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International trade in brown shares and economic development

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Abstract

Using global share ownership data from 2002 to 2021, we find that investors' aggregate carbon sensitivity, i.e., their tendency to divest from more polluting firms, increases with per capita GDP, especially after the adoption of the Paris Agreement in 2015. As an implication, investors in higher-income countries are predicted to hold greener portfolios, which is borne out by the data. Especially investment managers, who invest on behalf of their clients, and investors with longer investment horizons contribute to the portfolio greening effect of economic development. We find that this effect is weaker for smaller firms and for firms that are included in the MSCI World index.

Key words: Carbon Intensity; Divestment; Foreign Investment
JEL Codes: F21, G11

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1. Introduction

Finance has a key role to play in bringing about an orderly transition to a low-carbon economy to limit climate change. In practice, the financing of firms with varying levels of carbon emissions is affected by policy as well as by decisions of institutional and individual investors. The Paris Agreement of 2015, for instance, exerts developed countries to "continue to take the lead in mobilizing climate finance from a wide variety of sources, instruments and channels". Consistent with this, individual countries are taking measures to promote investments in green firms. Ireland, for instance, passed the Fossil Fuel Divestment Act in 2018, which forces the Ireland Strategic Investment Fund, with a size of about 9 billion euros, to divest completely from oil, gas, and coal (Carrington (2018)). Institutional investors, such as pension funds, in some instances have also reduced their exposure to carbon-intensive firms ((Boermans and Galema (2019), Bolton and Kacperczyk (2021), Benz et al. (2020), Atta-Darkua et al. (2023), Heath et al. (2023)).

Any divestment from brown firms is matched by investment in such firms by another party. In particular, divestment by investors in one country can lead to investment by investors in another country, giving rise to potentially different carbon intensities of investment portfolios internationally. This paper shows the existence of such a divergence, where investors in poorer nations tend to hold more carbon-intensive overall stock as well as foreign stock portfolios. Consistent with this, our empirical analysis shows that the national ownership share of relatively carbon-intensive firms declines with investor-country economic development as proxied by GDP per capita.

We analyze share ownership data during 2002-2021 of individual firms, for which we know the level of greenhouse gas emissions and can identify the large majority of the ownership (75% or more), using ownership data available from Refinitiv Workspace. Specifically, we relate the ownership share in individual firms at the national level to an interaction of a measure of the firm's carbon intensity and investor-country log GDP per capita in a specification that includes firm-year and investor country-year fixed effects. This interaction term is estimated to be negative, suggesting that investors in a country divest more from carbon-intensive firms as per capita income rises. Comparing two firms with a difference in carbon intensity of one standard deviation, we find that an increase in log GDP per capita by one standard deviation reduces ownership in the high-carbon intensity firm by 2.9 percent more compared to ownership in the low-carbon intensity firm after the adoption of the Paris Agreement. This relative reduction in investment in the high-carbon intensity firm amounts to 15.9% of the standard deviation of the pertinent ownership share, which is an economically meaningful effect. As an implication of our estimation, richer countries will hold greener portfolios.

We obtain consistent results when we estimate a gravity model where we aggregate ownership data at the bilateral national and sectoral levels. Furthermore, our main results are robust to including interactions of the emission intensity variable with sets of control variables related to a country's financial development, its legal and government institutions, and its climate risk exposure. We also obtain similar results when we apply the Poisson Pseudo Maximum Likelihood (PPML) estimator rather than linear regressions to our estimation with firm-level ownership data as suggested by Cohn et al. (2022).

To explain why investors in richer countries display a greater tendency to green their portfolios, we can see carbon divestment as the private provision of a public good represented by potentially less detrimental climate change.[2] A greater carbon divestment by investors in richer countries is consistent with the theory of private provision of public goods, which predicts that wealthier individuals contribute more to the supply of a public good, and that in equilibrium only the richest individuals may pay for the public good at all (Bergstrom et al.

[2] Several studies have shown that nonpecuniary motives play a role in divestment decisions ((Barber et al. (2021), Hartzmark and Sussman (2019), Heeb et al. (2023)).

(1986)). A few papers have taken a global public goods perspective in understanding the national (under-)commitment to climate change mitigation. Murdoch and Sandler (1997) consider national efforts to curb chlorofluorocarbon emissions in response to the Montreal protocol, and Chen and Zeckhauser (2018) examine countries' Nationally Determined Contributions following the Paris Agreement. Both papers find a positive impact of national income on the pertinent commitment level. Our finding of a positive relationship between per capita income and portfolio greening is also consistent with observed donations to the United Nation foundation (Atkinson (2004)). Unlike earlier work, however, our paper entails a unique setting where the national outcome, in the form of carbon divestment, reflects individual private actions.

In an extension to our analysis, we consider the role of the distance between investor and firm location countries in the portfolio decarbonization process. We find that investors have a greater tendency to divest from carbon-intensive companies that are located farther away, perhaps reflecting greater perceived uncertainties associated with far-away polluting firms. However, the tendency for investors in higher-income countries to divest more from carbon-intensive stocks is attenuated by distance, conceivably reflecting a greater ability of investors from high-income countries to assess the risks associated with investments in carbon-intensive firms at a distance.

In a further test, we consider investor heterogeneity, distinguishing between investment managers who make portfolio decisions on behalf of their clients and strategic investors who maintain stakes in certain firms for strategic reason. We find evidence of a tendency of investment managers in richer countries to divest from more polluting firms, but this does not hold for strategic investors. This could reflect that investment managers can more easily exit from carbon-intensive firms that are no longer deemed part of desired portfolios, while investments by strategic investors tend to be less flexible. We further distinguish among investors based on their investment horizon as indicated by their average portfolio turnover, expecting that more frequent traders in higher-income countries are less inclined to green their portfolios. We show evidence consistent with this hypothesis.

Investors may be more inclined to divest from carbon-intensive firms particularly if these firms belong to brown industries such as Oil and Gas, and Metals and Mining. To test this, we consider firms that belong to brown industries and non-brown industries separately. We find that investors in higher-income countries have a tendency to divest mainly from more carbon-intensive firms in brown industries. This suggests that investors screen firms based on their firm-level carbon intensity as well as industry affiliation in line with survey evidence provided by Amel-Zadeh and Serafeim (2018). Furthermore, we find that investors in richer countries are more prone to reduce their investments in larger carbon-intensive firms, which could reflect the greater visibility of larger firms or the perception that larger firms have a greater impact on climate change (Azar et al. (2021)).

Many investors are index investors and hence do not screen individual stocks based on their carbon sensitivity. This suggests that investments in firms that belong to a main stock market index may be less sensitive to the joint effect of firm-level carbon intensity and investor-country economic development. To test this, we separately consider firms that are and are not included in the MSCI World index, finding that this joint effect is strengthened significantly after the adoption of the Paris Agreement only for firms that are not in the index. The absence of a tendency of investors in wealthier countries to divest from browner firms that are included in the MSCI World index following the Paris Agreement suggests that index investing can have the effect of slowing down the greening of the investment portfolios of these wealthier investors.

Several studies have examined the impact of investment decisions on the pricing of brown vs. green financial assets, and on firm behavior. Bolton, Halem, and Kacperczyk (2022), Bolton and Kacperczyk (2021), and Hsu et al. (2023) together document a brown equity premium and lower price-earnings ratios for brown firms which could reflect investor preferences for holding greener assets or a greater riskiness of brown assets, while Ilhan et al. (2021) find a larger cost of option protection against downside tail risks for firms with higher carbon intensities. Dyck et al. (2019) and Rohleder et al. (2022) find evidence of a positive effect of institutional investors' divestment activity on firms' environmental and social performance. Two recent papers have argued that the effectiveness of divestment and the alternative of voice (engagement) depends on the relative strength of socially responsible capital. Specifically, Berk and Van Binsbergen (2021) estimate the impact of divestiture on the cost of capital to be too little to materially alter real investment decisions, because the set of divesting investors and the set of target firms comprises too small a portion of the market. In addition, in a theoretical analysis, Broccardo, Hart, and Zingales (2022) find that voice achieves the socially optimal outcome only if the majority of investors is socially responsible.

It is likely that the increasing ownership of brown firms by investors in poorer countries documented in this paper also has important implications for the intended global transition to carbon neutrality. By acting as backstop owners of brown equities, investors in poorer countries could limit the impact of divestment in richer countries on brown firms' cost of capital, potentially reducing its greening impact. Furthermore, additional ownership of brown firms by investors in poorer countries could slow down the decarbonization process, if such investors are less able or willing to use voice to guide brown firms to become greener. Our documentation of relatively large brown investments by investors in poorer countries introduces an important new dimension to the international carbon leakage issue, and it contributes a macro perspective to the financial decarbonization literature.[3]

Our finding of differential divestment responses to economic development by subgroups

[3] Recent research shows that carbon leakage, i.e. an international or interregional relocation of carbon-related

of investors that differ in their investment purpose and revealed portfolio turnover supplements previous literature on the greening of portfolios by certain classes of institutional investors. Boermans and Galema (2019) find that Dutch pension funds have actively decarbonized their portfolios by reducing exposures to carbon-intensive industries, and this pattern is shared by some other large European pension funds (Egli et al. (2022)). Evidence of portfolio decarbonizing by climate-conscious institutions more generally exists both for Europe (Gibson Brandon et al. (2022)) and globally (Atta-Darkua et al. (2023), Heath et al.(2023)). Benz et al. (2020) find that the decarbonization herds are led by hedge funds and investment advisors, while responsible hedge funds experience greater investor flows (Liang et al. (2022)).

The remainder of this paper is organized as follows. Section 2 describes the data and provides some initial evidence on the relation between the carbon intensity of national equity portfolios and economic development. Section 3 outlines the empirical approach. Section 4 presents our basic results, and section 5 provides some extensions and robustness checks. Section 6 concludes.

2. Data

In this study, we combine data from several sources. We obtain ownership data for public companies globally, including information on pertinent investors as well as accounting and financial information, from Refinitiv Workspace. Our main data source for emissions is the Carbon Disclosure Project (CDP) that provides self-reported environmental disclosures of individual firms. We supplement these emissions data with reported and estimated emissions data from Refinitiv Workspace. Data on GDP per capita and national institutional variables are from the World Bank's World Development Indicators. In addition, we obtain data on distances

activity in response to national carbon mitigating requirements, has arisen in the areas of bank lending (Benincasa (2021), Benincasa et al. (2022), Laeven and Popov (2023)) and of firm production (Bartram et al. (2022), Ben-David et al. (2021)).

between countries from the Centre for Prospective Studies and International Information (CEPII), on investments of main categories of institutional investors at the national level from the OECD, and on signatory countries of the Paris Agreement from the United Nations. Next, we describe the ownership, emissions, and other variables, and take an initial look at the relation between the carbon intensity of national equity portfolios and economic development as proxied by GDP per capita. A detailed list of variables and data sources is provided in Table A2 in the Appendix.

2.1. Ownership data

Our ownership data cover the equities of public companies globally from 2002 to 2021. The ownership data, among other things, include the address country of the shareholder. Our interest is in the international ownership of ordinary shares. Almost all firms (96.9%) have issued only one class of ordinary shares, but in some specifications, we include information on multiple classes of ordinary shares if firms have issued them. We restrict ourselves to shares for which price information is available.

The availability of ownership data varies with time and geographically, reflecting variation in mandatory ownership reporting and in voluntary reporting by pertinent firms, investors, and the financial sector. We have ownership information for 17,682 and 48,340 firms in 2002 and 2021, respectively (see Table A1 in the Appendix on the availability of ownership information for each year during 2002-2021). Table 1 provides information on the coverage of our ownership data relative to stock market capitalizations for major regions of the world in 2020.[4] The overall ownership coverage is 73.88%, while at the regional level ownership coverage varies from a high of 78.49% for firms in the Americas to a low of 32.62% for African firms.

In the empirical analysis, we consider the relation between the ownership shares of firms

[4] The data on domestic market capitalization are current as of 2020. Information on the ownership coverage relative to the captured stock capitalizations for individual countries in the years 2001 and 2021 is provided in Figure A1 in the Appendix, showing that coverage has improved materially between these years.

with varying emission levels by all or subgroups of investors internationally and economic development. In our main analysis, we only include firms with a single class of ordinary shares to be able to calculate unambiguous ownership shares. In addition, we consider firms for which at least 75% of the ownership is known to ensure that the ownership information is representative of the firm's owners. Furthermore, we require that a firm has at least three consecutive years of ownership information, and we only include continuous ownership spans.[5] To exclude possible double accounting, we exclude firms that are subsidiaries of another firm in the sample.

Most comprehensively, *Ownership share* is calculated as the sum of the ownership shares of all investors with a reported address in a particular country, implying that we consider direct ownership. In practice, however, many investors channel their investments through an offshore financial center (OFC) to reduce their tax liability or to hide their identity. In these instances, the country of direct ownership differs from the country of ultimate ownership. For this reason, we exclude OFCs as investor countries in our main analysis. Based on Garcia-Bernardo et al. (2017), we identify the following countries as OFCs: the Bahamas, Barbados, Cyprus, Gibraltar, Hong Kong, Ireland, Luxembourg, Marshall Islands, Netherlands, Singapore, Switzerland and the United Kingdom.[6] As an alternative ownership variable, we consider *Holding value*, constructed as the value of the national ownership in a firm divided by investor-country GDP. Both ownership measures are winsorized at the 0.01 level.

The requirement of at least 75% ownership information and sufficiently long continuous ownership spans, and the necessity to have emissions information as discussed below limit the number of firms that we can include in our firm-level analysis. To be able to expand the number of firms in our analysis, we supplement our firm-level ownership analysis with a gravity model

[5] For a firm with multiple ownership spans of at least 3 years, we keep the longest one. When there are multiple ownership spans of equal length, we then keep the most recent one.
[6] We take list of conduit-OFCs from their Table S4 (the column of Threshold 100). Data on GDP per capita are available for all these OFCs but Gibraltar.

approach. More specifically, we consider the bilateral national ownership of firms at the sector level, with the sectoral ownership variables based on all available international ownership information of all ordinary shares. Hence, when we construct the bilateral national ownership variable at the sector level, we drop the previous requirements of at least 75% ownership information, sufficiently long continuous ownership spans, and the existence of a single class of ordinary shares but keep the non-subsidiary condition. The resulting ownership variable, denoted *Bilateral holding*, is constructed as the value of bilateral national stock holdings divided by the GDPs of investor as well as firm-location countries. In the main gravity estimation, we also exclude offshore financial centers (OFCs) entirely, i.e., as investor as well as firm location countries.

2.2. Emissions data

In the firm-level analysis, we consider a firm's emissions relative to its revenues, denoted Emission Intensity in Revenue (EIR), as the main carbon intensity variable. *EIR* represents total greenhouse gas emissions, i.e., the sum of scope 1 and 2 emissions. We focus on emissions intensity in terms of revenue, as this carbon intensity variable measures emissions relative to the total value of production, resulting from all inputs into production.[7] Hence, *EIR* can be taken to be a good measure of potential environmental damage and risks at the firm level as perceived by investors. For this reason, *EIR* is widely used in the financial industry and favored as an emission index by the Partnership For Carbon Accounting Financials (PCFA, 2022). Our main sample contains 2190 firms in 2021 (see Table A1 in the Appendix). *Ownership share* has 320,081 observations, and its mean is 5.1% (Table 2, Panel A). The mean of *EIR* is 0.42 CO2e (CO2 equivalent) per thousand USD of revenue.

The emission variable used in the gravity analysis is denoted the Sectoral Emission

[7] In contrast, emissions intensity in terms of assets measures emissions primarily relative to capital inputs as proxied by assets.

Intensity in Revenue (SEIR). To construct *SEIR*, we first compute *EIR* for all the firms with emission data available regardless of the country of location, and then take the yearly median within each sector. Our use of sectoral medians as a proxy for how environmentally damaging and risky each sector is follows a similar practice of the European Central Bank (European Central Bank, 2022). We initially computed *SEIR* for 13 economic sectors identified in our data source based on the Refinitiv Business Classifications (TRBC). However, for three sectors, namely (i) Institutions, Associations and Organizations, (ii) Government Activity, and (iii) Academic and Educational Services, we have insufficient emissions data to construct *SEIR* for all years, and we exclude these three sectors from the analysis.[8] The remaining 10 sectors are: Energy, Basic Materials, Industrials, Consumer Cyclicals, Consumer Non-cyclicals, Financials, Healthcare, Technology, Utilities, and Real Estate. Of these, the most carbon-intensive sectors are Energy, Basic Materials, and Utilities.[9] *Bilateral holding* has 1,980,000 observations (Table 2, Panel B). The mean of *SEIR* is 0.32 CO2e per thousand USD of revenue.

In an additional test, we make a distinction between brown and non-brown industries, based on the subcategories of the 10 TRBC sectors. We identify brown industries as the industries with consistently high yearly medians of emission measures (see the online Appendix for details on how we determine which industries are brown). The industries that are labeled brown are: Oil and Gas, Metals and Mining, Construction Materials, Paper and Forest Products, Freight and Logistics Services, Passenger Transportation Services, Electric Utilities and IPPs, Natural Gas Utilities, Multiline Utilities, Chemicals, Containers and Packaging, Consumer Goods Conglomerates, Healthcare Providers and Services, Food and Tobacco, and

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[8] Very few companies belong to these three sectors, which implies that there is little variation in bilateral holdings for these sectors.

[9] Different analyses rely on different sector classifications, but the relative rankings are consistent. For example, the U.S. *Environmental Protection* Agency (EPA) ranks the top three most emitting sectors as (i) Electricity and Heat Production, (ii) Industry, and (iii) Agriculture, Forestry and Other Land Use. To compare, the TRBC sectors Energy and Utilities belong to the most emitting economic sector Electricity and Heat Production according to EPA, and the TRBC sector Basic Materials belongs to the second most emitting sector Industry from EPA.

Homebuilding and Construction Supplies.

2.3. Other data

In the firm-level analysis, *Distance* is the log of the distance between the capital cities of the investor and firm's location countries. Investors may be less inclined to hold far-off risky investments, and that may also apply to relatively risky carbon intensive investments.

We distinguish three types of investors based on the purpose of their investments. In doing so, we follow the London Stock Exchange Group's classification of investor types as implemented by our data source. First, investment managers are "buy-side institutions that have discretionary power over assets under management and make buy [or] sell decisions" (Refinitiv, 2019). Second, strategic investors are entities (sometimes individuals) that do not invest for investment management purposes, but rather they hold strategic stakes in companies for other purposes. Third, other investors are a remaining category. Given the discretionary nature of the investments of investment managers, we hypothesize that these investors have a greater propensity to reduce their ownership shares of browner firms at higher levels of economic development.

Finally, we classify investors according to the average turnover of their holdings. Investor turnover, as calculated by Refinitiv, is based on the absolute values of all the shares bought or sold for the past 12 months relative to the total value of the portfolio. High-turnover investors are defined as investors that have an average holding period of less than one year, while medium-turnover investors and low-turnover investors are taken to have average holding periods between 1 and 2 years and more than 2 years, respectively.

2.4. Correlations between emissions intensity of national portfolios and economic development

Using ownership data from the firm-level sample, we consider the relation between the portfolio-weighted *EIR* of national stock portfolios and per capita GDP. In particular, the portfolio-weighted *EIR* is computed as the national ownership weighted emissions (scope 1 and 2) divided by national ownership weighted firm-level revenues as follows,

$$\frac{\sum_{i \in Portfolio_t} \; w_{it} \times Emissions_{it}}{\sum_{i \in Portfolio_t} \; w_{it} \times Revenues_{it}},$$

where *i* is a firm index, *t* is a year index, and w_{it} represents the national ownership share in firm *i* at the end of year *t*.

Figure 1 provides a scatter diagram of the portfolio *EIR* and GDP per capita for the overall national portfolio, including domestic and foreign stocks, for the year 2017, shortly after the adoption of the Paris Agreement in 2015. The figure displays a negative relation between the portfolio *EIR* and GDP per capita, with a negative correlation of -0.12. We see that poorer countries such as India, Syria, and Ukraine display a higher portfolio-weighted *EIR*, while richer countries such as Liechtenstein and Monaco display lower portfolio-weighted carbon intensities. Similarly, Figure 2 provides a scatter plot of the foreign portfolio-weighted *EIR* and GDP per capita. Again, the shown relation is negative, with a negative correlation of -0.08.

Alternatively, Figures A2 and A3 in the Appendix plot the portfolio-weighted carbon intensity on assets (rather than revenues) of national overall and foreign portfolios against per capita GDP for 2017, displaying negative relations as before. Figures A4 and A5 in the Appendix provide analogous plots for each of the years in the 2002-2021 period, which show that negative relations between portfolio-weighted carbon intensities and GDP per capita are apparent throughout this period. Overall, the various scatter diagrams are consistent with the notion that richer countries tend to hold greener overall and foreign portfolios, motivating our empirical analysis.

3. Empirical approach

Our main hypothesis is that the propensity of investors to own shares of carbon-intensive firms declines with economic development. To test this, we use data on international holdings of shares at the firm level and alternatively at the bilateral national and sectoral level. In this section, we discuss the estimation specifications that are used in the two approaches.

In case of investments in individual firms, we estimate the following specification,

$$Ownership\ share_{fct} = \alpha + \beta EIR_{ft} \times Log\ GDP\ per\ capita_{ct} + \gamma_{ft} + \delta_{ct} + \epsilon_{fct}, \quad (1)$$

where $Ownership\ share_{fct}$ is the ownership share of firm *f* by investors in country *c* at time *t*, and EIR_{ft} is emissions relative to revenues of firm f in year t. We include time-varying firm fixed effects (γ_{ft}) to control for firm characteristics including the perceived financial risk and return, and the firm's carbon intensity. In addition, we include time-varying investor country fixed effects (δ_{ct}), which among other things control for the overall portfolio size of an investor country. Standard errors are clustered at the firm level.

The parameter β measures how the carbon sensitivity of investment, i.e. $\frac{\partial\ Ownership\ share_{fct}}{\partial\ EIR_{ft}}$ equaling $\beta Log\ GDP\ per\ capita_{ct}$, varies with economic development as proxied by $Log\ GDP\ per\ capita_{ct}$. A more negative estimated value of β implies that the carbon sensitivity of investment increases with economic development (in absolute terms), i.e., that investors in richer countries have a lower tendency to invest in carbon-intensive firms.

To test whether the relation between the carbon sensitivity of investment and economic development is different after the adoption of the Paris Agreement, we modify equation (1) as follows,

$$\begin{aligned} Ownership\ share_{fct} &\quad (2) \\ = \alpha + \beta_1 EIR_{ft} \times Log\ GDP\ per\ capita_{ct} & \\ + \beta_2 EIR_{ft} \times Log\ GDP\ per\ capita_{ct} \times PostPA_t + \gamma_{ft} + \delta_{ct} + \epsilon_{fct}, & \end{aligned}$$

where $PostPA_t$ is a dummy variable that equals 1 in the years 2015-2021 (the post-PA period), and is zero in earlier years (pre-PA).[10] A negative estimated β_2 is interpreted as evidence of a greater tendency of investors in richer countries to divest from carbon-intensive firms since the

[10] We include the year 2015 in the post-PA period as the UN climate conference COP21 where the Paris Agreement was adopted took place in 2015, and our data concern the year-end holdings.

adoption of the Paris Agreement.[11]

In addition to the firm-level analysis, we consider a gravity model where we compare bilateral national holding of shares across sectors with varying levels of emission intensities. Several papers have applied a gravity model approach to estimating the determinants of foreign direct investment (Di Giovanni (2005), Gu and Hale (2023), Head and Ries (2008)) and financial asset holdings (Chiţu et al (2014), Karolyi (2016), Portes and Rey (2005)).[12] Extending this literature, we specify a gravity equation for bilateral national and sectoral asset holdings as follows,

$$Bilateral\ holding_{ijt}^{k} = Exp[\alpha + \beta SEIR_{t}^{k} \times Log\ GDP\ per\ capita_{it} + \Lambda]\ \eta_{ijt}, \qquad (3)$$

where $Bilateral\ holding_{ijt}^{k}$ is the value of holdings by country *i* of shares of firms in country *j* and sector k divided by the two countries' GDPs at time *t*, and $SEIR_{t}^{k}$ is the median emission intensity in terms of revenue of sector k in year t. The term Λ represents sets of host country × investor country, host country × sector × year, and investor country × year fixed effects, absorbing the traditional gravity model components such as economic sizes and distance.

Recent contributions to the trade-related gravity literature (Head and Mayer (2014), Yotov et al. (2016)) recommend sets of country-pair, importer country-year, and exporter country-year fixed effects. We follow this specification of fixed effects, with the only difference that we extend the host country × year fixed effect to host country × sector × year fixed effects. Conforming to the earlier gravity literature, the included host country × investor country fixed effects control for time-invariant characteristics for each country pair, such as distances, historical relationships, and common languages. Furthermore, investor country × year fixed effects control for time-varying characteristics of investor countries, for instance, in the form

[11] Monasterolo and De Angelis (2020) find that the weight of low-carbon indices within an optimal portfolio tends to increase after the Paris Agreement.

[12] Several papers (Coeurdacier and Martin (2009), Martin and Rey (2004), Okawa and Van Wincoop (2012)) provide theoretical foundations for bilateral asset holdings consistent with a gravity model.

of investor-country portfolio size, while host country × sector × year fixed effects control for time-varying host-country and sector characteristics, for instance, in the form of variation in the volumes of investable shares at the host-country and sector levels.

In the gravity setting, we can define the carbon sensitivity of bilateral investments as $\frac{\partial \, \mathrm{Log}\, Bilateral\ holding_{ijt}^{k}}{\partial SEIR_{t}^{k}}$, i.e., $\beta Log\ GDP\ per\ capita_{it}$. The parameter β measures how this carbon sensitivity varies with economic development as proxied by $Log\ GPD\ per\ capita_{it.}$ A more negative estimated value of β is interpreted as evidence of a greater inclination of investors in richer countries to reduce their holdings of carbon-intensive firms.

To test whether this inclination is greater after the adoption of the Paris Agreement, we estimate the following specification,

$$\begin{aligned} Bilateral\ holding_{ijt}^{k} &= Exp\big[\alpha + \beta_1 SEIR_t^k \times Log\ GDP\ per\ capita_{it} \\ &+ \beta_2 SEIR_t^k \times Log\ GDP\ per\ capita_{it} \times PostPA_t + \Lambda\big]\, \eta_{ijt}. \end{aligned} \tag{4}$$

A negative estimate of $\boldsymbol{\beta_2}$ points at a greater tendency of investors in richer countries to divest from carbon intensive firms after 2015. We estimate equations (3) and (4) using the Poisson Pseudo Maximum Likelihood (PPML) estimator including values of zero following Silva and Tenreyro (2006). We apply a three-way clustering to standard errors at the levels of investor country, host country and year, as suggested by Egger and Tarlea (2015).[13]

4. Basic results

We start with discussing the results of estimating specification (1) using the firm-level sample for the entire period 2002-2021. As shown in column 1 of Table 3, the interaction *EIR × Log GDP per capita* receives a negative coefficient of -9.18 that is significant at 10%, consistent with a greater carbon sensitivity of investment for richer countries. Column 2 shows

[13] Standard errors are clustered at the levels of the investor country, the host country, the year, every double interaction of these three, and a triple interaction.

the results of estimating specification (2), which includes the interaction *EIR* × *Log GDP per capita* × *PostPA.* In this regression the double and triple interactions involving *EIR* obtain coefficients of -4.74 (significant at 10%) and -77.55 (significant at 1%), respectively, suggesting a greater tendency of investors in richer countries to divest from more carbon-intensive firms after the signing of the Paris Agreement.

The estimated coefficients imply that the relatively greater carbon sensitivity of investment for investors in higher-income countries is economically meaningful. To see this, note that a one-standard-deviation increase of *Log GDP per capita* of 0.72 occasions a change in the carbon sensitivity of investment of -59.25 (=(-4.741-77.55)*0.72) in the post-PA period. Comparing two firms with a difference in *EIR* of one standard deviation (4.86), we see that an increase in *Log GDP per capita* of 0.72 reduces ownership in the high-EIR firm by 287.95 (=4.86*59.25) basis points more compared to the ownership share in the low-EIR firm. This relative reduction in ownership of the high-EIR firm amounts to 15.90% (=288/1811.35) of the standard deviation of the ownership variable, which is a material effect.

Next, we consider to what extent our finding of a stronger relation between the carbon sensitivity of investment and economic development in the post-PA period reflects the investment behavior of investors in signatory and non-signatory countries to the Paris Agreement. We categorize signatory countries as countries that had signed the agreement before it entered into force on 4 November 2016.[14] Specifically, we split the sample into two subsamples with either signatory countries or non-signatory countries as investor countries, restricting ourselves to the post-PA period of 2015-2022. Column 3 shows a negative and significant coefficient for *EIR* × *Log GDP per capita* for the subsample of signatory countries, while the corresponding coefficient is insignificant in column 4 for the non-signatory countries.

[14] The Paris Agreement was open for signature from 22 April 2016 to 21 April 2017. On 5 October 2016, the threshold for the entry into force of the Paris Agreement was already achieved. The response window our criterion captures is roughly the first 6 month after the opening for signature.

Thus, especially signatory countries of the Paris Agreement display a stronger relation between the carbon sensitivity of investment and economic development in the post-PA period.

As an alternative ownership variable, we consider the value of a country's investment in a firm relative to its GDP, denoted *Holding value*, which is an appropriate investment variable if investors perceive their choice to be to invest certain absolute amounts of money in particular firms, rather than to choose an ownership share. Columns 5 and 6 provide the results for this ownership variable from regressions that are analogous to columns 1 and 2. The results confirm a stronger joint impact of a firm's carbon intensity and investor-country economic development in the post-PA period. The value of a country's investment in a certain firm relative to its GDP, i.e., *Holding value*, reflects the quantity as well as any price effects of investor behavior. In the remainder of this paper, when examining investments in individual firms, we will only consider *Ownership share*, thereby abstracting from any price response to investment behavior.

Our analysis so far has been based on samples that exclude OFCs as investor countries on the grounds that OFCs often act as conduit countries for investors that are residents of other countries. Columns 7-8 show the results of re-estimating regressions 1-2 after we extend the sample to include OFCs with GDP per capita available as investor countries. These results confirm a stronger relation between the carbon sensitivity of investment and economic development in the post-PA period although the estimated coefficients are slightly less negative.

Table 4 presents the results of estimating the gravity specifications, with *Bilateral holding* as the dependent variable. Specifically, columns 1 and 2 provide the results of estimating specifications (3) and (4) for the full sample, analogously to regressions 1 and 2 in Table 3 for the firm-level analysis. The interaction *SEIR* × *Log GDP per capita* × *PostPA* receives a significant negative coefficient in column 2, suggesting a greater impact of economic development on the carbon sensitivity of investment in the post-PA period.

Columns 3 and 4 provide a sample split into signatory and non-signatory investor countries for the post-PA period, similarly to columns 3 and 4 in Table 3. *SEIR* × *Log GDP per capita* is estimated with a negative significant coefficient in column 3, and with an insignificant coefficient in column 4. Thus, the relation between the carbon sensitivity of investment and economic development is only significantly stronger for signatory countries in the gravity analysis in the post-PA period, similarly to the results in columns 3 and 4 of Table 3.

In columns 5 and 6, the dependent variable is *Bilateral holding* as based only on investments in firms with a single class of ordinary shares, yielding results that are similar to columns 1 and 2.

Finally, in columns 7 and 8 we extend the sample of investor countries to include the set of OFCs, analogously to columns 7 and 8 in Table 3.[15] The estimated coefficient for the interaction *SEIR* × *Log GDP per capita* is positive and significant in columns 7 and 8, unlike in columns 1 and 2. These results are consistent with the notion that investors with addresses in richer OFCs are less inclined to decarbonize their equity portfolios compared to investors in other richer countries. However, column 8 provides a significantly negative estimate for the coefficient of the triple interaction involving *SEIR*, and a negative sum of the estimated coefficients for the double and triple interactions. Thus, we find evidence that investors in richer countries tend to divest more from brown firms in the post-PA period, even when we include OFCs in the sample.

As a robustness check, we estimate regressions 1-4 of Tables 3 and 4 using alternative emission variables representing emissions relative to assets and emissions per se. The results are shown in Table A3 in the Appendix, confirming a tendency for richer countries to hold greener portfolios.

The differential investment behavior of investors in signatory countries to the Paris

[15] These results are consistent with the corresponding firm-level findings. The estimates of *EIR* × *Log GDP per capita* are less negative in columns 7 and 8 compared to the other columns of Table 3 that exclude observations for OFCs.

Agreement evident from Tables 3 and 4 can have at least three distinct causes. First, the Paris Agreement imposed binding restrictions on CO2 emissions at the national level, leading to increasing national restrictions on emitting activities. This can have negative implications for the relative returns and thus the demand of investable brown assets. Second, Article 9 of the Agreement requires signatory countries to take the lead in mobilizing climate finance, which could prompt policy making that promotes low-carbon investments, giving rise to greener portfolios. Third, signatory countries could have greener preferences, which by themselves or by their impact on national policy making could also advance portfolio greening.

We are unable to determine the relative importance of these potential channels in explaining the differential investment behavior of investors between signatory and non-signatory countries in the post-PA period. However, we can test whether investment behavior of signatory countries was already different in the pre-PA period, which would be consistent with signatory and non-signatory countries having different investor preferences or economic policies regarding the green transition before the Paris Agreement.

To test this, we estimate gravity specification (3) separately for the samples of signatory and non-signatory countries by year, for a window of ±6 years around the signing year of 2015. Figure 3 displays the estimated yearly coefficients for *SEIR × Log GDP per capita* and their 95% confidence intervals for the two samples of countries. The figure shows that estimated coefficients are already negative and significant during 2012-2014 for the group of signatory countries, consistent with these countries displaying greener preferences in their investment behavior early on. From 2015, estimated coefficients are also negative and significant for the signatory countries in all years except for 2020.[16] In contrast, Figure 3 shows that estimated coefficients are insignificant for the group of non-signatory countries throughout the 2009-

[16] The year 2020 may have been different, if environmental risk became a secondary concern during economic turbulence caused by the Covid-19 outbreak. Consistent with this, the annual report of the International Platform on Sustainable Finance (International Platform on Sustainable Finance (2020)) shows that new issue volume of green bonds unprecedentedly dropped in the first three quarters of the year 2020.

2021 period, suggesting that the carbon sensitivity of investment did not depend on economic development for these countries throughout this period.

5. Extensions and robustness

In this section, we provide further tests of the hypothesis that economic development has a positive effect on investment decarbonization at the firm level. Specifically, we investigate the roles of distance and borders, investor heterogeneity, and sector and firm heterogeneity. In addition, we perform several robustness checks regarding the estimation technique and added control variables.

5.1. The role of distance and borders

Gravity theory is based on the notion that financial frictions and information asymmetries increase with distance, which reduces the capability and efficiency of evaluating prospective investment (Aviat and Coeurdacier (2007), Portes et al. (2001), Portes and Rey (2005)). This should apply especially to relatively risky assets such as brown assets. Therefore, we expect countries to invest less in brown firms that are located far away. We refer to this hypothesis as the *distance divestment hypothesis*.

As a related issue, investors must decide on the relative brownness of their domestic and foreign investment portfolios. There are several reasons why investors may end up holding relatively more brown assets in their foreign portfolios. First, in some countries stringent environmental policies may reduce the supply of domestic brown stocks, causing investors in these countries to switch to holding more foreign brown stocks. Second, investors could be subject to behavioral biases in the form of the “not-in-my-backyard” notion (Marks and Von Winterfeldt (1984)), and the "out of sight, out of mind" notion (Barnes (2019)), which could also lead them to invest relatively more in foreign brown stocks.[17] We refer to the idea that

[17] In the case of CO_2 emissions, this is irrational as global warming depends on global rather than local emissions.

investors reduce the brownness of especially their domestic portfolio as a *home bias in divestment.*[18] This home bias in divestment implies a relatively larger reduction of brown investments domestically as compared to abroad, complementary to the distance divestment hypothesis which inherently informs more about the allocation within the foreign portfolio.

To explore the role of distance, we extend specification (2) as follows,

$$\begin{aligned} Ownership\ share_{fct} &= \alpha + \beta EIR_{ft} \times Log\ GDP\ per\ capita_{ct} + \gamma_1 Distance_{fc} \\ &+ \gamma_2 EIR_{ft} \times Distance_{fc} + \gamma_3 Log\ GDP\ per\ capita_{ct} \times Distance_{fc} \\ &+ \gamma_4\ EIR_{ft} \times Log\ GDP\ per\ capita_{ct} \times Distance_{fc} + \gamma_{ft} + \delta_{ct} \\ &+ \epsilon_{fct}, \end{aligned} \quad (5)$$

where $Distance_{fc}$ is the log of the distance between the firm's location and investor countries in thousands of kilometers.

We expect distance per se to discourage investment consistent with finding $\gamma_1 < 0$. The included interaction $EIR_{ft} \times Distance_{fc}$ allows for the possibility that investors hold especially fewer brown assets at a distance if $\gamma_2 < 0$, consistent with the distance divestment hypothesis. Further, the term $Log\ GDP\ per\ capita_{ct} \times Distance_{fc}$ informs on whether richer countries face fewer difficulties in investing at a distance corresponding to $\gamma_3 > 0$, in line with the finding of Chan et al. (2005) that international portfolio diversification is associated with domestic economic development. Finally, the additional interaction $EIR_{ft} \times Log\ GDP\ per\ capita_{ct} \times Distance_{fc}$ informs on whether the previously found positive impact of economic development on the carbon sensitivity of investment fades with distance corresponding to $\gamma_4 > 0$, reflecting difficulties of evaluating carbon intensity at a distance.

Specification (5) does not distinguish between domestic and foreign shares, and hence it does not offer a direct test of whether richer countries decarbonize their national portfolios by especially reducing the carbon intensity of domestic holdings.[19] However, indirectly we can

[18] Chan et al. (2005) find a home bias in the investments of mutual funds without considering carbon intensities.
[19] Note that included firm times year fixed effects preclude the estimation of (5) for the sample of only domestic firms.

gain information on the comparative home bias in divestment. More specifically, by estimating the earlier specification (2) for the sample of all stocks (as we did in Table 3) and for the sample of only foreign stocks and then comparing pertinent estimated coefficients, we can assess whether our finding that richer countries divest more from browner stocks applies especially to domestic stocks. A less negative estimated coefficient for $EIR_{ft} \times Log\ GDP\ per\ capita_{ct}$ in the regression for the sample of only foreign stocks is consistent with the notion that richer countries divest especially from domestic brown stocks, reflecting a stronger home bias in divestment.

To start, column 1 of Table 5 shows the results of estimating specification (5) for the full sample during the entire period 2002-2021. The ownership share decreases significantly with distance. This effect is stronger for browner shares consistent with the distance divestment hypothesis, but it is weaker for countries with a higher per capita GDP. Furthermore, we find that *EIR* × *Log GDP per capita* and *EIR* × *Log GDP per capita* × *Distance* obtain significant coefficients of -6.31 and 2.42, respectively, indicating that the carbon sensitivity of investment increases with per capita GDP, but this effect is weaker for more distant stocks.

In column 2, we include interactions of included variables with the *PostPA* dummy, differentiating between the pre-PA and post-PA periods. We see that effects involving *EIR* are estimated to be significantly stronger in the post-PA period compared to the pre-PA period. Specifically, the term *EIR* × *Distance* × *PostPA* obtains a negative and significant coefficient, indicating stronger evidence for the distance divestment hypothesis in the later period. To illustrate, the estimated coefficient of -89.16 implies that a one-standard-deviation increase in *Distance* of 1.08 leads to an additional reduction in ownership shares in high-EIR vs. low-EIR firms shares that are one standard deviation (4.86) apart by 467.98 (=89.16*1.08*4.86) basis points in the post-PA period relative to the pre-PA period, which amounts to 25.84% (=467.98/1811.35) of the standard deviation of the ownership share. This is an economically significant effect. We further see that the dependence of the carbon sensitivity of investment on *Log GDP per capita* as well as the distance-related attenuation thereof are, respectively, about 17 and 18 times larger in the post-PA period than before.

Columns 3-8 provide additional results based on the sample of only foreign firms. Specifically, results in columns 3 and 4 are analogous to columns 1 and 2 in Table 3 for the overall sample. In columns 3 and 4, *EIR* × *Log GDP per capita* is insignificant, while *EIR* × *Log GDP per capita* × *PostPA* is negative and significant at -10.87 in column 4. But this estimated coefficient is less negative than the analogous estimate of -77.55 in column 2 of Table 3. This suggests that the propensity for richer countries to hold greener stocks is stronger for domestic stocks than foreign stocks in the post-PA period, consistent with a home bias in divestment. Next, columns 5-6 and 7-8 provide results analogous to columns 3-4 for subsamples of long-distance and short-distance foreign stocks, respectively. The estimated coefficients for *EIR* × *Log GDP per capita* are more negative in columns 5-6 than in columns 7-8, suggesting that the propensity of richer countries to divest of browner stocks is stronger for long-distance stocks than short-distance stocks, consistent with the distance divestment hypothesis as applied to more developed countries.

Taken together, our findings are threefold. First, distance increases the carbon sensitivity of investment, consistent with the distance divestment hypothesis. Second, the carbon sensitivity of investment is more strongly related to economic development for long-distance foreign stocks than short-distance foreign stocks, consistent with a distance divestment hypothesis in the case of especially richer countries. Third, economic development increases the carbon sensitivity of investment more for domestic stocks than foreign stocks, consistent with a home bias in divestment. Overall, distance and borders are demonstrated to be important factors in the international portfolio decarbonization process.

5.2. Investor heterogeneity

So far, we have considered investments in companies aggregated at the investor country level. These aggregate investments are the sums of investments by heterogenous investors, and different investor categories may adjust the carbon intensity of their investments differently to changes in economic development. To examine this, in this section we consider investor heterogeneity along two dimensions: we distinguish among investors by investment objective and by revealed portfolio turnover.

Starting with investor type, we distinguish among investment managers, strategic investors, and a remainder category. Investment managers, comprising banks and trusts, endowment funds, hedge funds, investment advisors, insurance companies, pension funds, private equities, venture capitals and sovereign wealth funds, are investors that invest on behalf of their clients. In particular, investment managers choose a risk-return profile and possibly carbon intensity of the overall portfolio that they deem appropriate for the clients that they represent. To achieve their objectives, investment managers can choose to exit from particular carbon-intensive firms. They can do this either to please existing customers or to attract additional environmentally conscious ones.[20] In contrast, strategic investors maintain stakes in certain firms for strategic reasons, which implies that their holdings tend to be more committed, less flexible or even irreplaceable (Espenlaub et al. (2016)). Strategic investors comprise corporations, government agencies, holding companies, individual investors, and other insider investors. Finally, other investors are investors that do not fit into either of the two prior categories, including brokerage firms and portfolio-type funds that are managed by investors themselves. We expect investment managers to be relatively sensitive to the carbon intensity of their investments, and as a corollary we expect such managers to display a relatively higher propensity to divest from brown stocks at a higher level of GDP per capita.

[20] In line with this, Hartzmark and Sussman (2019) document a transfer of capital from U.S. mutual funds categorized as low sustainability to their high-sustainability counterparts.

To test whether investor type affects carbon-related investment decisions, we aggregate ownership shares in individual companies at the national level for each of the three investor categories, and re-estimate our benchmark regressions in columns 1 and 2 of Table 3 separately for the three investor categories.

Columns 1 and 2 of Table 6 report the results for the ownership share of investment managers, showing significant negative coefficients for *EIR* × *Log GDP per capita* in columns 1 and 2, and for *EIR* × *Log GDP per capita* × *PostPA* in column 2. Thus, the carbon sensitivity of holdings by investment managers increases with GDP per capita, especially in the post-PA period, consistent with the earlier results in Table 3. In contrast, the analogous estimates are insignificant in columns 3-4 for strategic investors, and in columns 5-6 for other investors. These results suggest that our earlier finding that investors in richer countries tend to divest from browner stocks is driven by the investment behavior of investment managers who invest on behalf of their clients.

To supplement this analysis, we consider investor heterogeneity related to the investment horizon. We conjecture that frequent traders are more interested in immediate returns and less in the long-term climate effects of their investments. Hence, we expect frequent traders to display a weaker dependence of the carbon sensitivity of their investments on GDP per capita.

To test this, we estimate separate regressions analogous to columns 1 and 2 of Table 3 for holdings by investors with high, medium, and low turnover. As seen in Table 7, the portfolio greening effect of economic development decreases in portfolio turnover, consistent with our hypothesis of a negative relation between trading frequency and a preference for green assets. In particular, the post-PA increment in the greening effect of economic development is strongest for the group of investors with a lowest turnover rate (i.e., with average holding periods exceeding 2 years). This result is consistent with the finding by Kim et al. (2019) that long-term investors promote corporate social responsibility activities, and also with the notion that institutional investors lead the green portfolio transition (Benz et al. (2020), Dyck et al. (2019), Gantchev et al. (2022)).

Combining our benchmark and the investor heterogeneity results, we conclude that the divergence in the financial decarbonization processes between rich and poor countries is driven more by certain groups of investors, including investment managers and investors with longer horizons.

5.3. Sector and firm heterogeneity

In this subsection, we examine whether the investment greening effect of economic development applies particularly to certain sectors or certain types of firms. To start, we distinguish between firms in brown and non-brown industries.

In Table 8, columns 1-2 show that the investment greening effect of economic development is estimated to be significant for firms in brown industries, while columns 3-4 show insignificant results for firms in non-brown industries. Thus, the decarbonization process associated with economic development is only apparent for firms in the most polluting industries, including but not limited to fossil fuel companies. This also suggests that investors practice negative screening of firms on the basis of industry affiliation in line with Amel-Zadeh and Serafeim (2018).

Next, we consider two firm-level characteristics: firm size and inclusion in the MSCI World index. In particular, we analyze two pairs of subsamples: large vs. small firms based on assets, and MSCI World constituents vs. non-constituents as of June 2023. The results are displayed in Table 9. From columns 1-4, we learn that the carbon sensitivity of holdings in larger firms is estimated to be relatively more responsive to economic development. Perhaps this reflects the greater visibility of larger firms, and that larger firms are perceived to have a greater impact on climate change (Azar et al. (2021)).

Comparing MSCI World index constituents and non-constituents in columns 5-8, we notice an important difference during the post-PA years. Specifically, we find a large negative effect only for non-constituent firms, even though we expect less information on emissions to be available for those firms. The absence of such an effect for constituent firms suggests that, in relative terms, there may have been a redirection of investments from non-constituent polluting firms towards constituent polluting firms for investors in more developed countries.

To learn more about the time patterns of the carbon sensitivity of investments in constituent and non-constituent firms, we estimate regression 5 and 7 in Table 9 by year, and display the respective estimated coefficients with the associated 95% confidence intervals in Figure 4. Estimated coefficients for firms that are included in the MSCI World index are insignificant throughout the 2010-2022 period. In contrast, estimated coefficients for non-included firms are already significantly negative in the pre-PA period except for two years, while they are significant and more negative in all post-PA years. These results confirm that investment greening in richer countries is applied more strongly to non-included firms, especially in the post-PA period.[21] These results possibly reflect the ease and low cost of investing in index funds, which in practice may trump portfolio greening considerations.

5.4. Robustness checks

As a first robustness check, we control for aspects of financial development that could affect the carbon intensity of investments. At a general level, financial development could promote financial decarbonization, if it improves access to finance for firms that wish to decarbonize or creates additional investment channels for investors with a longer-term perspective. The nature of economic development, including improvements of financial infrastructure and institutions, may further affect decarbonization, as De Haas and Popov (2023) find evidence that stock markets are better suited to finance the green transition than debt

[21] Major investors that do not exit from firms included in a major index can be effective by engagement in reducing carbon emissions at these companies (Azar et al. (2021)).

markets.

To control for the potential role of financial development, we include interactions of *EIR* with the assets of deposit money banks, pension funds, investment funds and insurance corporations, as well as stock market capitalization, respectively, as a percentage of GDP in the benchmark regression 1 of Table 3. We also further adjust regression 2 of Table 3 to include interactions of *EIR* × *PostPA* with the abovementioned variables. Estimated coefficients for variables involving *Log GDP per capita* are reported in columns 1 and 2 of Table 10, showing that *EIR* × *Log GDP per capita* is significant only in column 1, while *EIR* × *Log GDP per capita* × *PostPA* remains negative and significant in column 2.

Similarly, our estimated effects relating decarbonization and economic development could reflect the quality of legal and other institutions. Better institutions generally improve the efficiency of the investment process, and perhaps also of efforts of investors to green their portfolios. To control for the institutional environment, we consider interactions of *EIR* and *EIR* × *PostPA* with the following institutional variables: government effectiveness, regulatory quality, rule of law, voice and accountability, and total government education expenditure to GDP. Columns 3 and 4 of Table 10 show that results are very similar when we control for these institutional factors.

Furthermore, investor preferences for green investments could be shaped by investors' own exposure to climate change risk. Specifically, investors that are more exposed to heat waves or floods may feel more urgent needs to slow down climate change (Al Mamun et al. (2022)), and hence be more inclined to green their investment portfolios. To allow for this, we add interactions of *EIR* and *EIR* × *PostPA* with Heat index 35 (days per year when the daily mean Heat index rose above 35°C), heating degree days (days per year when heating would be needed), and the additional share of the population exposed to annual coastal floods due to sea level rise. The latter variable is a cross-sectional variable resulting from a max-exposurescenario projection for 2050, and thus it is time-invariant. Results shown in columns 5 and 6 remain very similar.

Columns 7 and 8 collectively include the interactions with control variables that render significant coefficients in columns 1-6, showing results that are qualitatively similar to the benchmark, although estimated effects are larger.[22] After including a wide variety of control variables, we continue to find that portfolio decarbonization progresses with economic development.

As a final robustness check, we re-estimate regressions 1-4 of Table 3 using the PPML estimator as our OLS estimation using only observations with positive values may lead to bias.[23] In this PPML estimation, we include observations of zero for countries that have positive ownership share observations for a particular stock in some years in the OLS estimation, and we do not winsorize this variable. Table A4 in the Appendix reports results that are similar with the exception that estimated coefficients are no longer significant in column 2 where we introduce the interaction *EIR* × *Log GDP per capita* × *PostPA* in a regression for the entire period. However, we find that *EIR* × *Log GDP per capita* is significantly negative in a regression where we restrict the sample to the post-PA period. Moreover, the estimated coefficient in this regression is more negative than in the regression for the overall sample period, consistent with a stronger impact of economic development on investment greening in the post-PA period.

6. Conclusion

Previous research on the greening of portfolios by institutional investors raises the question

[22] The control variables used in columns 7-8 are financial assets of, respectively, pension funds and investment funds to GDP, stock market capitalization to GDP, indicators of government effectiveness and rule of law, government expenditure on education to GDP, heating degree days, and additional population exposed to annual coastal floods due to sea level rise.
[23] Furthermore, ownership share is a count-like outcome variable that may not lead to efficient estimation using a linear regression model according to Cohn et al. (2022).

of who the purchasers of the divested brown assets have been. In this paper, we examine the holdings of stocks of varying carbon intensity internationally, shedding light on which countries have been buyers and sellers in the worldwide market for brown stocks.

Using global stock ownership data, we find a robust negative relation between the tendency by investors to hold brown assets and economic development as measured by log GDP per capita. This empirical relation has two key implications. First, at the country level, economic development is likely to lead to a greening of the national stock portfolio. Second, cross-sectionally, richer countries will tend to hold greener portfolios. Confirming this second implication, we find that the carbon intensities of national overall and foreign stock portfolios are negatively correlated with economic development as proxied by GDP per capita. Our finding that richer countries make greater efforts to green their portfolios is consistent with the theory of the private provision of public goods, if we see portfolio decarbonization as an international public good.

The distance between investor and firm location countries is shown to play a key role in the portfolio decarbonization process. Specifically, investors divest more from carbon-intensive companies that are located farther away. On the other hand, distance attenuates the negative relationship between economic development and the ownership of brown stocks. At the same time, we find evidence suggesting that investors from richer countries reduce the brownness of especially domestic portfolios.

Our analysis also explores investor heterogeneity in the holdings of brown assets internationally. We find that especially investment managers, who manage portfolios on behalf of their clients, and investors with longer investment horizons show a tendency to reduce their holdings of brown assets if resident in a richer country.

Furthermore, we find evidence of negative screening of firms in brown industries, as investors in richer countries tend to reduce their holdings of browner firms especially for firms that belong to brown industries. At the same time, investors in richer countries are more prone to reduce their investments in larger carbon-intensive firms, which could reflect the greater visibility of larger firms or the perception that larger firms have a greater impact on climate change.

Finally, we find that investors in richer countries have a lower propensity to divest from browner firms that are included in the MSCI World index, which does not consider firms' carbon intensities. Regulatory developments towards wider carbon disclosure, such as the Corporate Sustainability Reporting Directive in the European Union and the Financial Conduct Authority Reporting Requirements in the UK, could facilitate the construction of additional international indices that do consider carbon intensities, thereby possibly mitigating the effect of index investing on the portfolio decarbonization process.

Table 1: Summary information on coverage of ownership data in 2020

Continent	Share of world market capitalization (%)	Market value coverage (%)	Holding value coverage (%)
Africa	1.39	46.86	32.62
Americas	49.12	99.42	78.49
Asia	40.64	101.18	73.11
Europe	6.84	103.38	64.44
Oceania	2.02	93.10	37.64
Total	100.00	99.71	73.88

The statistics in this table concern all the ownership data retrieved from Refinitiv with available price information. The coverage ratios are computed using the following formulas:

$$Market\ value\ coverage = \frac{\sum Market\ value\ of\ any\ firm\ on\ a\ continent\ in\ data\ set}{\sum Stock\ market\ capitalization\ of\ countries\ on\ a\ continent},$$

$$Holing\ value\ coverage = \frac{\sum Value\ held\ by\ all\ investors\ in\ any\ firm\ on\ a\ continent\ in\ data\ set}{\sum Stock\ market\ capitalization\ of\ countries\ on\ a\ continent}.$$

The world market capitalization used here takes the sum of all the country-level market capitalizations available from the World Bank database. We take the year 2020 because this is the most recent year for which domestic market capitalization data are available from the World Bank database. To be consistent with the World Bank statistics, we exclude the financial holding companies from the underlying firm set. If several classes of shares exist for a company, all these classes are included, as the World Bank explains. A discrepancy still exists between the World Bank data and our own aggregation because our firm market capitalization data are sourced differently. This is the reason why for two regions the Market value coverage in our data set is slightly over 100%.

Table 2: Summary statistics for firm-level and gravity analysis samples

Panel A: Summary statistics for firm-level sample

	N	Mean	Std	Min	Max
Ownership share, basis points	320,081	514.74	1811.35	0.02	8,676.79
Holding value, USD per million GDP	320,081	140.53	599.69	0.00	4,891.05
EIR, ton CO2e per thousand USD	320,081	0.42	4.86	0	725.43
Log GDP per capita	320,081	3.62	0.72	-1.53	5.46
PostPA	320,081	0.55	0.50	0	1
Distance	320,081	1.50	1.08	-5.90	2.98

Panel B: Summary statistics for sample for gravity analysis.

	N	Mean	Std	Min	Max
Bilateral holding, thousand USD scaled by GDPs in billion USDs	1,980,000	1.70	320.83	0	217,561.9
SEIR, ton CO2e per thousand USD	1,980,000	0.32	0.57	0	2.64
Log GDP per capita	1,980,000	2.41	1.32	-1.42	5.46
PostPA	1,980,000	0.35	0.48	0	1

Panel A presents summary statistics for the sample of the regressions 1-6 in Table 3, and for *Distance* in regression 1 in Table 5. *Ownership share* is the national ownership share of a stock. *Holding value* is the value of the national ownership share of a stock relative to investor country GDP. *EIR* is carbon emissions divided by revenue. *Log GDP per capita* is the log of GDP per capita in thousands of US dollars of the investor country. *PostPA* is a dummy variable for the years 2015-2021. *Distance* is the log of bilateral distance between investor and host countries in kilometers. *Ownership share* and *Holding value* are winsorized at the 0.01 level. Panel B presents the summary statistics corresponding to regressions 1-4 in Table 4. *Bilateral holding* is the value of bilateral stock holding in a sector divided by both source country and investor country GPDs. *SEIR* is median emissions divided by revenue at the sector level.

Table 3: Ownership share and holding value with firm-level data

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Ownership share		Ownership share		Holding value		Ownership share	
			Signatory	*Non-signatory*				
EIR × Log GDP per capita	-9.183* (4.707)	-4.741* (2.548)	-85.71*** (18.03)	40.77 (26.18)	-3.120* (1.856)	-1.939 (1.376)	-7.422* (4.090)	-3.775 (2.387)
EIR × Log GDP per capita × PostPA		-77.55*** (17.41)				-20.61*** (5.941)		-57.14*** (13.46)
Constant	525.7*** (7.147)	576.9*** (13.25)	678.5*** (24.27)	252.8*** (42.87)	143.7*** (2.818)	157.3*** (4.702)	450.7*** (6.504)	490.0*** (10.94)
Excluding OFCs	Y	Y	Y	Y	Y	Y	N	N
Observations	320081	320081	169108	7478	320081	320081	449719	449719
Adjusted R^2	0.455	0.457	0.437	0.551	0.238	0.239	0.411	0.412

The dependent variables are *Ownership share* in regression 1-4 and 7-8, and *Holding value* in regressions 5-6. *Ownership share* is the national ownership share of a stock. *Holding value* is the value of the national ownership share of a stock relative to investor-country GDP. *EIR* is carbon emissions divided by revenue. *Log GDP per capita* is the log of GDP per capita in thousands of US dollars of the investor country. *PostPA* is a dummy variable for the years 2015-2021. Firm-year and investor country-year fixed effects are included. Standard errors are clustered at the firm level. Regressions 3-4 are limited to the period 2015-2021 with observations for signatory and non-signatory investor countries, respectively. Regressions 7-8 include observations for OFCs as investor countries, which are Bahamas, Barbados, Cyprus, Hong Kong, Ireland, Luxembourg, Marshall Islands, Netherlands, Singapore, Switzerland, and the United Kingdom. Standard errors in parentheses, *: $p < 0.10$, **: $p < 0.05$, ***: $p < 0.01$.

Table 4: Gravity analysis results

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Bilateral holding		Bilateral holding		Bilateral holding		Bilateral holding	
			Signatory	*Non-signatory*				
SEIR × Log GDP per capita	-0.379 (0.324)	-0.308 (0.298)	-1.721*** (0.383)	0.217 (1.488)	-0.367 (0.324)	-0.302 (0.299)	0.722*** (0.163)	0.807*** (0.150)
SEIR × Log GDP per capita × PostPA		-0.426*** (0.150)				-0.390*** (0.147)		-0.861** (0.364)
Constant	9.385*** (0.163)	9.410*** (0.171)	8.676*** (0.0999)	7.722*** (0.981)	9.319*** (0.170)	9.343*** (0.179)	9.108*** (0.206)	9.270*** (0.118)
Excluding OFCs	Y	Y	Y	Y	Y	Y	N	N
Firms of single-class ordinary share only	N	N	N	N	Y	Y	N	N
Observations	1980000	1980000	623700	69300	1980000	1980000	2442000	2442000
Pseudo R^2	0.960	0.960	0.961	0.970	0.958	0.958	0.968	0.968

The dependent variable is *Bilateral holding*, which is the value of bilateral stock holding in a sector divided by both investor and source country GPDs. *SEIR* is median emissions divided by revenue at the sector level. *Log GDP per capita* is the log of GDP per capita in thousands of US dollars of the investor country. *PostPA* is a dummy variable for the years 2015-2021. Country-pair, investor country-year, and source country-sector-year fixed are included. Standard errors are clustered at the levels of the investor country, the host country, the year, every double interaction, and a triple interaction. Regressions 3-4 are limited to the period 2015-2021 for signatory and non-signatory investor countries. In regressions 5-6, *Bilateral holding* also reflects firms with multiple classes of common stock. Regressions 7-8 including OFCs as investors countries, which are Bahamas, Barbados, Cyprus, Hong Kong, Ireland, Luxembourg, Marshall Islands, Netherlands, Singapore, Switzerland, and the United Kingdom. Standard errors in parentheses, *: $p < 0.10$, **: $p < 0.05$, ***: $p < 0.01$.

Table 5: Ownership share, distance, and foreign firms

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Ownership share		Ownership share		Ownership share		Ownership share	
	All firms		*Foreign firms: all*		*Foreign firms: long distance*		*Foreign firms: short distance*	
EIR × Log GDP per capita	-6.313** (3.175)	-3.418*** (1.087)	-2.425 (1.814)	-1.752 (1.383)	-9.205*** (3.306)	-8.223*** (2.420)	-1.150* (0.673)	-0.806* (0.417)
Distance	-2056.5*** (66.27)	-2049.7*** (84.59)						
EIR × Distance	-9.415* (5.392)	-4.595** (2.083)						
Log GDP per capita × Distance	351.4*** (17.01)	366.1*** (21.70)						
EIR × Log GDP per capita × Distance	2.418* (1.337)	1.322*** (0.471)						
EIR × Log GDP per capita × PostPA		-54.00*** (14.14)		-10.87** (4.664)		-18.60 (22.54)		-6.048*** (2.211)
Distance × PostPA		51.29 (76.76)						
EIR × Distance × PostPA		-89.16*** (23.32)						
Log GDP per capita × Distance × PostPA		-40.98** (19.78)						
EIR × Log GDP per capita × Distance × PostPA		22.30*** (5.926)						
Constant	1740.0*** (20.45)	1768.6*** (22.48)	115.5*** (2.755)	122.6*** (3.795)	158.0*** (5.616)	169.6*** (17.64)	96.65*** (1.006)	100.6*** (1.641)
Observations	320081	320081	301662	301662	63468	63468	238194	238194
Adjusted R^2	0.601	0.602	0.239	0.240	0.495	0.495	0.292	0.292

The dependent variable is *Ownership share*, which is the national ownership share of a stock. *EIR* is carbon emissions divided by revenue. *Log GDP per capita* is the log of GDP per capita in thousands of US dollars of the investor country. *Distance* is the log of bilateral distance between investor and host countries. Short-distance countries are countries with a bilateral distance below 2588 kilometers, and long-distance countries have a longer distance. *PostPA* is a dummy variable for the years 2015-2021. Firm-year and investor country-year fixed effects are included. Regressions 3-4 include all foreign firms. Regressions 5-6 include short-distance foreign firms. Regressions 7-8 include long-distance foreign firms. Standard errors in parentheses, *: $p < 0.10$, **: $p < 0.05$, ***: $p < 0.01$.

Table 6: Ownership share by investor type

	(1)	(2)	(3)	(4)	(5)	(6)
	Ownership share: investment managers		Ownership share: strategic investors		Ownership share: other investors	
EIR × Log GDP per capita	-2.996* (1.589)	-1.082** (0.460)	1.219 (0.947)	1.386 (0.858)	-3.479 (5.503)	-2.034 (4.359)
EIR × Log GDP per capita × PostPA		-33.19*** (7.005)		-41.37 (57.21)		-2.691 (9.296)
Constant	364.2*** (2.391)	386.0*** (5.213)	734.4*** (1.620)	757.7*** (32.97)	91.13*** (5.294)	90.78*** (4.556)
Observations	315004	315004	33999	33999	26859	26859
Adjusted R^2	0.591	0.592	0.221	0.221	0.602	0.602

The dependent variable is *Ownership share* by investor type, which is the national ownership share of a stock by the indicated type of investors. *EIR* is carbon emissions divided by revenue. *Log GDP per capita* is the log of GDP per capita in thousands of US dollars of the investor country. *PostPA* is a dummy variable for the years 2015-2021. Firm-year and investor country-year fixed effects are included. *Ownership share* in regressions 1-2 is based on holdings by investment managers. *Ownership share* in regressions 3-4 is based on holdings by strategic investors. *Ownership share* in regressions 5-6 is based on holdings by other investors. Standard errors are clustered at the firm level. Standard errors in parentheses, *: $p < 0.10$, **: $p < 0.05$, ***: $p < 0.01$.

Table 7: Ownership shares of investors with different portfolio turnover

	(1)	(2)	(3)	(4)	(5)	(6)
	Ownership share: investors with high turnover		Ownership share: investors with medium turnover		Ownership share: investors with low turnover	
EIR × Log GDP per capita	-0.222 (0.208)	-0.0885 (0.179)	-0.547 (0.389)	-0.141 (0.121)	-4.772* (2.685)	-1.931 (1.176)
EIR × Log GDP per capita × PostPA		-2.730** (1.346)		-8.718*** (2.346)		-67.86*** (13.67)
Constant	69.19*** (0.275)	70.80*** (0.882)	114.3*** (0.538)	119.3*** (1.637)	501.2*** (4.077)	548.6*** (10.43)
Observations	141371	141371	213330	213330	229688	229688
Adjusted R^2	0.390	0.390	0.510	0.506	0.446	0.448

The dependent variable is *Ownership share* by investor type, which is the national ownership share of a stock by the indicated type of investors. *EIR* is carbon emissions divided by revenue. *Log GDP per capita* is the log of GDP per capita in thousands of US dollars of the investor country. *PostPA* is a dummy variable for the years 2015-2021. Firm-year and investor country-year fixed effects are included. *Ownership share* in regressions 1-2 is based on holdings by investors with an average holding period of less than one year. *Ownership share* in regressions 3-4 is based on holdings by investors with an average holding period between 1 and 2 years. *Ownership share* in regressions 5-6 is based on holdings by investors with an average holding period of more than 2 years. Standard errors are clustered at the firm level. Standard errors in parentheses, *: $p < 0.10$, **: $p < 0.05$, ***: $p < 0.01$.

Table 8: Ownership shares of firms in brown and non-brown industries

	(1)	(2)	(3)	(4)
	Ownership share		Ownership share	
	Firms in brown industries		*Firms in non-brown industries*	
EIR × Log GDP per capita	-6.173* (3.303)	-3.940* (2.313)	-20.44 (14.90)	-27.87 (24.46)
EIR × Log GDP per capita × PostPA		-64.68*** (17.06)		10.09 (28.05)
Constant	555.2*** (18.45)	709.1*** (44.93)	517.8*** (6.642)	518.4*** (6.572)
Observations	66802	66802	253279	253279
Adjusted R^2	0.328	0.331	0.503	0.503

The dependent variable is *Ownership share*, which is the national ownership share of a stock. *EIR* is carbon emissions divided by revenue. *Log GDP per capita* is the log of GDP per capita in thousands of US dollars of the investor country. *PostPA* is a dummy variable for the years 2015-2021. Firm-year and investor country-year fixed effects are included. *Ownership share* in regressions 1-2 is the ownership share for firms in brown industries. *Ownership share* in regressions 3-4 is the ownership share for firms in non-brown industries. Standard errors are clustered at the firm level. Standard errors in parentheses, *: $p < 0.10$, **: $p < 0.05$, ***: $p < 0.01$.

Table 9: Ownership share of firms by size and inclusion in the MSCI World index

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Ownership share		Ownership share		Ownership share		Ownership share	
	Firms of size above the median		*Firms of size below the median*		*Firms in MSCI World index*		*Firms not in MSCI World index*	
EIR × Log GDP per capita	-47.38** (21.77)	-27.39* (15.83)	-4.299* (2.422)	-2.513 (1.816)	-6.126*** (0.830)	-6.487*** (0.701)	-7.084* (3.818)	-3.822* (2.234)
EIR × Log GDP per capita × PostPA		-75.61*** (24.20)		-60.34** (25.84)		3.018 (5.185)		-62.68*** (17.63)
Constant	496.5*** (36.85)	526.6*** (21.62)	618.7*** (3.224)	655.1*** (16.67)	380.1*** (0.807)	379.1*** (2.472)	599.0*** (6.922)	650.0*** (16.25)
Observations	164894	164894	155187	155187	112247	112247	207834	207834
Adjusted R^2	0.458	0.459	0.458	0.459	0.723	0.723	0.399	0.400

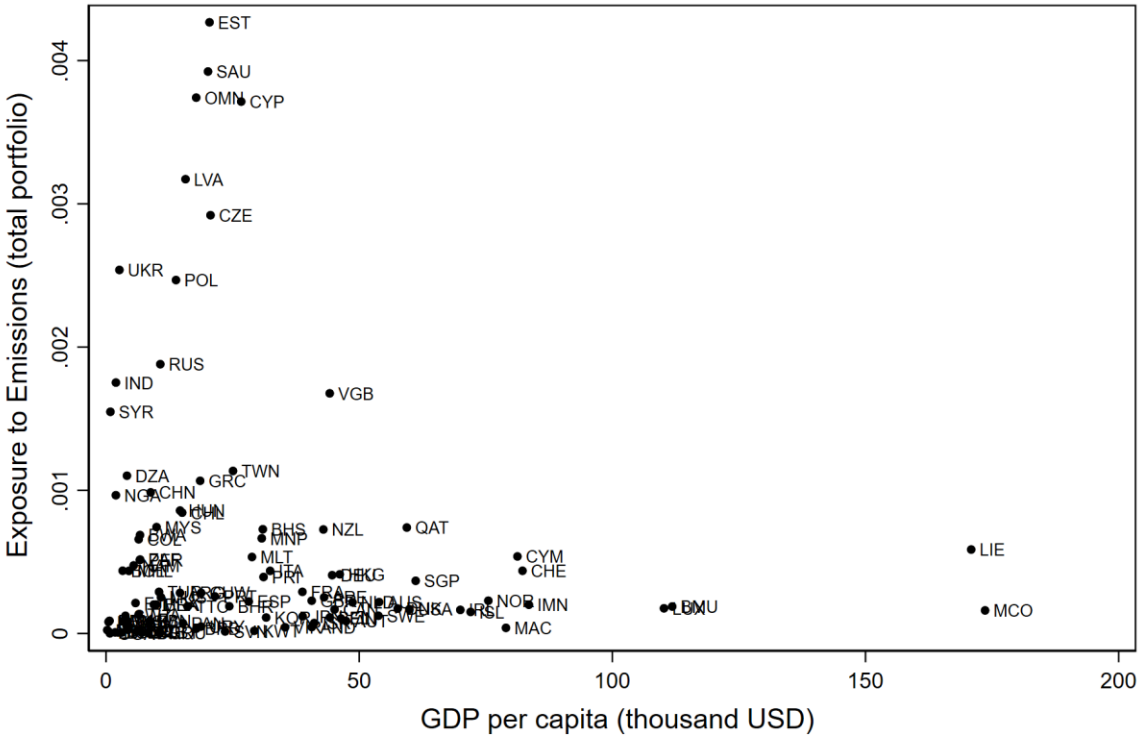
The dependent variable is *Ownership share*, which is the national ownership share of a stock. *EIR* is carbon emissions divided by revenue. *Log GDP per capita* is the log of GDP per capita in thousands of US dollars of the investor country. *PostPA* is a dummy variable for the years 2015-2021. Firm-year and investor country-year fixed effects are included. Regressions 1-2 and 3-4 include observations for firms with log assets above and below the median of 8.67, respectively. Regressions 5-6 and 7-8 include observations for firms that are and are not included in the MSCI Word index, respectively. Standard errors are clustered at the firm level. Standard errors in parentheses, *: $p < 0.10$, **: $p < 0.05$, ***: $p < 0.01$.

Table 10: Ownership share after controlling for other factors

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Ownership share		Ownership share		Ownership share		Ownership share	
EIR × Log GDP per capita	-62.48** (25.50)	-10.70 (12.12)	-10.76** (5.029)	-6.438** (2.912)	-10.36* (5.731)	-5.107 (3.264)	-109.8*** (38.49)	-49.84 (30.51)
EIR × Log GDP per capita × PostPA		-148.5* (78.03)		-150.0*** (36.25)		-83.55*** (17.20)		-369.6*** (100.6)
Constant	1006.3*** (49.18)	1004.5*** (62.71)	519.0*** (7.648)	594.8*** (25.82)	568.5*** (7.623)	620.2*** (11.05)	963.4*** (60.97)	1126.1*** (73.34)
Additional controls	Financial development		Institutional and other country characteristics		Climate risk exposure		All three groups	
Observations	126382	126382	252539	252539	258682	258682	120832	120832
Adjusted R^2	0.549	0.549	0.438	0.441	0.463	0.464	0.517	0.518

The dependent variable is *Ownership share*, which is the national ownership share of a stock. *EIR* is carbon emissions divided by revenue. *Log GDP per capita* is the log of GDP per capita in thousands of US dollars of the investor country. *PostPA* is a dummy variable for the years 2015-2021. Firm-year and investor country-year fixed effects are included. Regressions 1-2 include controls related to financial development, which are total financial assets of, respectively, deposit money banks, pension funds, investment funds, and insurance corporations as a percentage of GDP as well as stock market capitalization to GDP. Regressions 3-4 include institutional and other country characteristics which are indicators of government effectiveness, regulatory quality, rule of law, and voice and accountability, as well as government expenditure on education as a percentage of GDP. Regressions 5-6 include controls related to climate risk, which are heat index 35, heating degree days, and additional population exposed to annual coastal floods due to sea level rise. Regressions 7-8 include all the significant control variables from regression 1-6, consisting of financial assets of, respectively, pension funds and investment funds to GDP, stock market capitalization to GDP, indicators of government effectiveness and rule of law, government expenditure on education to GDP, heating degree days, and additional population exposed to annual coastal floods due to sea level rise. Standard errors are clustered at the firm level. Standard errors in parentheses, *: $p < 0.10$, **: $p < 0.05$, ***: $p < 0.01$.

Figure 1:Full portfolio exposure to emissions relative to revenues and GDP per capita in 2017

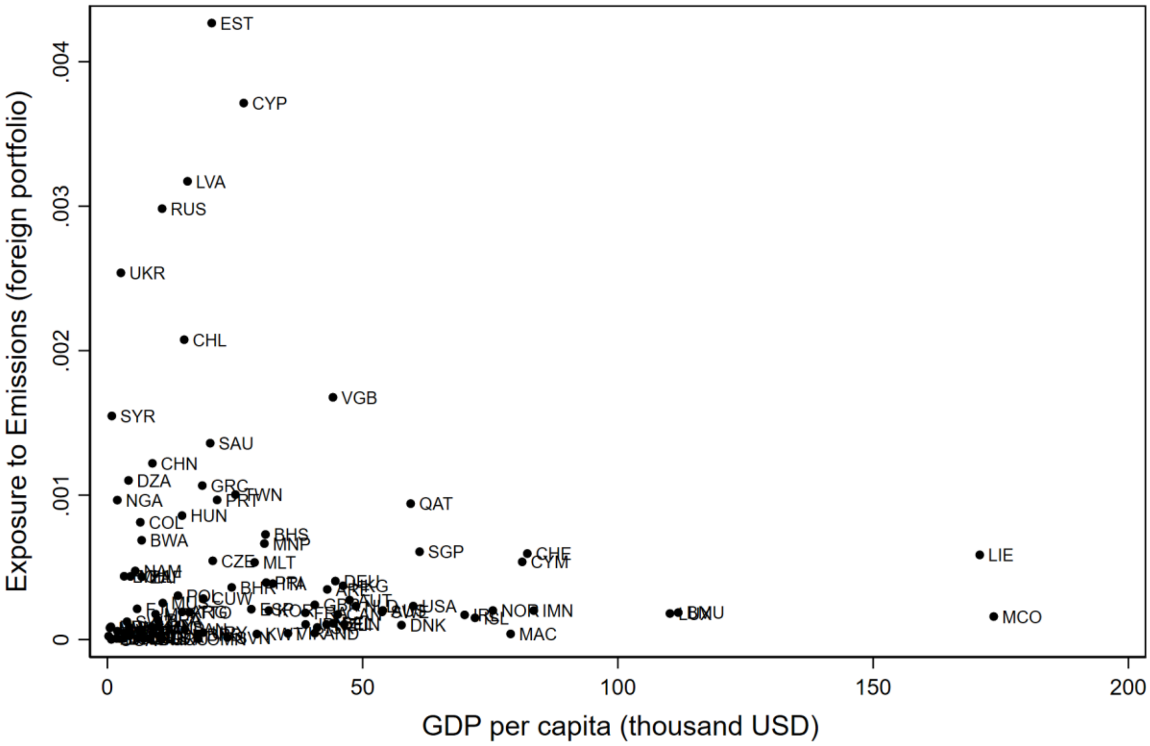


This figure plots the national portfolio exposure to emissions relative to revenues against GDP per capita for countries included in the firm-level sample for the year 2017. This exposure is computed using information for all firms in the firm-level sample as follows,

$$\frac{\sum_{i \in Full\ Portfolio_t} w_{it} \times Emissions_{it}}{\sum_{i \in Full\ Portfolio_t} w_{it} \times Total\ revenue_{it}}$$

where i is a firm index, t is the year 2017, and w_{it} represents the percentage ownership held by a country in firm i at the end of 2017. Emissions are the sum of scope 1 and scope 2 emissions. Emissions data are from CDP and, if not available, they are estimates from Refinitiv Workspace.

Figure 2: Foreign portfolio exposure to emissions relative to revenues and GDP per capita in 2017

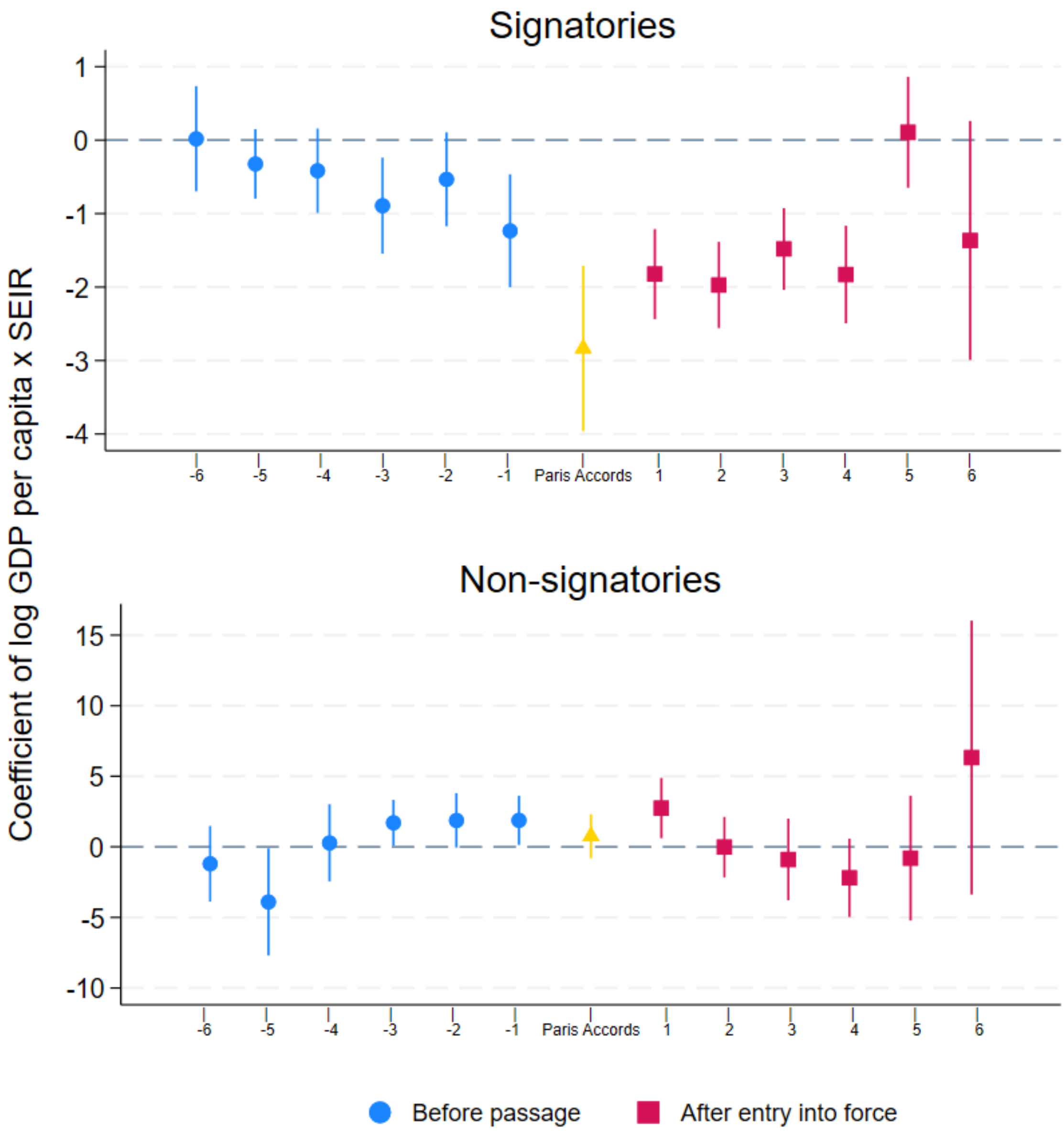


This figure plots the national foreign portfolio exposure to emissions relative to revenues against GDP per capita for countries included in the firm-level sample for the year 2017. This exposure is computed using information for all foreign firms in the firm-level sample as follows,

$$\frac{\sum_{i \in Foreign\ Portfolio_t} w_{it} \times Emissions_{it}}{\sum_{i \in Foreign\ Portfolio_t} w_{it} \times Total\ revenue_{it}}$$

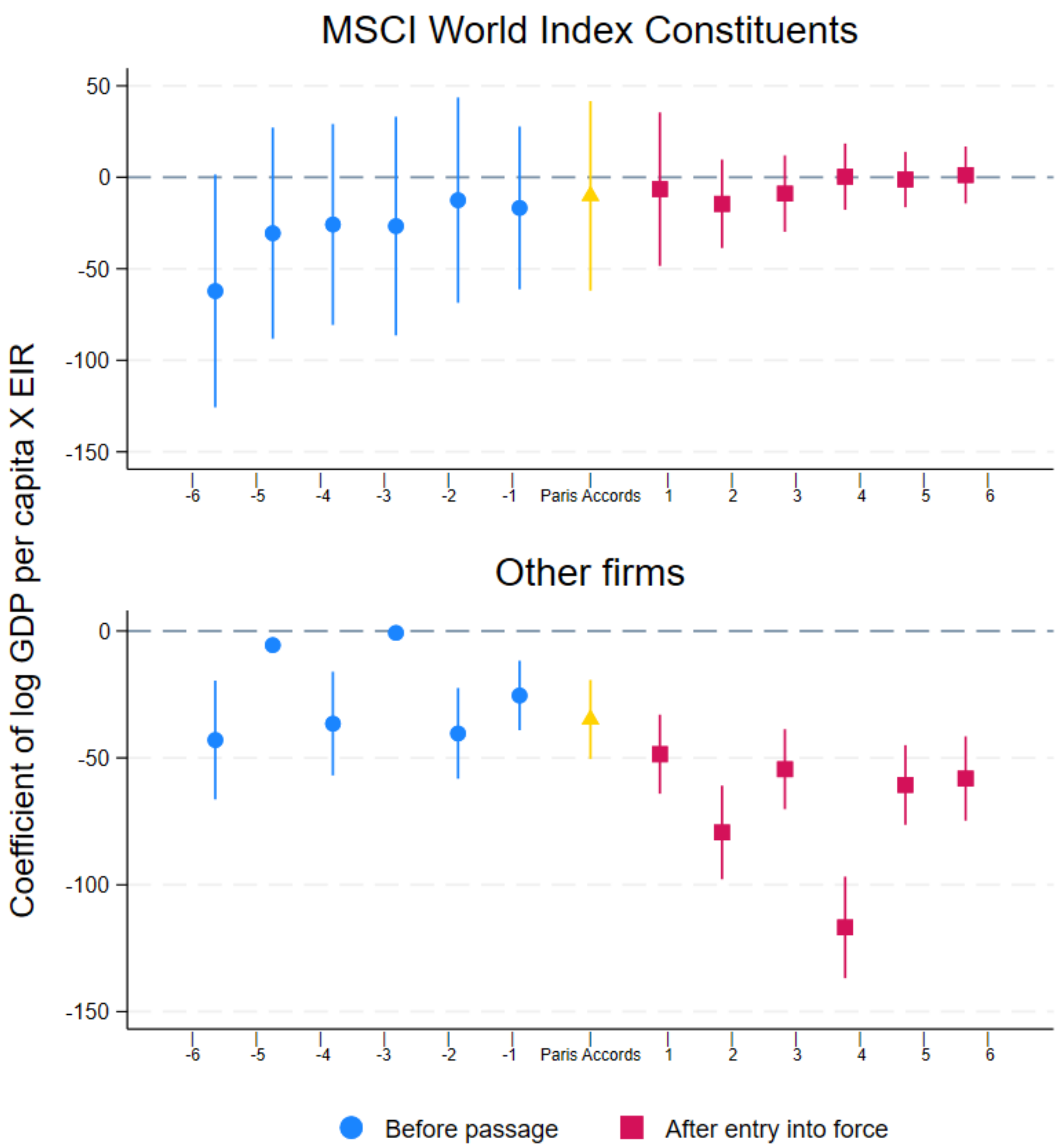
where *i* is a firm index, *t* is the year 2017, and w_{it} represents the percentage ownership held by a country in firm *i* at the end of 2017. Emissions are the sum of scope 1 and scope 2 emissions. Emissions data are from CDP and, if not available, they are estimates from Refinitiv Workspace.

Figure 3: Gravity analysis results for signatory and non-signatory countries by year



This figure plots estimated coefficients and 95% confidence intervals for *SEIR* × *Log GDP per capita* in yearly regressions analogous to specification (3) during 2009-2021, separately for signatory and non-signatory countries as investor countries. The period of 2009-2021 ranges from 6 years before the adoption of the Paris Agreement in 2015 to six years afterwards.

Figure 4: Ownership regressions for MSCI World index constituents and other firms by year



This figure plots estimated coefficients and 95% confidence intervals for *EIR* × *Log GDP per capita* in yearly regressions analogous to specification (1) during 2009-2021, separately for MSCI World index constituents and other firms. The period of 2009-2021 ranges from 6 years before the adoption of the Paris Agreement in 2015 to six years afterwards.

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Appendix: Additional tables and figures

Table A1: Numbers of firms with ownership and emissions data

Year	(1) Number of firms with ownership data available	(2) Number of firms with ownership and emissions information available	(3) Number of firms in the firm-level sample
2002	17682	473	92
2003	19190	653	157
2004	20522	1065	258
2005	22266	1458	372
2006	24704	1696	442
2007	28708	1862	497
2008	30931	2170	617
2009	32854	2489	739
2010	34165	2927	903
2011	35108	3188	1016
2012	36035	3312	1076
2013	36748	3419	1154
2014	37836	3511	1168
2015	38976	3947	1303
2016	39282	4619	1636
2017	40887	5596	2020
2018	42463	6310	2373
2019	43418	7232	2661
2020	44872	8357	2471
2021	48340	9246	2190

Column 1 provides information on the number of firms with ownership data in each year. Column 2 provides information on the number of firms with ownership and emissions information in each year. Column 3 provides information on the number of firms for which we additionally require that the firm has a single class of common stock, that at least 75% of the ownership is known, that there are at least 3 consecutive observations, and that they are not subsidiaries of other firms in the sample. The number of firms in column 3 corresponds to those included in regressions 1-4 of Table 3.

Table A2: Variable definitions and data sources

Variable	Description	Data Source
Ownership share	National ownership shares of a stock, aggregated from the investor-firm-year holding data.	Refinitiv Workspace API.
Holding value	Value of the national ownership share of a stock, aggregated from the investor-firm-year holding data and deflated by GDP.	Holding data: Refinitiv Workspace API. GDP: World Bank, United Nations database, and official reports from the national bureaus of statistics.
Bilateral holding	Value measure of bilateral stock holding in a sector divided by both investor and source country gross domestic products (GDP) in current U.S. dollars.	GDP: World Bank, United Nations database, and official reports from the national bureaus of statistics.
Log GDP per capita	Income per capita (logarithm).	World Bank, United Nations database, and official reports from the national bureaus of statistics.
EIR	Emission intensity on revenue, computed as total GHG emissions divided by revenues.	GHG emissions: CDP and Refinitiv Workspace API. Revenues: Refinitiv Workspace API, Compustat Global, and Compustat North America.
SEIR	Sectoral median of Emission intensity on revenue.	GHG emissions: CDP and Refinitiv Workspace API. Revenues: Refinitiv Workspace API, Compustat Global, and Compustat North America.

(continued)

Variable	Description	Data Source
PostPA	Dummy variable to that equals one from 2015 to distinguish years before and after the Paris Agreement.	
Distance	Distance between investor and host countries in thousands of kilometers (logarithm).	CEPII GeoDist.
Investor type	Investor type by the purpose of their investments. ("Strategic investors" in the paper refer to the type of "strategic entities" in the data.)	Refinitiv Workspace API.
Turnover	The values of all bought or sold for the past 12 months relative to the total value of the portfolio as reported.	Refinitiv Workspace API.
Firm size	Firm assets (logarithm).	Refinitiv Workspace API, Compustat Global, and Compustat North America.
Deposit money banks' assets to GDP (%)	Total assets held by deposit money banks as a share of GDP.	World Bank.
Pension funds' assets to GDP (%)	Ratio of assets of pension funds to GDP.	World Bank.
Investment funds' assets to GDP (%)	Total financial assets of investment funds as a percentage of GDP.	OECD.
Insurance corporations' assets to GDP (%)	Total financial assets of insurance corporations as a percentage of GDP.	OECD.
Stock capitalization to GDP (%)	Ratio of stock market capitalization of domestic listed companies to GDP.	Stock market capitalization of domestic listed companies: World Bank. GDP: World Bank, United Nations database, and official reports from the national bureaus of statistics.
Government effectiveness	One dimension of governance from the Worldwide Governance Indicators. It measures "the quality of public services, civil service, policy formulation and implementation, the credibility of the government's commitment to such policies, and the degree of its independence from political pressures".	World Bank.
Regulatory quality	One dimension of governance from the Worldwide Governance Indicators. It measures "the ability of the government to formulate and implement sound policies and regulations that permit and promote private sector development".	World Bank.
Rule of law	One dimension of governance from the Worldwide Governance Indicators. It measures "the extent to which agents have confidence in and abide by the rules of society, and in particular the quality of contract enforcement, property rights, the police, and the courts, as well as the likelihood of crime and violence".	World Bank.
Voice and accountability	One dimension of governance from the Worldwide Governance Indicators. It measures "the extent to which a country's citizens are able to participate in selecting their government, as well as freedom of expression, freedom of association, and a free media".	World Bank.
Total government education expenditure to GDP (%)	General government expenditure on education as a percentage of GDP.	World Bank.
Heat index 35	Total count of days per year where the daily mean Heat index rose above 35°C. A heat index is a measure of how hot it feels once humidity is factored in with air temperature.	World Bank.
Heating degree days	A measure of how low the temperature is during a year given by the number of days in a year when heating would be needed.	World Bank.
Additional population exposure to floods	Additional population exposed to annual coastal floods due to sea level rise, as a share of actual population. This takes the max exposure projected to 2050.	World Bank.

Table A3: Alternative emissions variables

Panel A: Ownership share

	(1)	(2)	(3)	(4)
	Ownership share		Ownership share	
Emissions variable × Log GDP per capita	-91.91***	-80.92***	-7.212***	-5.561***
	(29.88)	(28.21)	(1.249)	(1.862)
Emissions variable × Log GDP per capita × PostPA		-17.72		-3.194
		(48.87)		(2.413)
Constant	576.2***	575.0***	570.2***	569.7***
	(20.95)	(19.97)	(10.11)	(9.716)
Emissions variable	Emissions divided by assets (ton Co2e per thousand USD)		Total emissions (million-ton Co2e)	
Observations	320066	320066	320081	320081
Adjusted R^2	0.456	0.456	0.456	0.456

The dependent variable is *Ownership share*, which is the national ownership share of a stock. *Log GDP per capita* is the log of GDP per capita in thousands of US dollars of the investor country. *PostPA* is a dummy variable for the years 2015-2021. Firm-year and investor country-year fixed effects are included. In regressions 1 and 2 the emissions variable is emissions divided by assets. In regressions 3 and 4 the emissions variable is total emissions. Standard errors are clustered at the firm level. Standard errors in parentheses, *: $p < 0.10$, **: $p < 0.05$, ***: $p < 0.01$.

Panel B: Gravity analysis results

	(1)	(2)	(3)	(4)
	Bilateral holding		Bilateral holding	
Emissions variable × Log GDP per capita	-0.513	-0.352	-0.0454	-0.0331
	(0.796)	(0.730)	(0.0619)	(0.0543)
Emissions variable × Log GDP per capita × PostPA		-1.531***		-0.349***
		(0.469)		(0.126)
Constant	9.299***	9.357***	9.247***	9.289***
	(0.164)	(0.178)	(0.0736)	(0.0846)
Emissions variable (sectoral median)	Emissions divided by assets (ton Co2e per thousand USD)		Total emissions (million-ton Co2e)	
Observations	1980000	1980000	1980000	1980000
Pseudo R^2	0.960	0.960	0.960	0.960

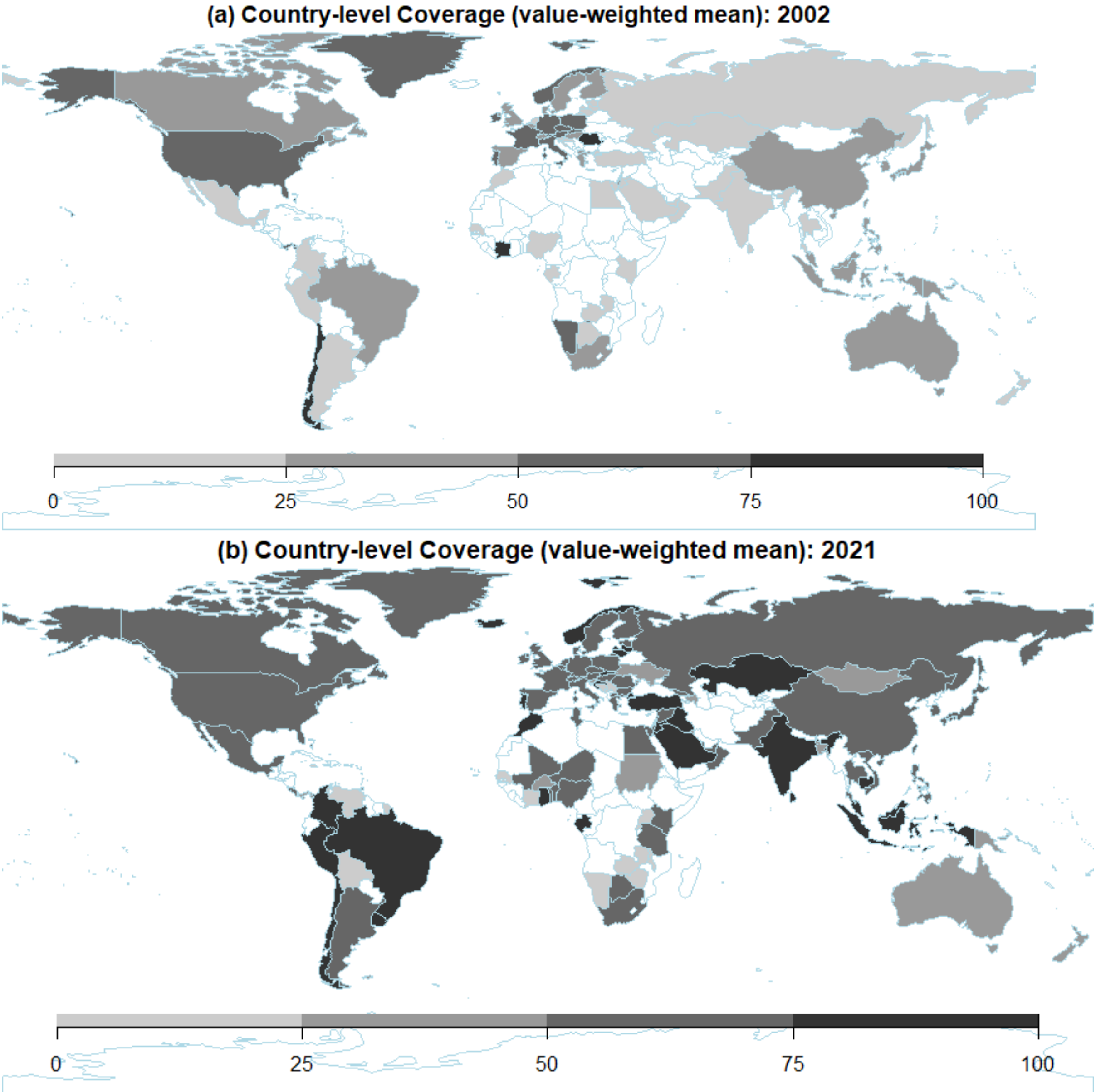
The dependent variable is *Bilateral holding*, which is the value of bilateral stock holding in a sector divided by both investor and source country GDPs. *Log GDP per capita* is the log of GDP per capita in thousands of US dollars of the investor country. *PostPA* is a dummy variable for the years 2015-2021. In regressions 1-2 the emissions variable is the sectoral median of emissions divided by assets. In regressions 3 and 4 the emissions variable is the sectoral median of total emissions. Country-pair, investor country-year, and source country-sector-year fixed are included. Standard errors are clustered at the levels of the investor country, the host country, the year, every double interaction, and a triple interaction. Standard errors in parentheses, *: $p < 0.10$, **: $p < 0.05$, ***: $p < 0.01$.

Table A4: Ownership share with zero values included

	(1)	(2)	(3)	(4)	(5)
	Ownership share		Ownership share		
	All countries		All countries	Signatory	Non-Signatory
EIR × Log GDP per capita	-0.0651***	-0.0369	-0.0836***	-0.0983***	0.0727
	(0.0173)	(0.0243)	(0.0190)	(0.0234)	(0.0828)
EIR × Log GDP per capita × PostPA		-0.0468			
		(0.0289)			
Constant	7.830***	7.830***	7.833***	7.873***	7.834***
	(0.0247)	(0.0227)	(0.0272)	(0.0320)	(0.511)
Observations	342113	342113	185768	177401	8367
Pseudo R^2	0.638	0.639	0.613	0.618	0.937

The dependent variable is *Ownership share*, which is the unwinsorized national ownership share of a stock. *EIR* is carbon emissions divided by revenue. *Log GDP per capita* is the log of GDP per capita in thousands of US dollars of the investor country. *PostPA* is a dummy variable for the years 2015-2021. Firm-year and investor country-year fixed effects are included. Regressions 3-5 include observations for the period 2015-2021. Zero values of a particular country's ownership share in a firm are included if there are positive values for the ownership share in at least one year between 2002 and 2021. Estimation is by PPML. Standard errors are clustered at the firm level. Standard errors in parentheses, *: $p < 0.10$, **: $p < 0.05$, ***: $p < 0.01$.

Figure A1: Average in-sample coverage of ownership data in 2002 and 2021

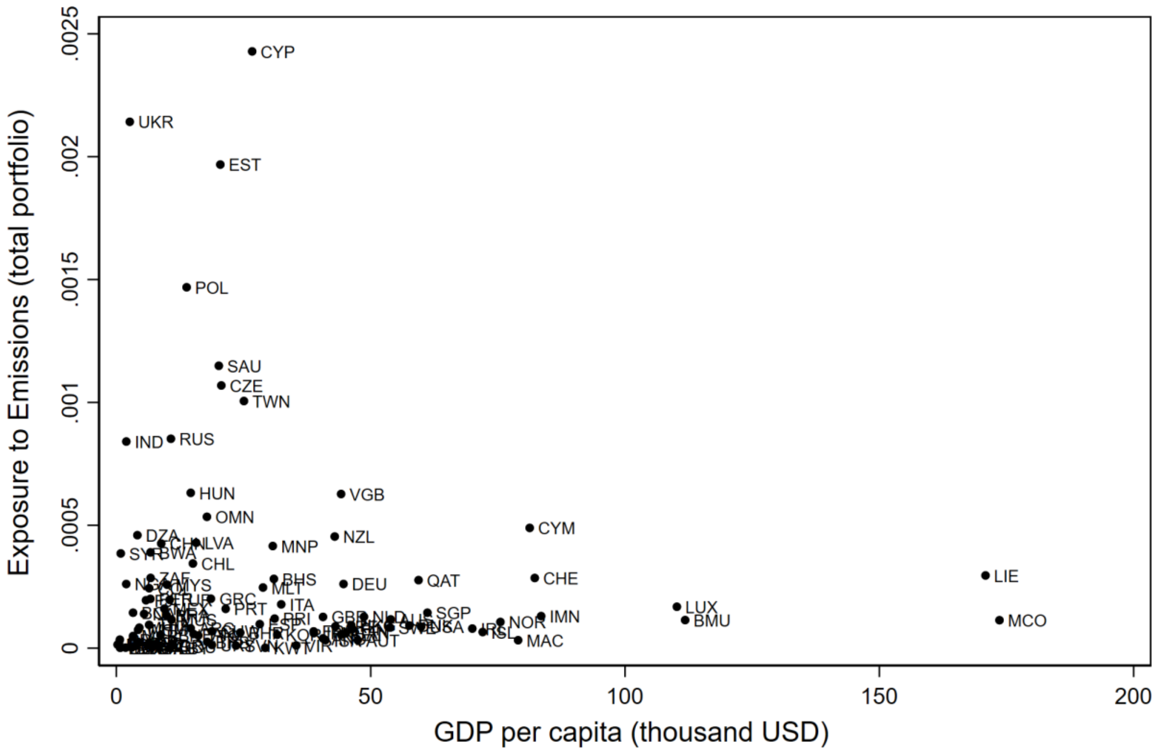


This figure presents a comparison of the ownership coverage by the data provider of firms at the country-year level for the years 2002 and 2021 based on all available ownership information for all public firms within the database. Ownership coverage in the figure is computed as the percentage coverage of individual public firms with any ownership information within each country-year, weighted by firm-level market capitalization as follow,

$$Ownership\ coverage\ for\ country\ c\ in\ year\ t = \sum_{i \in firm\ set^{ct}} Ownership\ coverage_{it} \times \frac{Market\ cap_{it}}{\sum_{i \in firm\ set^{ct}} Market\ cap_{it}},$$

where *i* is a firm index. Firms with more than 100% reported coverage are excluded from this calculation.

Figure A2: Full portfolio exposure to emissions relative to assets and GDP per capita in 2017

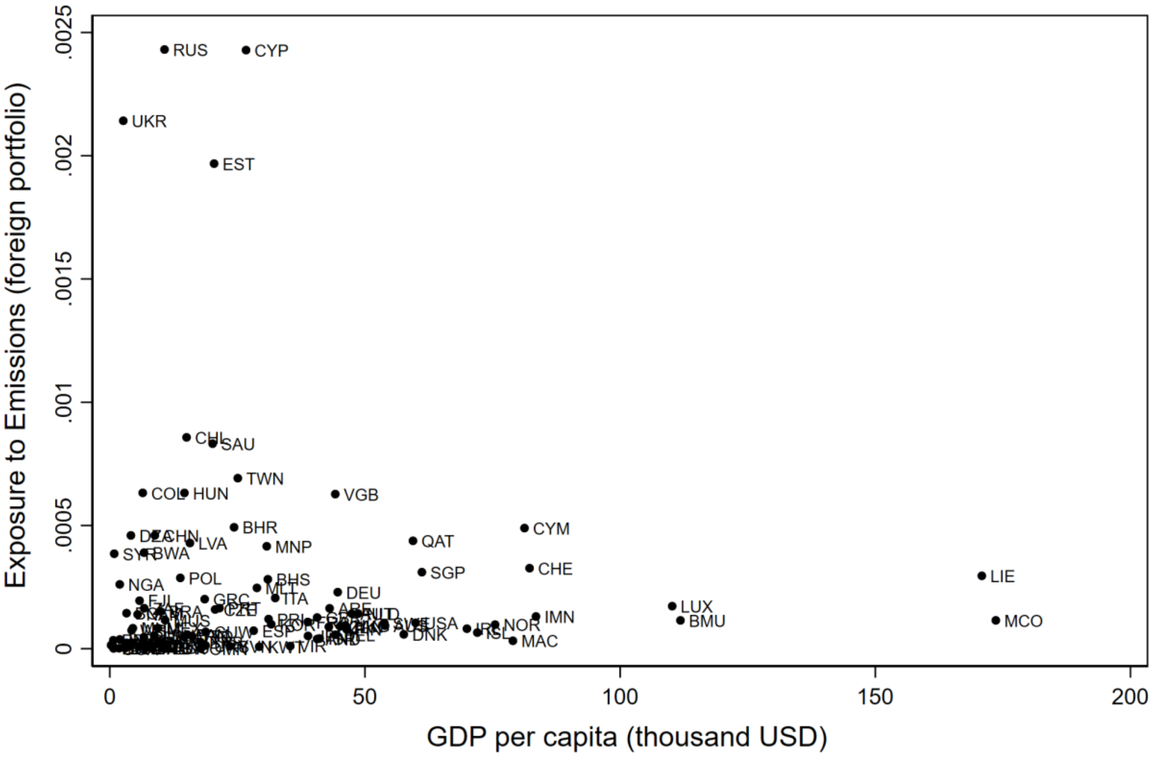


This figure plots the national portfolio exposure to emissions relative to total assets against GDP per capita for countries included in the firm-level sample for the year 2017. This exposure is computed using information for all firms in the firm-level sample as follows,

$$\frac{\sum_{i \in Full\ Portfolio_t} w_{it} \times Emissions_{it}}{\sum_{i \in Full\ Portfolio_t} w_{it} \times Assets_{it}}$$

where *i* is a firm index, *t* is the year 2017, and w_{it} represents the percentage ownership held by a country in firm *i* at the end of 2017. Emissions are the sum of scope 1 and scope 2 emissions. Emissions data are from CDP and, if not available, they are estimates from Refinitiv Workspace.

Figure A3: Foreign portfolio exposure to emissions relative to assets and GDP per capita in 2017

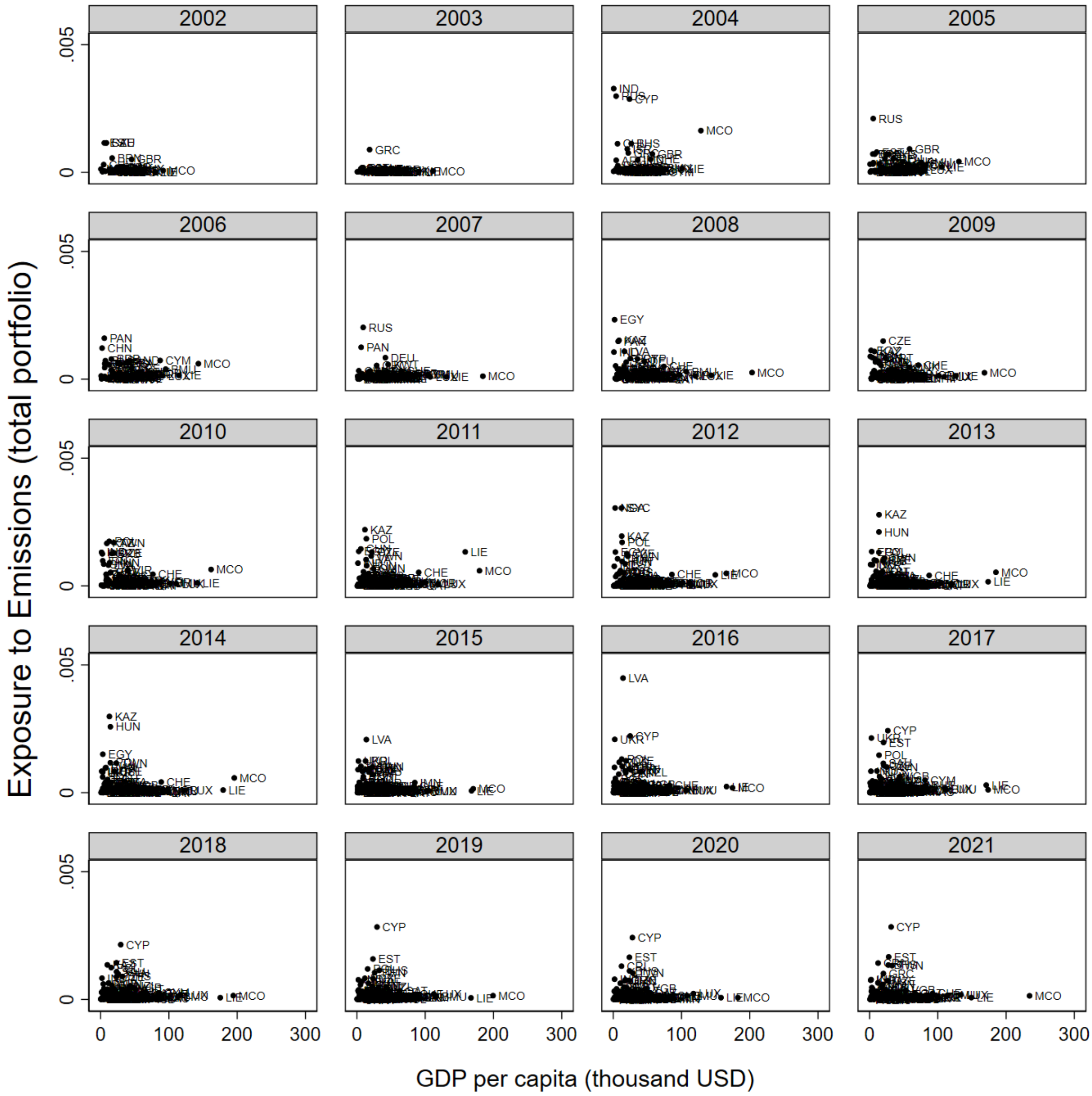


This figure plots the national foreign portfolio exposure to emissions relative to total assets against GDP per capita for countries included in the firm-level sample for the year 2017. This exposure is computed using information for all foreign firms in the firm-level sample as follows,

$$\frac{\sum_{i \in Foreign\ Portfolio_t} w_{it} \times Emissions_{it}}{\sum_{i \in Foreign\ Portfolio_t} w_{it} \times Assets_{it}}$$

where i is a firm index, t is the year 2017, and w_{it} represents the percentage ownership held by a country in firm i at the end of 2017. Emissions are the sum of scope 1 and scope 2 emissions. Emissions data are from CDP and, if not available, they are estimates from Refinitiv Workspace.

Figure A4: Full portfolio emissions relative to asserts and GDP per capita, 2002-2021

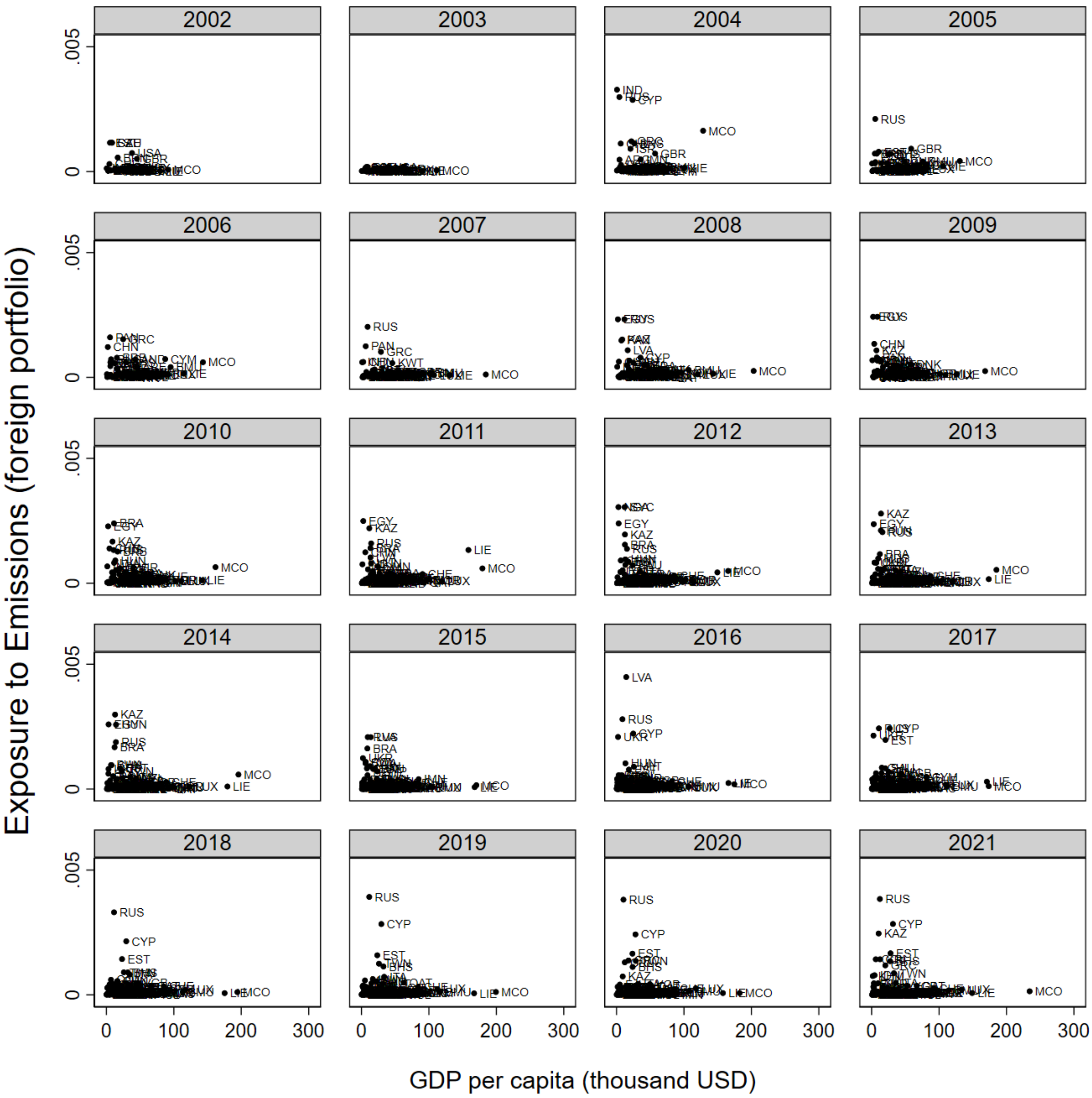


This figure plots the national portfolio exposure to emissions relative to revenues against GDP per capita for countries included in the firm-level sample for each year during 2002-2021. This exposure is computed using information for all firms in the firm-level sample as follows,

$$\frac{\sum_{i \in Full\ Portfolio_t} w_{it} \times Emissions_{it}}{\sum_{i \in Full\ Portfolio_t} w_{it} \times Total\ revenue_{it}}$$

where i is a firm index, t is the year index, and w_{it} represents the percentage ownership held by a country in firm i at the end of the year. Emissions are the sum of scope 1 and scope 2 emissions. Emissions data are from CDP and, if not available, they are estimates from Refinitiv Workspace.

Figure A5: Foreign portfolio exposure to emissions relative to assets and GDP per capita, 2002-2021



This figure plots the national foreign portfolio exposure to emissions relative to revenues against GDP per capita for countries included in the firm-level sample for each year during 2002-2021. This exposure is computed using information for all foreign firms in the firm-level sample as follows,

$$\frac{\sum_{i \in Foreign\ Portfolio_t} w_{it} \times Emissions_{it}}{\sum_{i \in Foreign\ Portfolio_t} w_{it} \times Assets_{it}}$$

where i is a firm index, t is the year index, and w_{it} represents the percentage ownership held by a country in firm i at the end of the year. Emissions are the sum of scope 1 and scope 2 emissions. Emissions data are from CDP and, if not available, they are estimates from Refinitiv Workspace.

Online appendix

1. Determination of Market value
2. Determination of brown and non-brown sectors (including TRBC industry codebook)
3. List of countries (including list of OFCs)