagging scheme. The third one, 'Green patents (excluding transportation and waste)', counts all granted patents that belong to the EPO Y02/Y04S CCMT tagging scheme, with the exception of Y02T (Climate change mitigation technologies related to transportation) and Y02T (Climate change mitigation technologies related to solid and liquid waste treatment). The resulting group of patents consists of patents related to energy efficiency in production processes (Y02P), buildings and home appliances (Y02B), alternative (none fossil) energy sources (Y02E), and smart grids (Y04S). The fourth variable, 'Green patents (industrial production)', counts patents that belong only to the arguably most important category of patents when it comes to green innovation, Y02P.

With these data in hand, we estimate Model (7) and report the results in Table 8. This table follows the logic of the previous one in that we test for the role of FD and FS jointly. The results indicate that carbon-intensive sectors do not have a different propensity to patent compared with greener sectors in countries with deepening financial systems. This is the case for total patents (column (1)) and for various green patent definitions (columns (2)–(4)). Carbon-intensive sectors are also not more likely to generate more patents overall in economies where the relative importance of stock markets is increasing over time (column (1)).

Yet, at the same time, we find that the number of green patents increases more rapidly in carbon-intensive sectors in countries with deepening stock markets (column (2)). We find the same when we exclude green patents related to transportation and waste (column (3)). In both cases, the effect of stock markets on green innovation is significant at the 10-percent statistical level. Strikingly, when we focus on the 'greenest' possible patents, those that are directly intended to increase energy efficiency in the production or processing of goods, we find that an increasing share of equity funding is strongly associated with an increase in that type of patents. This effect is significant at the 5-percent statistical level (column (4)). These effects are economically meaningful, too. For example, the coefficient of 0.1801 in column (4) indicates that moving from the 25^{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 0.0180 patents per million. This equals 45 percent of the sample mean. These results complement those of Hsu, Tian and Xu (2014), who show that industries that depend on external finance and are high-tech intensive are more (less) likely to file patents in countries with better developed 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.[17]

5.2.5 Sample choice

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).[18] 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 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 four heaviest polluters in terms of carbon emissions per unit of output—the sectors "Electricity, gas, and water supply", "Land transport – transport via pipelines", "Water transport" and "Air transport"—are not part of manufacturing (see Table 2). In this way, we make sure 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 9 reports the results. We still find that deeper stock markets are associated with a reduction in per capita pollution levels (column (1)) and that this result is fully driven by an

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

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

increase in within-industry efficiency (column (3)). We no longer find any differential impact of deeper stock markets on growth in carbon-intensive versus greener sectors (column (2)). Table 11 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.

5.2.6 Underlying mechanisms

The set of results we have documented so far raises a natural question about the deeper mechanisms at play. Our findings suggest that financial structure affects aggregate carbon emissions via two separate channels: when financial systems become more skewed towards equity markets, 1) "green" sectors grow relatively faster, and 2) carbon-intensive sectors become more energy efficient, partly due to increased green innovation. 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 carbon-intensive sectors are more innovation intensive, and stock markets are better at funding innovation than banks are (Kim and Weisbach, 2008; Brown, Martinsson and Petersen, 2017). A number of theoretical contributions, discussed in Section 2, have argued for this link. For example, banks may refuse to finance new technologies because these erode the value of the collateral that underlies existing loans (Minetti, 2011). They may also lack the skills to evaluate technologies at early development stages (Ueda, 2004), or they may operate with a time horizon that is inadequate to the funding of long-term innovation. If this is the case, then controlling for the sector's propensity to innovate should, for example, explain away the statistical association between financial structure and reallocation from carbon-intensive towards "green" sectors.

Another possibility is that carbon-intensive projects involve relatively more tangible assets. Banks may then refuse to finance green projects because they find the underlying intangible assets difficult to redeploy elsewhere and therefore 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 such intangible assets. If this mechanism is driving our results, then the sector's asset tangibility is another factor that can explain away the statistical association between financial structure and reallocation towards "green" sector.

Third, it is possible that stock markets dominate banks in ways that are related more directly to climate risk. For example, 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 also 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 would have an incentive to stay away from carbon-intensive sectors, and to push for a "greening" of the sectors' technologies to reduce future litigation risk, if they become involved in these. If this is the case, then controlling for the likelihood of future litigation should, for example, moot the statistical association between financial structure and 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 is constructed by taking 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 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. These data include information on violations, enforcement actions and penalties on EPA-regulated facilities. Data on value added come from WIOD.

Appendix Table A9 reports industry-level correlations between carbon intensity, R&D intensity, asset tangibility, and litigation risk. The statistics presented in this table suggest that all of the mechanisms discussed above could be at play. For example, carbon-intensive sectors are less R&D-intensive (correlation of -0.37) and more asset-tangible (correlation of 0.40). This suggests that the decline in carbon-intensive sectors as stock markets deepen documented in Table 5 could be due to equity investors having a comprabale advantage in innovative sectors rich in intangible assets. Carbon-intensive sectors are also more litigation-prone (correlation of 0.75), suggesting that the efficiency gains in carbon-intensive sectors as stock markets deepen documented in Table 6 could be due to equity investors trying to minimize litigation risk.

We test the two sets of mechanisms separately in Table 10. In Panel A, we test for the possibility that the relative increase in "green" sectors in countries with deepening stock markets that we documented in Table 5 is explained by such sectors being also more R&D-intensive, less asset-tangible, and less litigation-prone. To that end, we augment our Model (5) with an interaction of FD and FS with the three benchmarks just discussed, introducing them one by one. We also do so both for the full sample and for the OECD sample, maximizing alternatively the country dimensions and the sector dimension of our dataset.

We find that 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 growth faster in economies that rely relatively more on bank financing (column (3)). These results are entirely in line with the intuition discussed. Importantly, in both cases the impact of FS on growth in "green" relative to carbon-intensive sectors goes away. This suggests that indeed, the reallocation of investment towards "green" sectors in countries with deepening stock markets is entirely explained by 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 for the possibility that carbon-intensive sectors being also less R&D-intensive, more asset-tangible, and more litigation-prone explains the increase in carbon efficiency in carbon-intensive sectors in countries with deepening stock markets that we documented in Table 6. We find that carbon emissions per unit of value added decline relatively more in R&D-intensive sectors as stock markets develop (column (1)). At the same time, this effect does not explain away the decline in such emissions in carbon-intensive sectors. The same is true once we control for the possibility that equity-markets induce innovation in asset-intangible sectors (columns (3) and (4)).

Importantly, we do find that stock market deepening reduces carbon emissions per unit of output in litigation-prone sectors in the OECD sample (column (6)), and that this reduces the statistical association between carbon efficiency gains, carbon intensity, and FS. Our evidence thus suggests that the technological "greening" of carbon-intensive sector as stock markets develop is to some degree explained by equity investors being concerned about potential litigation risk. These results go into the same direction as a number of recent findings in the literature. For example, Fernando, Sharfman and Uysal (2017) find that institutional investors tend to avoid stocks with high environmental risk exposure, and Akey and Appel (2018) find that increased liability protection leads to a significant increase in toxic emissions, as a result of lower investment in abatement technologies. At the same time, even in this regression FS continues to exert a negative impact on carbon emissions per unit of output in carbon-intensive sectors. We conclude that litigation risk does not fully explain the results documented in Table 6. Our results thus leave a role for alternative possibilities that are difficult to test, such as individual investors having different social objectives than banks, for example.

5.2.7 The role of outsourcing

A final issue that we address is the hypothesis that the decline in domestic industrial pollution as a result of stock market development might be driven—and potentially fully compensated—by the outsourcing of carbon-intensive activities to emerging economies (Eskeland and Harrison, 2003). Because funding through stock markets is ultimately provided by investors with their own social objectives (Bolton, Li, Ravina and Rosenthal, 2019), stock markets may be more sensitive to firms that perform badly in environmental terms (Salinger, 1992; Klassen and McLaughlin, 1996). One unintended consequence of this social objective may be that firms close domestic operations, but open foreign ones, under the assumption that poor environmental performance away from home will be more acceptable (or less observable) to investors. If so, then the decline in pollution domestically could be neutered by a proportionate increase in pollution in emerging markets, making for a null effect from a global point of view. Previous evidence suggests that this may particularly be the case in "footloose" sectors, i.e., sectors that are associated with a relatively low cost of establishing operations abroad (Ederington, Levinson, and Minier, 2005).

To test this hypothesis, we proceed in the following way. First, we download data from the World Input Output Tables on bilateral imports and exports over the sample period. We then use the data on carbon emissions from the IEA to calculate the amount of carbon emissions associated with the import of goods, for each country-sector-year, in the following way. First, we determine what share of output in a country-sector-year is exported and what share is sold domestically, and we split the CO_2 associated with all exports proportionately. Then, we determine what share of total exports of goods in a particular sector by country i was imported by country j, and we assign to country j a proportionate share of the overall CO_2 associated with all exports by this sector. Then we sum over all countries i exporting to country j to get the full amount of CO_2 associated with the import by country j of goods produced abroad. We also determine the ultimate consumer of these imported goods, and assign to each a proportionate share of the CO_2 associated with the production of goods produced by a particular sector imported by country j. There are five categories of final consumers: housholds; the same sector; other sectors; gross fixed capital formation; and government. In the case of the same sector and of other sectors, these are typically purchases of intermediary goods—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). Finally, for each of these categories, we calculate per-capita carbon emissions, to make the analysis comparable to the one presented in Table 4.

Second, the literature has suggested that some sectors are more "footloose" than others, i.e., the physical and transportation costs of outsourcing production abroad are lower. This would suggest that carbon emissions associated with the production of imported goods will be higher in more "footloose" sectors. We acquire data from Ederington, Levinson, and Minier (2005) on the costs associated with outsourcing production abroad, and aggregate it to match the sectoral classification used in our paper. The combination of these new data allows us to test for whether in countries with higher share of equity financing, carbon emissions from imports are higher in the case of carbon-intensive sectors, especially if they are easier to outsource.

Table 11 reports the estimates from this modified version of Model (4) where the dependent variable is per-capita carbon emissions associated with the production of imported goods, in total and for the five different categories of final consumers. In Panel A, we estimate this regression using data on all sectors. The evidence in column (1) strongly suggests that more equity-based countries import more goods from cabon-intensive sectors. This implies that part of the decline in domestic carbon emissions due to increased equity financing is neutered by an increase in carbon emission abroad during the production of imported goods in the same sector. However, the magnitude of the point estimate is one-half of the one in Table 4, column (3), and overall imports are around one-fifth of domestic production. Therefore, the overall increase in carbon emissions associated with the production of imported goods is only around one-tenth of the reduction in domestic carbon emissions due to the relative increase in equity markets.

The analysis across final consumers further reveals an interesting pattern. Goods purchased by the household sector account for around 5% of the overall increase in carbon emissions from the production of imported goods (column (2)). Intermediary goods purchased by the same sector (column (3)) and by other sectors (column (4)) account for the remaining 95%, in a roughly equal proportion. Changes in gross fixed capital formation and in government purchases do not affect significantly carbon emissions involved in the production of foreign goods. Our estimates thus imply that the reduction in carbon emissions in carbon-intensive sectors as a result of domestic stock market development is accompanied by an increased reliance of these sectors on the production of intermediary goods abroad. At the same time, the increase in carbon emissions due to the increase in the production of intermediary goods abroad is dominated by a greening of the domestic economy by a factor of ten. In all, our findings are 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.

In Panels A and B, we split the dataset, respectively, in sectors that are relatively difficult versus sectors that are relatively easy to outsource. First, we find that the overall effect on carbon emissions associated with the production of imported goods is much stronger for footloose sectors (Panel C, column (1)) than for sectors that are relatively immobile (Panel B, column (1)). Second, the contribution of households to the increase in carbon emissions abroad documented in Panel A in the full sample is much stronger in the case of relatively immobile industries (Panel B, column (2)), while the contribution of domestic industrial sectors is much stronger in the case of relatively footloose industries (Panel C, columns (3) and (4)). Our results are consistent with the idea that the more footloose a sector is, the more likely it is to outsource the production of intermediary goods abroad. In the case of sectors that are more difficult to outsource, once they do, they are much more likely to move the production of final goods abroad.

5.3 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 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. Appendix Table A3 reports the estimates from these alternative tests. We again follow the structure of Table 7 and test for the simultaneous impact of FD and FS on carbon emissions per capita (column (1)), sector growth (column (2)), and carbon emissions per unit of output (column (3)). The specifications also control for the time-varying size of each sector as a share of the economy and for interactions of country-sector dummies, country-period dummies, and sector-period dummies. We find strong support for the three 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 output (column (3)). These effects are statistically significant at least at the 10-percent level, and at least at the 5 percent level in two of the three tests.

In Appendix Table A4, 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 credit market size has a significant positive, and an increase in stock market size a significant 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 output in carbon-intensive sectors (column (3)), confirming the main results of the paper.

Next, our baseline results in Tables 4–6 are confirmed when we control for how dependent on external finance a sector is (Appendix Table A5) and when we employ alternative benchmarks for carbon intensity, calculated using US data or contemporaneous sector-specific global averages (Appendix Table A6). Furthermore, we document that the main results in the paper become stronger when we include the depth of corporate bond markets (Appendix Table A7) or the size of private equity investment (Appendix Table A8) in the calculation of FD and FS. The latter likely reflects that private equity investments, such as venture capital and angel investments, are the gold standard in generating early-stage innovation (see Kortum and Lerner, 2000).

Lastly, the main results also survive when we control for country-industry-specific fuel subsidies (Appendix Table A9). 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. Relatedly, Newell, Jaffe and Stavins (1999) find that oil price increases stimulate innovation to make air conditioners more energy efficient, while Aghion, Dechezleprêtre, Hemous, Martin, and Van Reenen (2016) show how higher fuel prices redirect the car industry towards green innovation (electric and hybrid technologies) and away from brown technology (internal combustion engines).

6 Conclusion

The 2018 Sveriges Riksbank Nobel Prize in Economic Sciences was recently awarded to William Nordhaus for his work on 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-related policies. The rapid growth of green finance initiatives is a case in point and contrasts sharply with the paucity of the existing evidence on the link between conventional finance and carbon emissions.

To help quantify this role, we study the relationship between financial development and structure, on the one hand, and carbon emissions, on the other hand, in a large panel of countries and sectors over the period 1990–2013. We find that for a given level of economic development and environmental protection, financial sector size has no impact on carbon emissions, but that a financial structure tilted towards equity financing reduces per capita carbon emissions significantly. When further analyzing the role of financial development for sectors that generate more carbon emissions per unit of output for 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 empirical setting addresses this issue head on by juxtaposing the influence of bank and market intermediation. As stock markets tend to develop at later stages of development than credit markets, our findings show that financial development directly contributes to the concave shape of industrial pollution over time.

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 tend to reallocate investment towards "greener" sectors. The later result is largely explained by "green" sectors being more innovative, while the former result is to some degree explained by the fact that carbon-intensive sectors are also more litigation-prone, giving equity investors an incentive to invest in greener technologies. Crucially, 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.

In sum, our findings indicate that stock-market based financial systems are tightly associated with better environmental quality. This suggests 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 may 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.

In parallel, countries can take measures to counterbalance the tendency of credit markets to (continue to) finance relatively carbon-intensive industries. Examples include the green credit guidelines that China and Brazil introduced in 2012 and 2014, respectively, 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.[19] Strict adherence to these principles can also make governmental climate change policies more effective by accelerating capital reallocation and investment towards lower-carbon technologies.

[19] 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.

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Table 1. Summary statistics

Variable	Mean	Median	St. dev.	Min	Max
Country-level					
CO_2 per capita	6.909	6.169	4.794	0.105	29.018
Financial development (FD)	1.222	1.089	0.815	0.028	4.159
Financial structure (FS)	0.389	0.392	0.163	0.001	0.823
GDP per capita	23,040	13,033	21,919	553	110,001
Population	0.082	0.015	0.228	0.001	1.357
Recession	0.216	0	0.412	0	1
Environmental protection index	1.631	1.500	0.930	0.210	4.130
Equity liberalization	0.915	1	0.278	0	1
Pro-competitive bank regulation	2.595	3	0.746	0	3
Sector-level (UNIDO)					
CO_2 emissions per capita	0.448	0.073	1.176	0.000	15.479
Growth in value added	-0.076	0.010	0.186	-1.000	1.000
CO_2 emissions per value added	0.002	0.004	0.004	0.000	0.073
Total patents per capita	2.320	0.000	13.900	0.000	275.901
Green patents per capita	0.126	0.000	0.750	0.000	21.131
Green patents per capita (excl. transport and waste)	0.096	0.000	0.632	0.000	20.850
Green patents per capita (energy intensive sectors)	0.039	0.000	0.212	0.000	6.253
Sector share	0.009	0.006	0.010	0.001	0.132
Sector-level (OECD)					
CO_2 emissions per capita	0.579	0.112	1.378	0.000	15.479
Growth in value added	0.003	0.006	0.119	-1.000	1.000
CO_2 emissions per value added	0.002	0.002	0.005	0.000	0.217
Total patents per capita	3.991	0.000	18.201	0.000	275.901
Green patents per capita	0.216	0.000	0.978	0.000	21.131
Green patents per capita (excl. transport and waste)	0.165	0.000	0.825	0.000	20.850
Green patents per capita (energy intensive sectors)	0.066	0.000	0.275	0.000	6.253
Sector share	0.021	0.014	0.023	0.001	0.283

Notes: This table summarizes the data used in the paper. 'CO_2 emissions per capita' denotes aggregate or sector-specific emissions of carbon dioxide, in tons, divided by the country's population. 'Financial development' denotes the sum of credit to the private sector and the value of all listed stocks, divided by the country's GDP, 1-perod lagged. 'Financial structure' denotes the value of all listed stocks, divided by the sum of credit to the private sector and the value of all listed stocks, 1-perod lagged. 'GDP per capita' denotes the country's per-capita GDP. 'Population' denotes the country's population, in billions of inhabitants. 'Recession' is a dummy variable equal to one if the country is experiencing negative GDP growth. 'Environmental protection index' is an index of the stringency of environmental protection, available for OECD countries only. 'Equity liberalization' is a dummy equal to one if the country's stock market is open to foreign portfolio investment. 'Pro-competitive bank regulation' is an index of how pro-bank entry regulation is. 'CO_2 emissions per value added' denotes aggregate or sector-specific emissions of carbon dioxide, in tons, divided by the sector's value added. 'Growth in value added' denotes sector-specific growth in value added. 'Total patents per capita' denotes the number of total patents in a country-sector-year, per 1 mln. population. 'Green patents per capita' denotes the number of green patents in a country-sector-year, per 1 mln. population. 'Green patents (excl. transport and waste)' denotes 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. ‘Green patents (energy intensive sectors)’ denotes the number of patents in energy-intensive sectors in a country-sector-year, per 1 mln. population. ‘Sector share’ denotes the share in value added of the sector out of the whole economy.

Table 2. Sectoral benchmarks

ISIC code	Sector name	Carbon intensity	R&D intensity	Asset tangibility	Litigation risk
01—05	Agriculture, hunting, forestry, and fishing	0.256	0.002	0.350	0.004
10—14	Mining and quarrying	0.125	0.000	0.350	0.044
15—16	Food products, beverages, and tobacco	0.186	0.009	0.329	0.032
17—19	Textiles, textile products, leather, and footwear	0.120	0.013	0.203	0.075
20	Wood and products of wood and cork	0.108	0.075	0.380	0.121
21—22	Pulp, paper, paper products, printing, and publishing	0.192	0.009	0.429	0.034
23—25	Chemical, rubber, plastics, and fuel products	0.498	0.010	0.304	0.062
26	Other non-metallic mineral products	1.101	0.013	0.275	0.192
27	Basic metals	1.730	0.012	0.421	0.147
28—33	Fabricated metal products, machinery, and equipment	0.037	0.103	0.207	0.015
34—35	Transport equipment	0.064	0.020	0.255	0.030
40—41	Electricity, gas, and water supply	8.230	0.000	0.350	0.000
45	Construction	0.035	0.000	0.124	0.001
60	Land transport – transport via pipelines	3.168	0.000	0.667	0.016
61	Water transport	7.879	0.000	0.758	0.002
62	Air transport	3.311	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 CO2 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 average legal penalty per value added in the respective industry, from XXX.

Table 3. Financial development and aggregate pollution

	First stage		OLS		2SLS	
	FD	FS				
	(1)	(2)	(3)	(4)	(5)	(6)
Equity market liberalization	0.0029**	0.0020***				
	(0.0013)	(0.0005)				
Pro-competitive bank regulation	0.0638**	-0.0187*				
	(0.0290)	(0.0121)				
FD			-0.0001	-0.0001	0.0018	-0.0018
			(0.0001)	(0.0001)	(0.0011)	(0.0012)
FS			-0.0010***	-0.0006**	-0.0049***	-0.0040***
			(0.0003)	(0.0003)	(0.0023)	(0.0013)
Log GDP per capita			0.0088***	0.0059***	0.0063	-0.0084
			(0.0029)	(0.0023)	(0.0080)	(0.0058)
Log GDP per capita squared			-0.0003*	-0.0001	-0.0003	0.0007*
			(0.0002)	(0.0001)	(0.0005)	(0.0004)
Population			-0.0066***	-0.0055***	-0.0056	0.0009
			(0.0018)	(0.0019)	(0.0055)	(0.0046)
Recession			-0.0002***	-0.0002*	-0.0003**	-0.0004**
			(0.0001)	(0.0001)	(0.0001)	(0.0002)
Environmental protection index				-0.0002***		-0.0004*
				(0.0001)		(0.0002)
Country dummies	Yes	Yes	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes
F-statistics	8.16	11.04				
No. Observations	492	616	1,010	616	492	386
R-squared	0.92	0.70	0.97	0.98	0.98	0.98

Notes: This table reports estimates from OLS regressions. The dependent variable is 'CO_2 emissions per capita' which denotes aggregate emissions of carbon dioxide, in kilograms. 'FD' denotes the sum of credit to the private sector and the value of all listed stocks, divided by the country's GDP, 1-perod lagged. 'FS' denotes the value of all listed stocks, divided by the sum of credit to the private sector and the value of all listed stocks, 1-perod lagged. 'GDP per capita' denotes the country's per-capita GDP. 'Population' denotes the country's population, in billions of inhabitants. 'Recession' is a dummy variable equal to one if the country is experiencing negative GDP growth. 'Environmental protection index' is an index of the stringency of environmental protection, available for OECD countries only. In columns (5) and (6), '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 1990–2013. 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 4. Financial development and sector-level pollution per capita

	CO_2 emissions per capita		
	(1)	(2)	(3)
FD × Carbon intensity	0.0274		0.0283
	(0.0305)		(0.0296)
FS × Carbon intensity		-0.1273**	-0.1287**
		(0.0663)	(0.0666)
Sector share	0.0059*	0.0058*	0.0057*
	(0.0037)	(0.0037)	(0.0036)
Country × Sector dummies	Yes	Yes	Yes
Country × Year dummies	Yes	Yes	Yes
Sector × Year dummies	Yes	Yes	Yes
No. Observations	6,167	6,167	6,167
R-squared	0.77	0.77	0.77

Notes: The table reports estimates from OLS regressions. The dependent variable is 'CO_2 emissions per capita' which denotes sector-specific emissions of carbon dioxide, in kilograms, per capita. 'FD' denotes the sum of credit to the private sector and the value of all listed stocks, divided by the country's GDP, 1-perod lagged. 'FS' denotes the value of all listed stocks, divided by the sum of credit to the private sector and the value of all listed stocks, 1-perod lagged. 'Carbon intensity' denotes the average value, over the entire sample period, of each sector's CO_2 emissions per value added, for all countries in the sample. '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 1990–2013. 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. Cross-sector reallocation

	Growth in value added		
	(1)	(2)	(3)
FD × Carbon intensity	-0.1593		-0.1567
	(0.1459)		(0.1447)
FS × Carbon intensity		-0.6463*	-0.6420*
		(0.4025)	(0.3935)
Sector share	-0.1449***	-0.1462***	-0.1461***
	(0.0232)	(0.0231)	(0.0230)
Country × Sector dummies	Yes	Yes	Yes
Country × Year dummies	Yes	Yes	Yes
Sector × Year dummies	Yes	Yes	Yes
No. Observations	6,079	6,079	6,079
R-squared	0.56	0.56	0.56

Notes: The table reports estimates from OLS regressions. The dependent variable is 'Growth in value added' which denotes sector-specific growth in value added. 'FD' denotes the sum of credit to the private sector and the value of all listed stocks, divided by the country's GDP, 1-perod lagged. 'FS' denotes the value of all listed stocks, divided by the sum of credit to the private sector and the value of all listed stocks, 1-perod lagged. 'Carbon intensity' denotes the average value, over the entire sample period, of each sector's CO_2 emissions per value added, for all countries in the sample. '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 1990–2013. 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. Sector-level pollution per unit of output

	CO_2 emissions per value added		
	(1)	(2)	(3)
FD × Carbon intensity	-0.1797		-0.1709
	(0.4234)		(0.3787)
FS × Carbon intensity		-4.3300***	-4.3275***
		(1.0531)	(1.0493)
Sector share	0.0048	-0.0034	-0.0033
	(0.0142)	(0.0139)	(0.0141)
Country × Sector dummies	Yes	Yes	Yes
Country × Year dummies	Yes	Yes	Yes
Sector × Year dummies	Yes	Yes	Yes
No. Observations	5,806	5,806	5,806
R-squared	0.83	0.83	0.83

Notes: The table reports estimates from OLS regressions. The dependent variable is 'CO_2 emissions per value added' which denotes sector-specific emissions of carbon dioxide, in kilograms, per unit of value added. 'FD' denotes the sum of credit to the private sector and the value of all listed stocks, divided by the country's GDP, 1-perod lagged. 'FS' denotes the value of all listed stocks, divided by the sum of credit to the private sector and the value of all listed stocks, 1-perod lagged. 'Carbon intensity' denotes the average value, over the entire sample period, of each sector's CO_2 emissions per value added, for all countries in the sample. '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 1990–2013. 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 pollution: 2SLS

	CO2 emissions per capita	Growth in value added	CO2 emissions per value added
	(1)	(2)	(3)
FD × Carbon intensity	0.1027	0.2549	2.0860
	(0.0990)	(2.4820)	(3.2466)
FS × Carbon intensity	-0.1607***	-2.7515*	-7.6217**
	(0.0534)	(1.7592)	(3.2721)
Sector share	0.0004*	-0.2109***	-0.0168*
	(0.0003)	(0.0446)	(0.0098)
Country × Sector dummies	Yes	Yes	Yes
Country × Year dummies	Yes	Yes	Yes
Sector × Year dummies	Yes	Yes	Yes
No. Observations	3,469	3,179	2,985
R-squared	0.97	0.51	0.93

Notes: The table reports estimates from 2SLS regressions. The dependent variable is the ratio of the sector's total emissions of carbon dioxide to its value added (column (1)); the sector's annual growth in value added (column (2)); and the sector's emissions of carbon dioxide, in kilograms, per unit of value added (column (3)). 'FD' denotes the sum of credit to the private sector and the value of all listed stocks, divided by the country's GDP, 1-perod lagged. 'FS' denotes the value of all listed stocks, divided by the sum of credit to the private sector and the value of all listed stocks, 1-perod lagged. In all tests, 'FD' and 'FS' are instrumented using the equity market liberalization events from Bekaert et al. (2005) and an index of pro-competitive bank regulation from Abiad et al. (2008). 'Carbon intensity' denotes the average value, over the entire sample period, of each sector's CO_2 emissions per value added, for all countries in the sample. 'Sector share' denotes the share in value added of the sector out of the whole economy. Sector-specific data come from IEA and UNIDO. The sample period is 1990–2013. 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. Financial development and green innovation

	Total patents per capita	Green patents per capita	Green patents per capita (excl. transport and waste)	Green patents per capita (energy intensive sectors)
	(1)	(2)	(3)	(4)
FD × Carbon intensity	-0.0005	-0.1698	-0.1842	-0.0144
	(0.0011)	(0.2040)	(0.2003)	(0.0454)
FS × Carbon intensity	0.0006	0.5270*	0.5297*	0.1801**
	(0.0030)	(0.3571)	(0.3476)	(0.0897)
Sector share	0.0001	-0.0048	-0.0021	-0.0021
	(0.0002)	(0.0081)	(0.0065)	(0.0019)
Country × Sector dummies	Yes	Yes	Yes	Yes
Country × Year dummies	Yes	Yes	Yes	Yes
Sector × Year dummies	Yes	Yes	Yes	Yes
No. Observations	6,471	6,471	6,471	6,471
R-squared	0.96	0.82	0.77	0.76

Notes: The table reports estimates from OLS regressions. The dependent variable is the number of total patents in a country-sector-year, per 1 mln. population (column (1)); the number of green patents in a country-sector-year, per 1 mln. population (column (2)); 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 (3)); and the number of patents in energy-intensive sectors in a country-sector-year, per 1 mln. population (column (4)). 'FD' denotes the sum of credit to the private sector and the value of all listed stocks, divided by the country's GDP, 1-perod lagged. 'FS' denotes the value of all listed stocks, divided by the sum of credit to the private sector and the value of all listed stocks, 1-perod lagged. 'Carbon intensity' denotes the average value, over the entire sample period, of each sector's CO_2 emissions per value added, for all countries in the sample. 'Sector share' denotes the share in value added of the sector out of the whole economy. Sector-specific data come from IEA and UNIDO. The sample period is 1990–2013. 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 and sector-level pollution: OECD

	CO_2 emissions per capita	Growth in value added	CO_2 emissions per value added
	(1)	(2)	(3)
Financial development × Carbon intensity	-0.0040	-0.0472*	-0.0807
	(0.0139)	(0.0241)	(0.0995)
Financial structure × Carbon intensity	-0.0446*	0.0584	-0.5955**
	(0.0290)	(0.0806)	(0.2984)
Sector share	0.0039	-0.0301***	-0.0141**
	(0.0030)	(0.0049)	(0.0065)
Country × Sector dummies	Yes	Yes	Yes
Country × Year dummies	Yes	Yes	Yes
Sector × Year dummies	Yes	Yes	Yes
No. Observations	6,807	6,810	6,596
R-squared	0.95	0.42	0.76

Notes: The table reports estimates from OLS regressions. The dependent variable is the sector's emissions of carbon dioxide, in kilograms, per capita (column (1)); the sector's annual growth in value added (column (2)); and the sector's emissions of carbon dioxide, in kilograms, per unit of value added (column (3)). 'FD' denotes the sum of credit to the private sector and the value of all listed stocks, divided by the country's GDP, 1-perod lagged. 'FS' denotes the value of all listed stocks, divided by the sum of credit to the private sector and the value of all listed stocks, 1-perod lagged. 'Carbon intensity' denotes the average value, over the entire sample period, of each sector's CO_2 emissions per value added, for all countries in the sample. 'Sector share' denotes the share in value added of the sector out of the whole economy. Sector-specific data for 33 OECD countries come from IEA and STAN. The sample period is 1990–2013. 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. Financial development and sector-level pollution: Mechanisms

Panel A. Finance and reallocation

	Growth in value added					
	Full sample	OECD sample	Full sample	OECD sample	Full sample	OECD sample
	(1)	(2)	(3)	(4)	(5)	(6)
FD × Carbon intensity	-0.1597	-0.0497*	-0.0936	-0.0467*	-0.0796	-0.0482
	(0.1518)	(0.0254)	(0.1441)	(0.0240)	(0.2221)	(0.0357)
FS × Carbon intensity	-0.3879	0.0883	-0.3916	0.0811	-1.0539*	0.1915
	(0.4065)	(0.0846)	(0.3848)	(0.0707)	(0.5837)	(0.1380)
FD × R&D intensity	0.0008	-0.0069				
	(0.0029)	(0.0167)				
FS × R&D intensity	0.1511*	0.0836*				
	(0.0911)	(0.0511)				
FD × Asset tangibility			-0.0013	-0.0001		
			(0.0009)	(0.0003)		
FS × Asset tangibility			-0.0054**	-0.0006		
			(0.0027)	(0.0011)		
FD × Litigation risk					-0.9804	-0.1276
					(1.9111)	(0.7304)
FS × Litigation risk					5.2840	-0.1238
					(5.1708)	(2.4005)
Sector share	-0.1483***	-0.0307***	-0.1474***	-0.0301***	-0.1455***	-0.0291***
	(0.0229)	(0.0050)	(0.0226)	(0.0049)	(0.0231)	(0.0048)
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	6,079	6,810	6,079	6,810	6,079	6,810
R-squared	0.56	0.42	0.56	0.42	0.56	0.43

Panel B. Finance and innovation

	CO_2 emissions per value added					
	Full sample	OECD sample	Full sample	OECD sample	Full sample	OECD sample
	(1)	(2)	(3)	(4)	(5)	(6)
FD × Carbon intensity	-0.1777	0.0800	-0.1865	-0.0519	-0.0174	-0.1512
	(0.4047)	(0.1030)	(0.3552)	(0.0887)	(0.5898)	(0.1567)
FS × Carbon intensity	-4.5634***	-0.5906**	-4.1349***	-0.5885**	-4.6887***	-0.7182*
	(1.0937)	(0.3035)	(1.0443)	(0.3024)	(1.5134)	(0.4701)
FD × R&D intensity	-0.0046	0.0018				
	(0.0233)	(0.0154)				
FS × R&D intensity	-0.1404*	0.0140				
	(0.0783)	(0.0366)				
FD × Asset tangibility			0.0004	-0.0007		
			(0.0013)	(0.0011)		
FS × Asset tangibility			-0.0043	-0.0002		
			(0.0047)	(0.0037)		
FD × Litigation risk					-1.9402	0.5075
					(3.6235)	(1.0262)
FS × Litigation risk					4.6165	-5.4095**
					(11.8254)	(2.8488)
Sector share	-0.0009	-0.0142**	-0.0041	-0.0141**	-0.0028	-0.0106*
	(0.0145)	(0.0066)	(0.0143)	(0.0066)	(0.0141)	(0.0060)
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	5,806	6,596	5,806	6,596	5,806	6,596
R-squared	0.83	0.76	0.83	0.76	0.83	0.72

Notes: The table reports estimates from OLS regressions. The dependent variable is the sector's emissions of carbon dioxide, in kilograms, per capita (columns (1)–(3)); the sector's annual growth in value added (columns (4)–(6)); and the sector's emissions of carbon dioxide, in kilograms, per unit of value added (columns (7)–(9)). 'FD' denotes the sum of credit to the private sector and the value of all listed stocks, divided by the country's GDP, 1-perod lagged. 'FS' denotes the value of all listed stocks, divided by the sum of credit to the private sector and the value of all listed stocks, 1-perod lagged. 'Carbon intensity' denotes the average value, over the entire sample period, of each sector's CO_2 emissions per value added, for all countries in the sample. 'R&D intensity' denotes the sector's average ratio of R&D investment to total assets. 'Asset tangibility' denotes the sector's average ratio of tangible assets to total assets. 'Litigation risk' denotes the industry-specific average penalty per year as a share of value added over the period 2000–2014. '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 1990–2013. 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 11. Financial development and pollution: Importing from dirty sectors

Panel A. All 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	0.0083	0.0009	0.0069	0.0003	0.0001	0.0000
	(0.0151)	(0.0008)	(0.0125)	(0.0030)	(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

Panel B. 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 C. 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	-0.0020	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 an OLS regressions. The dependent variable is the total emissions of carbon dioxide associated with the production of foreign-produced goods purchased by the total economy (column (1)), purchased by households (column (2)), purchased by the same industry (column (3)), purchased by other industries (column (4)), purchased for the purpose of gross fixed capital formation (column (5)), and purchased by the government (column (6)), in kilograms, per capita. 'FD' denotes the sum of credit to the private sector and the value of all listed stocks, divided by the country's GDP, 1-perod lagged. 'FS' denotes the value of all listed stocks, divided by the sum of credit to the private sector and the value of all listed stocks, 1-perod lagged. 'Carbon intensity' denotes the average value, over the entire sample period, of each sector's CO_2 emissions per value added, for all countries in the sample. 'Sector share' denotes the share in value added of the sector out of the whole economy. Import data come from WIOD. Sector-specific data come from IEA and UNIDO. The sample period is 1995–2009. The sample includes all sectors (Panel A); sectors with above-median transport costs, or low-footloose sectors (Panel B), and sectors with below-median transport costs, or high-footloose sectors (Panel C). 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.

Appendix Table 2. Main variables by country (1990–2013 averages)

Country	FD	FS	CO_2 per capita
Argentina	0.246	0.339	3.541
Australia	1.451	0.508	15.682
Austria	0.986	0.144	7.535
Azerbaijan	0.028	0.023	3.812
Belgium	0.859	0.420	10.769
Brazil	0.736	0.407	1.468
Bulgaria	0.486	0.149	6.142
Canada	1.940	0.490	15.848
Chile	1.596	0.560	2.681
China	1.341	0.220	3.247
Colombia	0.565	0.412	1.309
Costa Rica	0.360	0.229	1.092
Croatia	0.761	0.344	3.946
Czech Republic	0.658	0.282	11.643
Denmark	1.134	0.344	10.396
Estonia	0.826	0.301	12.256
Finland	1.331	0.417	10.693
France	1.181	0.291	6.296
Germany	1.205	0.217	11.188
Greece	0.948	0.365	6.556
Hungary	0.583	0.307	6.104
India	0.761	0.547	0.734
Ireland	1.595	0.338	8.835
Italy	0.984	0.298	6.689
Japan	2.267	0.271	8.402
Kazakhstan	0.432	0.360	11.404
Lithuania	0.448	0.381	4.159
Luxembourg	1.924	0.468	25.911
Macedonia	0.342	0.166	4.345
Mexico	0.365	0.399	3.349
Morocco	0.789	0.387	0.954
Netherlands	1.432	0.369	9.950
New Zealand	1.287	0.328	6.638
Norway	1.005	0.269	7.018
Philippines	0.808	0.573	0.740
Poland	0.495	0.337	9.292
Portugal	1.319	0.228	3.926
Russia	0.592	0.535	10.908
Slovenia	0.690	0.268	7.307
Spain	1.623	0.373	5.622
Sweden	1.524	0.338	6.072
Switzerland	2.795	0.455	5.889
Thailand	1.657	0.322	1.892
Turkey	0.431	0.482	2.582
Ukraine	0.543	0.327	7.237
United Kingdom	1.860	0.486	9.165
United States	2.155	0.370	19.189
Zambia	0.201	0.587	0.332

Appendix Table 3. Financial development and sector-level pollution: 5-year averages

	CO_2 emissions per capita	Growth in value added	CO2 emissions per value added
	(1)	(2)	(3)
FD × Carbon intensity	-0.0001	-0.0001	0.0003
	(0.0002)	(0.0002)	(0.0003)
FS × Carbon intensity	-0.0001*	-0.0010**	-0.0038***
	(0.0000)	(0.0005)	(0.0015)
Sector share	0.0025*	-0.0547***	0.0111
	(0.0014)	(0.0117)	(0.0108)
Country × Sector dummies	Yes	Yes	Yes
Country × Period dummies	Yes	Yes	Yes
Sector × Period dummies	Yes	Yes	Yes
No. Observations	1,227	1,144	1,163
R-squared	0.90	0.71	0.93

Notes: The table reports estimates from OLS regressions. The dependent variable is the sector's emissions of carbon dioxide, in kilograms, per capita (column (1)); the sector's annual growth in value added (column (2)); and the sector's emissions of carbon dioxide, in kilograms, per unit of value added (column (3)). 'FD' denotes the sum of credit to the private sector and the value of all listed stocks, divided by the country's GDP, 1-perod lagged. 'FS' denotes the value of all listed stocks, divided by the sum of credit to the private sector and the value of all listed stocks, 1-perod lagged. 'Carbon intensity' denotes the average value, over the entire sample period, of each sector's CO_2 emissions per value added, for all countries in the sample. 'Sector share' denotes the 1-period lagged share in value added of the sector out of the whole economy. All variables are averages over five non-overlapping 5-year intervals (1990–1993, 1994–1998, 1999–2003, 2004–2008, 2009–2013). 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-year level are included in parentheses, where ***, **, and * denote significance at the 1, 5, and 10 percent statistical level, respectively.

Appendix Table 4. Credit markets, stock markets, and sector-level pollution

	CO_2 emissions per capita	Growth in value added	CO2 emissions per value added
	(1)	(2)	(3)
Credit/GDP × Carbon intensity	0.1327*	0.1117	0.5559
	(0.0883)	(0.1777)	(0.5170)
Stocks/GDP × Carbon intensity	-0.0788*	-0.4432**	-0.9556***
	(0.0453)	(0.2052)	(0.3847)
Sector share	0.0054*	-0.1469***	-0.0009
	(0.0034)	(0.0231)	(0.0147)
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	0.83

Notes: The table reports estimates from OLS regressions. The dependent variable is the sector's emissions of carbon dioxide, in kilograms, per capita (column (1)); the sector's annual growth in value added (column (2)); and the sector's emissions of carbon dioxide, in kilograms, per unit of value added (column (3)). 'Credit/GDP' denotes the 1-period lagged ratio of credit to the private sector to the country's GDP. 'Stock/GDP' denotes the 1-period lagged ratio of the value of all listed stocks to the country's GDP. 'Carbon intensity' denotes the average value, over the entire sample period, of each sector's CO_2 emissions per value added, for all countries in the sample. '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 1990–2013. 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.

Appendix Table 5. Financial development and sector-level pollution: Controlling for external dependence

	CO2 emissions per capita	Growth in value added	CO2 emissions per value added
	(1)	(2)	(3)
FD × Carbon intensity	0.0401	-0.1673	-0.1260
	(0.0362)	(0.1603)	(0.4314)
FS × Carbon intensity	-0.1655**	-0.7663*	-4.6079***
	(0.0832)	(0.4256)	(1.1349)
FD × External dependence	0.0652	-0.0566	0.2576
	(0.0684)	(0.2365)	(0.5111)
FS × External dependence	-0.2030	0.6953	-1.5481
	(0.1619)	(0.6480)	(1.8513)
Sector share	0.0058*	-0.1458***	-0.0027
	(0.0036)	(0.0231)	(0.0141)
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	0.83

Notes: The table reports estimates from OLS regressions. The dependent variable is the sector's emissions of carbon dioxide, in kilograms, per capita (column (1)); the sector's annual growth in value added (column (2)); and the sector's emissions of carbon dioxide, in kilograms, per unit of value added (column (3)). 'FD' denotes the sum of credit to the private sector and the value of all listed stocks, divided by the country's GDP, 1-perod lagged. 'FS' denotes the value of all listed stocks, divided by the sum of credit to the private sector and the value of all listed stocks, 1-perod lagged. 'Carbon intensity' denotes the average value, over the entire sample period, of each sector's CO_2 emissions per value added, for all countries in the sample. 'External dependence' is the share of capital investment financed with sources other than retained earnings, for COMPUSTAT firms during 1990–2000. '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 1990–2013. 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.

Appendix Table 6. Alternative benchmarks for carbon intensity

	CO2 emissions per capita		Growth in value added		CO2 emissions per value added	
	(1)	(2)	(3)	(4)	(5)	(6)
FD × Carbon intensity (Contemporaneous)	-0.0004		0.0029		0.0243	
	(0.0013)		(0.0073)		(0.0161)	
FS × Carbon intensity (Contemporaneous)	-0.0092**		-0.0492*		-0.1749***	
	(0.0049)		(0.0264)		(0.0586)	
FD × Carbon intensity (US)		0.0347		-0.2263		-0.2706
		(0.0362)		(0.1902)		(0.4918)
FS × Carbon intensity (US)		-0.1615**		-0.8103		-5.4780***
		(0.0810)		(0.5073)		(1.3203)
Sector share	0.0061*	0.0060*	-0.1516***	-0.1518***	0.0003	-0.0039
	(0.0038)	(0.0038)	(0.0245)	(0.0242)	(0.0150)	(0.0146)
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	5,980	5,980	5,918	5,918	5,645	5,645
R-squared	0.77	0.77	0.56	0.56	0.83	0.83

Notes: The table reports estimates from OLS regressions. The dependent variable is the sector's emissions of carbon dioxide, in kilograms, per capita (columns (1)–(2)); the sector's annual growth in value added (columns (3)–(4)); and the sector's emissions of carbon dioxide, in kilograms, per unit of value added (columns (5)–(6)). 'FD' denotes the sum of credit to the private sector and the value of all listed stocks, divided by the country's GDP, 1-perod lagged. 'FS' denotes the value of all listed stocks, divided by the sum of credit to the private sector and the value of all listed stocks, 1-perod lagged. 'Carbon intensity (Contemporaneous)' denotes the average value, for each year, of each sector's CO_2 emissions per value added, for all countries in the sample. 'Carbon intensity (US)' denotes the average value, over the entire sample period, of each sector's CO2 emissions per value added in the US. 'Sector share' denotes the share in value added of the sector out of the whole economy. Sector-specific data come from IEA and UNIDO. The sample period is 1990–2013. 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.

Appendix Table 7. Financial development and sector-level pollution: Adding corporate bonds

Panel A. FS defined as ratio of equity finance to total finance

	CO_2 emissions per capita	Growth in value added	CO2 emissions per value added
	(1)	(2)	(3)
FD with bonds × Carbon intensity	0.0074	-0.1608	-0.0298
	(0.0158)	(0.1026)	(0.1186)
FS with bonds × Carbon intensity	-0.1730*	-1.1391**	-2.8286***
	(0.0968)	(0.4560)	(0.8607)
Sector share	0.0024*	-0.1148***	-0.0132
	(0.0014)	(0.0187)	(0.0159)
Country × Sector dummies	Yes	Yes	Yes
Country × Year dummies	Yes	Yes	Yes
Sector × Year dummies	Yes	Yes	Yes
No. Observations	4,781	4,635	4,491
R-squared	0.87	0.60	0.83

Panel B. FS defined as ratio of market finance to total finance

	CO_2 emissions per capita	Growth in value added	CO2 emissions per value added
	(1)	(2)	(3)
FD with bonds × Carbon intensity	0.0109	-0.1598	-0.0560
	(0.0168)	(0.1119)	(0.1176)
FS with bonds × Carbon intensity	-0.0168	-1.2564***	-4.4218***
	(0.0597)	(0.4969)	(1.5509)
Sector share	0.0026*	-0.1146***	-0.0143
	(0.0015)	(0.0189)	(0.0159)
Country × Sector dummies	Yes	Yes	Yes
Country × Year dummies	Yes	Yes	Yes
Sector × Year dummies	Yes	Yes	Yes
No. Observations	4,781	4,635	4,491
R-squared	0.87	0.60	0.83

Notes: The table reports estimates from OLS regressions. The dependent variable is the sector's emissions of carbon dioxide, in kilograms, per capita (column (1)); the sector's annual growth in value added (column (2)); and the sector's emissions of carbon dioxide, in kilograms, per unit of value added (column (3)). 'FD' denotes the 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-perod lagged. In Panel A, '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-perod lagged. In Panel B, 'FS' denotes the sum of the value of all listed stocks and the value of all issued private corporate bonds, 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-perod lagged. 'Carbon intensity' denotes the average value, over the entire sample period, of each sector's CO_2 emissions per value added, for all countries in the sample. '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 1990–2013. 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.

Appendix Table 8. Adding private equity

	CO2 emissions per capita	Growth in value added	CO2 emissions per value added
	(1)	(2)	(3)
Financial development × Carbon intensity	0.0497	0.0683	-0.4538
	(0.0427)	(0.1706)	(0.6537)
Financial structure × Carbon intensity	-0.2033**	-0.2582	-5.8792***
	(0.0918)	(0.5856)	(1.7299)
Sector share	0.0170*	-0.1265***	0.0011
	(0.0112)	(0.0231)	(0.0189)
Country × Sector dummies	Yes	Yes	Yes
Country × Year dummies	Yes	Yes	Yes
Sector × Year dummies	Yes	Yes	Yes
No. Observations	3,511	3,470	3,418
R-squared	0.76	0.57	0.78

Notes: The table reports estimates from OLS regressions. The dependent variable is the sector's emissions of carbon dioxide, in kilograms, per capita (column (1)); the sector's annual growth in value added (column (2)); and the sector's emissions of carbon dioxide, in kilograms, per unit of value added (column (3)). 'FD' denotes the sum of credit to the private sector, the value of all listed stocks, and the value of all private equity investment, divided by the country's GDP, 1-perod lagged. 'FS' denotes the value of the sum of all listed stocks and of all private equity investment, divided by the sum of credit to the private sector, the value of all listed stocks, and the value of all private equity investment, 1-perod lagged. 'Carbon intensity' denotes the average value, over the entire sample period, of each sector's CO_2 emissions per value added, for all countries in the sample. 'Sector share' denotes the share in value added of the sector out of the whole economy. Sector-specific data come from IEA and UNIDO. The sample period is 1990–2013. 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.

Appendix Table 9. Finance and sector-level pollution: Controlling for fuel subsidies

	CO_2 emissions per capita	Growth in value added	CO2 emissions per value added
	(1)	(2)	(3)
FD × Carbon intensity	0.0265	-0.1486	-0.1627
	(0.0293)	(0.1429)	(0.3835)
FS × Carbon intensity	-0.1439**	-0.5852	-3.7514***
	(0.0736)	(0.4067)	(1.0548)
FD × Fuel subsidies	0.0006**	-0.0049	-0.0006
	(0.0003)	(0.0036)	(0.0085)
FS × Fuel subsidies	0.0003	0.0032	-0.0429
	(0.0008)	(0.0074)	(0.0182)
Sector share	0.0057*	-0.1462***	-0.0007
	(0.0036)	(0.0231)	(0.0134)
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

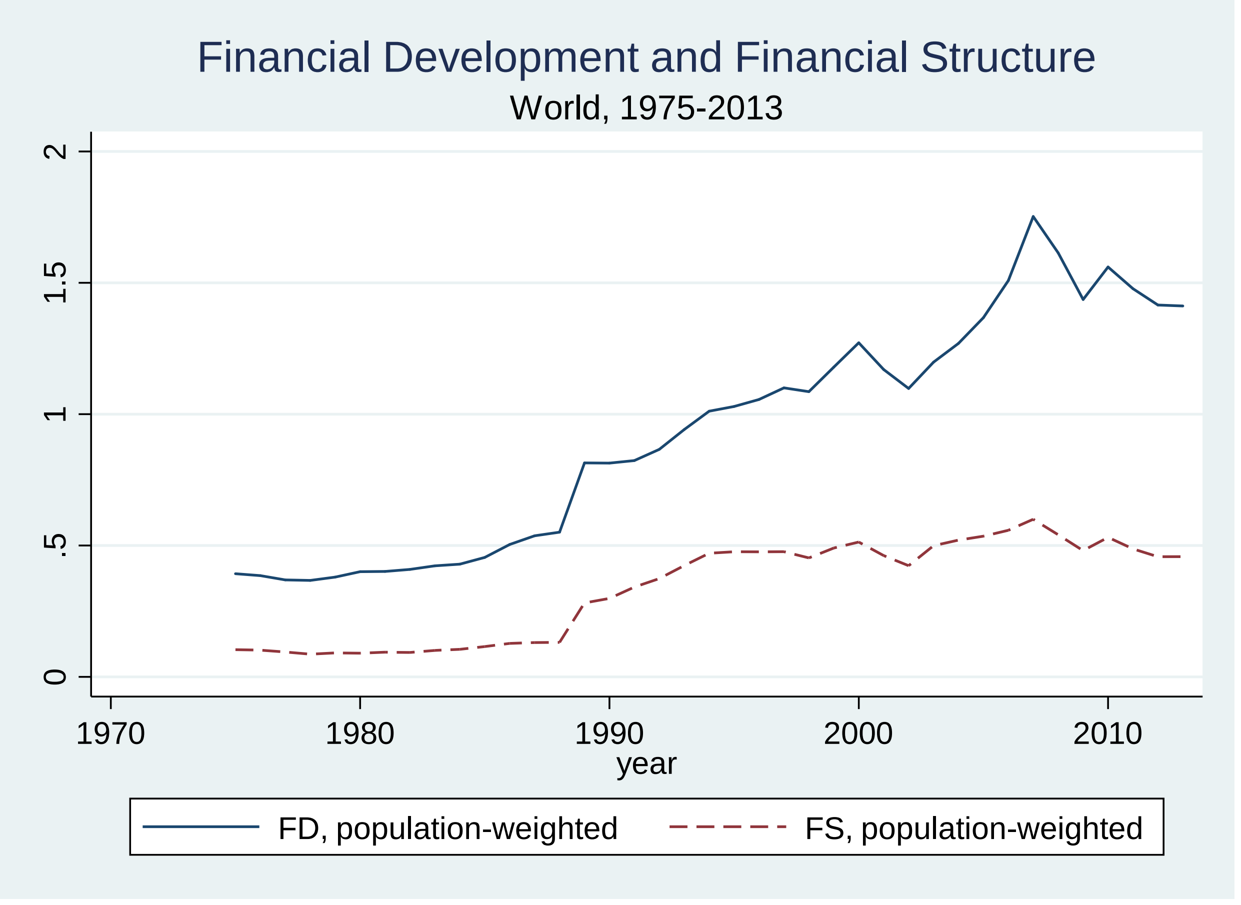
Notes: The table reports estimates from OLS regressions. The dependent variable is the sector's emissions of carbon dioxide, in kilograms, per capita (column (1)); the sector's annual growth in value added (column (2)); and the sector's emissions of carbon dioxide, in kilograms, per unit of value added (column (3)). 'FD' denotes the sum of credit to the private sector and the value of all listed stocks, divided by the country's GDP, 1-perod lagged. 'FS' denotes the value of all listed stocks, divided by the sum of credit to the private sector and the value of all listed stocks, 1-perod lagged. 'Carbon intensity' denotes the average value, over the entire sample period, of each sector's CO_2 emissions per value added, for all countries in the sample. 'Fuel subsidies' is the difference between the observed price of fuel and the benchmark price of fuel for a particular country-sector. 'Sector share' denotes the share in value added of the sector out of the whole economy. Sector-specific data come from IEA, IMF, and UNIDO. The sample period is 1990–2013. 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.

Appendix Table 10. 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

Note: The Table reports simple correlations between sector-level carbon intensity, R&D intensity, asset tangibility, and litigation risk.

Chart 1. Global financial development and structure over time



Note: The chart plots population-weighted global ‘Financial development’ and ‘Financial development’ between 1975 and 2013.

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