Carbon Leakage to Developing Countries*

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Abstract

How do climate policies in developed countries spill over to the developing world? Using a novel dataset that combines multinational firms' subsidiary locations with spatial emission data, we study how the carbon footprint of multinational firms in Africa changes in response to more stringent climate policies in Europe. Exploiting variation in multinationals' exposure to carbon prices across European countries, we find that emissions of their African subsidiaries increase as the multinationals' European operations face higher carbon prices. At the same time, multinationals facing higher carbon prices scale back their total activities and particularly reduce their domestic investment in tangible assets in Europe – consistent with these firms shifting some of their operations abroad. For local economies in Africa, we find evidence consistent with this reallocation of activities and emissions leading to higher formal employment without causing adverse health outcomes in the short term. We confirm these results at the aggregate level with a significant increase in emissions in Africa. Policies to mitigate leakage should thus balance environmental concerns against development and equity considerations.

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1 Introduction

The looming climate crisis is at the top of the global policy agenda. Governments around the world have started to implement carbon taxes, emissions trading schemes, and other regulatory measures to reduce carbon emissions. While there is mixed early evidence on the domestic effects of such policies, an important but underexplored question concerns the global spillover effects. A particular concern is carbon leakage, broadly defined as the shift of greenhouse gas emissions to countries with less stringent regulation. Developing countries are attractive destinations for carbon leakage because they tend to have more lenient environmental standards. This dynamic not only challenges the global effort to reduce carbon emissions but also places an undue environmental burden on developing nations. On the other hand, measures to prevent leakage may put poorer countries – which have historically contributed little to climate change and are in need of further development – at an economic disadvantage.

In this paper, we study how climate policies in developed countries spill over to the developing world through carbon leakage. We focus on ownership networks within multinational firms, which are a natural starting point to detect leakage. By studying the response of economic activity and emissions at subsidiaries abroad, we are able to directly detect carbon leakage. However, emissions data at the subsidiary level is largely unavailable, particularly in developing countries. We overcome this challenge by exploiting spatial emissions data around subsidiary locations from the Emission Database for Global Atmospheric Research (EDGAR). Based on a large hand collection effort, we construct a new dataset containing information on subsidiary locations of multinational firms. Using the spatial emissions data, we can then proxy how emissions have evolved at these locations over time.

Our analysis specifically targets multinational firms with European operations due to Europe's leading role in the climate policy sphere. Europe's advanced regulatory framework for reducing greenhouse gas emissions makes multinational firms with operations in European countries prime candidates for exploring carbon leakage. We focus on industries particularly prone to leakage such as manufacturing, mining and oil. As the cost of emitting carbon in these industries increases in Europe, firms have an incentive to shift their operations abroad. We focus on Africa as the destination for such leakage because of two main reasons: first, many African nations have relatively lax environmental standards, making them susceptible to becoming havens for displaced carbon-intensive activities. Second, due to geographical

proximity and existing economic ties, Africa is a particularly relevant destination for European businesses looking to relocate operations.

We construct a unique dataset that combines financial information on multinational firms with exposure to European carbon policies, ownership links in Europe and Africa, information on subsidiary locations, and spatial emissions data. Our dataset construction starts with more than 1,500 large multinational firms with almost 16,000 unique African subsidiaries and spans the period from 2010 to 2020. Consider two illustrative examples. For the U.S. conglomerate firm General Electric, our final dataset includes 16 African subsidiaries in 7 different African countries; for the German cement manufacturer HeidelbergCement AG, our dataset features 11 African subsidiaries in 8 different African countries. Our final dataset, which requires non-missing information on firms' exposure to European carbon policies with location and grid-cell-level emissions data for African subsidiaries, comprises nearly 800 unique multinational firms and approximately 4,700 African subsidiaries owned by these firms.

Our empirical approach leverages variation in climate policies across European countries. To motivate our setting, we start with a simple difference-in-differences design that exploits the fact that, in 2014, France introduced a carbon tax while Germany did not. Specifically, we compare African subsidiaries owned by French multinationals to subsidiaries of German multinationals. We find that local carbon emissions around African subsidiaries of French multinationals increase by approximately 4 percent more than emissions around German-owned subsidiaries after the introduction of the French carbon tax, with effect sizes increasing gradually over time.

To more comprehensively study carbon leakage, we exploit variation in the climate policy stance across European countries. There are two main climate policy pillars in Europe. First, there is the European Union Emissions Trading Scheme (EU ETS), which is one of the largest carbon markets in the world covering around 40 percent of EU greenhouse gas emissions. While the nominal price is determined at the EU level, there is variation in the effective, coverage-weighted price. The coverage of the EU ETS varies across countries mainly because of differences in industrial structure and composition, as well as additional national policies and exceptions. Second, many European countries – France only being one example – have complemented the ETS carbon market with national carbon taxes. These taxes mainly cover sectors and smaller installations that are not part of the EU ETS. To proxy the climate policy stance in a given country, we construct an effective carbon price measure which includes

coverage-weighted ETS prices and carbon tax rates.

To identify causal carbon leakage effects, we employ an exposure design akin to a reduced-form shift-share analysis. We measure multinational firms' exposure to European carbon prices via the firms' share of their subsidiary-level assets located in a given European country in three years prior to our sample, 2007-2009. We then interact these exposure shares with the annual effective carbon price in the country throughout our sample from 2010-2020. Consequently, our resulting carbon policy exposure measure reflects the extent to which a multinational firm faces higher carbon prices due to regulation across countries in Europe. We validate this interpretation by showing that our measure is associated with a greater extent and likelihood of firms' public disclosures of financial risks due to carbon taxes or ETS.

Our estimates point to significant carbon leakage effects. Increasing the exposure of firms to European carbon prices by one standard deviation increases emissions at the local grid-cell in which firms' African subsidiaries are located by more than ten percent. Based on a (long) differences design, we document increasing effect sizes over time. For a one-standard-deviation change in exposure to carbon prices over four years, local emissions in African grid-cells increase by almost 13 percent. The results are robust along several dimensions, including flexibly accounting for potential time-varying confounders using different sets of fixed effects, using alternative definitions of our exposure measure and subsamples, and using subsidiaries instead of grid cells as the unit of observation, which also allows us to control for parent firm-level characteristics and to vary the grid size around the subsidiaries in Africa. We also document that the carbon leakage effects are more pronounced in the least developed African countries and particularly in those with less stringent environmental policies. This finding indicates that multinational firms avoid higher policy-induced carbon prices to a significant extent by exporting emissions to the least regulated jurisdictions in the developing world.

Having established this new evidence on within-firm carbon leakage from Europe to Africa, we aim to shed light on the mechanism to support our inferences. Using multinational firm and subsidiary-level financial statement data, we document evidence consistent with multinationals lowering their fixed tangible capital investment at the consolidated, firm-wide level, and particularly in their European home countries in response to higher carbon prices. We find little evidence for the reallocation of economic activity within Europe to countries with lower carbon prices. This may reflect the fact that multinationals expect carbon prices in Europe to become more harmonized in the foreseeable future. At the firm-wide consolidated level, we

find that the effects of carbon policy exposure on total investment or employment are smaller and statistically less significant than at the European subsidiary level, pointing to a potential increase in investment outside of Europe.[1] Overall, these results are consistent with multinationals shifting some of their European operations abroad after an increase in their carbon policy exposure – providing further indirect evidence on carbon leakage effects.

Building on our evidence of carbon leakage and within-firm mechanisms, we also aim to inform the debate on the trade-off between environmental and development objectives. Specifically, we examine how carbon leakage from Europe affects local communities in Africa. On one hand, leakage undermines the policy goal of reducing global emissions and may lead to elevated local pollution levels, reducing quality of life. On the other hand, if leakage involves the reallocation of corporate activity, it may spur local economic growth, raise income levels, and ultimately improve living standards. To address this question, we link georeferenced survey data from the Demographic and Health Survey (DHS) to our grid-cell-level exposure to European carbon prices based on the multinational firms' subsidiaries in 34 African countries. Based on a similar empirical design to our main analysis, we find that greater grid-cell-level exposure is associated with modest increases in local employment, suggesting that carbon leakage may spur local economic activity. However, we detect no statistically significant effects on health outcomes, possibly due to the relatively low baseline emission levels and the offsetting effects of income gains. These findings highlight the tradeoffs between local development and environmental quality in the context of global carbon pricing.

Studying carbon leakage at the firm and firm-subsidiary levels allows us to credibly identify potential leakage effects. However, evidence from within multinational firms does not clearly establish the economic relevance of carbon leakage from a policy or macroeconomic perspective, given potential crowding-out and other general equilibrium effects in domestic markets. Further, leakage also occurs outside firm boundaries and not only to Africa. To address these issues, we corroborate our firm-level evidence using aggregate data. This exercise also helps assess the macroeconomic relevance of the phenomenon beyond the local boundaries around multinational firms' operations in developing countries. We exploit the differential exposure of developing countries to European carbon policies depending on their bilateral trade linkages in a panel of 125 low- and middle-income countries. Using this country-level

[1] Unfortunately, it is not possible to consistently use financial statement data to measure investment at the subsidiary level outside of Europe given the lack of financial reporting mandates.

shift-share design, we document a significant increase in aggregate emissions across African countries, particularly in low-income countries more exposed to European climate policy. A one-standard-deviation increase in exposure is associated with a 3–4 percent rise in national emissions in these countries. We also find consistent results using an alternative exposure measure based on the share of European subsidiaries operating in a given African country. Interestingly, we find similarly sized leakage effects when also examining low-income developing countries beyond of Africa, while we fail to document such effects for middle-income countries. Taken together, these findings suggest that multinational firm activity is a significant driver of aggregate carbon leakage.

Our results are highly policy relevant in light of recent policy initiatives that aim to prevent regulatory arbitrage and carbon leakage such as the EU's Carbon Border Adjustment Mechanism (CBAM), which will take effect from 2026. In summary, our findings highlight the importance of addressing carbon leakage from developed countries to the developing world. However, any potential measures to prevent leakage should also take equity and development considerations into account. Our findings indicate that carbon leakage also comes with a reallocation of economic activity to developing countries, which induces growth and potentially reduces economic inequality.

Related Literature and Contribution. The empirical literature on the economic effects of climate policy is still emerging. A number of studies analyze the effects on domestic emissions and economic activity at the macro level (see, e.g., Metcalf, 2019; Andersson, 2019; Metcalf and Stock, 2023; Känzig, 2022; Känzig and Konradt, 2023). However, identifying the macroeconomic effects of climate policies is challenging and does not directly speak to the mechanisms behind the aggregate effects. A burgeoning literature thus studies the local effects at the firm or installation level (Commins et al., 2011; Fowlie et al., 2012; Martin et al., 2016; Marin et al., 2018; Dechezleprêtre et al., 2019; Cui et al., 2021; Colmer et al., 2023; Brown et al., 2022; Erbertseder et al., 2023; Martinsson et al., 2024; Jacob and Zerwer, 2024, among others). This literature documents (modest) reductions in domestic or local emissions in response to the introduction of climate policies in the same jurisdiction. The effects on economic activity are more mixed; some studies find adverse economic effects on investment, some find positive effects on research and development expenditures, while others do not find a significant economic impact.

One potential reason for the muted economic impacts is carbon leakage. If firms can source

carbon-intensive inputs from abroad, they can avoid higher domestic carbon prices. However, the empirical evidence on the potential threat of carbon leakage is still sparse despite the potentially large impact on climate damages (Martin, De Preux and Wagner, 2014; Martin, Muûls, De Preux and Wagner, 2014; Greenstone et al., 2023). This is partly because, as Fowlie and Reguant (2018) argue, measuring carbon leakage is challenging. One strand of the literature proxies leakage by studying the carbon embodied in trade flows (Aichele and Felbermayr, 2012, 2015; Sato and Dechezleprêtre, 2015; Naegele and Zaklan, 2019; Teusch et al., 2024, among others). This has the advantage of measuring leakage at the macro level; however, imputing the carbon content of trade flows is complicated and relies on possibly stringent assumptions. Another strand has used survey data on multinational firms' carbon emissions by geographic region from the Carbon Disclosure Project (Ben-David et al., 2021; Dechezleprêtre et al., 2022). Zooming in on the micro level allows for more direct measures of leakage. A limitation, however, is that the survey data typically only covers a subset of large public firms and does not provide country-specific emissions by firm. Furthermore, the survey data could be subject to underreporting concerns, selection bias and measurement error.

There are a few other recent studies that study potential leakage effects within firm's operational networks.[2] Colmer et al. (2023) study the response of French manufacturing firms to carbon pricing during the early phase of the EU Emissions Trading System (ETS) over the period 1995–2012, and do not find robust evidence of carbon leakage. This absence of documented leakage may be explained by the generous allocation of free allowances during the early phase of the EU ETS, which was intended to mitigate the risk of leakage (Martin, Muûls, De Preux and Wagner, 2014), as well as relatively low ETS prices in general. However, more recent evidence based on satellite-derived proxies for emissions at ETS-regulated facilities does find suggestive evidence of leakage from the EU ETS (Kundu and Ruenzi, 2024). Cui et al. (2022) look into potential carbon leakage during the pilots of China's regional emission trading scheme. They find that carbon emissions of non-ETS firms in the same ownership network increase significantly compared to sibling firms covered by the ETS. Chen et al. (2023) study a prominent energy regulation affecting large Chinese manufacturers that are part of broader conglomerates. They show that regulated firms cut output and shift some production to unregulated firms in the same conglomerate instead of improving their energy efficiency. These

[2] Another potential channel contributing to carbon leakage at the macro level is the reallocation of activity and emission across firms, as evidenced by firms' divestitures of brown assets in response to carbon disclosure mandates (Ecker and Keeve, 2023).

studies leverage detailed administrative data on emissions within ownership networks and make significant progress on our understanding of leakage effects.

We contribute to this literature by focusing on the comprehensive set of climate policies in Europe and studying a global sample of firms with carbon-intensive operations. We develop a new approach to directly measure leakage effects in countries where high-quality administrative data are not available. Our novel dataset is available for a representative sample of multinational firms and allows us to isolate leakage at a very granular level. While our focus is on leakage to Africa, it is straightforward to extend our approach to study leakage to other parts of the world. By providing new evidence on carbon leakage from developed to developing countries, we also relate to a burgeoning development economics literature studying the consequences of global policies, technology, and regulation for developing and African economies in particular (e.g., Hjort and Poulsen, 2019; Rauter, 2020; Hoopes, Klein, Lester and Olbert, 2023; Christensen, Maffett and Rauter, 2024; Chang, Christensen and McKinley, 2024).

Outline. The paper proceeds as follows. Section 2 provides information on the policy setting and the relevant identifying variation. In Section 3, we provide more detail on our data set of multinational firms and their subsidiaries and introduce our novel approach to measure emissions at subsidiaries in developing countries. Section 4 discusses our micro evidence on leakage within multinational firms' ownership networks. Section 5 presents the macro evidence. Section 6 concludes.

2 Policy Setting and Identifying Variation

The European Union (EU) is widely recognized as a global leader in climate policy due to its comprehensive and ambitious strategies to combat climate change. The cornerstone of the EU's climate policy is the European Union Emission Trading System (EU ETS). It is the world's first major carbon market and continues to be one of the largest markets globally. Established in 2005, it covers more than 11,000 heavy energy-using installations, accounting for around 40 percent of the EU's greenhouse gas emissions.

Many European countries have also enacted national carbon taxes to strengthen their climate policy stance and complement the carbon market. These taxes sometimes overlap with the EU ETS, for instance, the carbon price floor in the United Kingdom covers the exact same

installations. However, in general, they cover installations that are not part of the ETS, either because the installation is below the size threshold, qualifies for an exemption, or operates in sectors or industries not covered by the ETS directive.

Table 1 presents the level and coverage of carbon pricing policies across European countries as of 2019. We show the carbon tax rate, expressed in euros per ton of CO2 equivalent (tCO2e), and the corresponding share of emissions covered by the tax for all European countries that have enacted such taxes in addition to the ETS. We can see that about half of the countries in our sample have introduced national carbon taxes. However, there are stark differences across these countries, both in terms of tax rates and coverage. Carbon taxes tend to be the highest in Scandinavian countries, with tax rates in excess of 50 euros per tCO2e in 2019. For most other countries, the rates are more moderate. The United Kingdom and France, the two largest economies which adopted a carbon tax, are in this group, with tax rates of 20 and 44 euros, respectively. Finally, some countries have enacted carbon taxes with very little bite, in particular Poland or Estonia where the rate is close to zero.

We also show ETS prices. While the ETS price is uniform and was around 24.5 euros per tCO2e in 2019, the coverage of the carbon market varies substantially across European countries. In Norway, for instance, about 50 percent of all the greenhouse gas emissions are covered by the market, while in France only about 21 percent of emissions are included.[3] This heterogeneity mainly emerges because of differences in sectoral structure and industrial composition. The ETS only covers heavy-emitting industries such as power generation, steel, cement and chemicals. Furthermore, only relatively large installations are required to participate. Thus countries with fewer heavy-emitting industries and fewer large installations will generally have a lower coverage rate. The EU ETS directive also allows for certain exemptions that member states can apply to specific sectors and installations. The use of these provisions can vary significantly from country to country, further affecting the overall coverage rate. As a result, the effective, coverage-weighted ETS price varies quite a bit across ETS countries.

Based on the carbon tax and ETS price information, we construct an overall, effective carbon price as the coverage-weighted sum of the two prices. This will be our relevant policy variable, which provides a comprehensive measure of the climate policy stance in European countries.[4] From the last column in Table 1, we can see that there is substantial variation in

[3]Note that for Norway, the overall coverage by carbon taxes and the EU ETS exceeds 100 percent. This is because some of the emissions are covered by both policies.

[4]In supplementary tests reported in the Appendix, we also show results when only using carbon taxes or ETS

Table 1: CARBON PRICES IN EUROPE AS OF 2019

Country	Carbon tax rate	Tax coverage	ETS price	ETS coverage	Effective carbon price
Austria			24.45	40%	9.87
Belgium			24.45	37%	9.23
Bulgaria			24.45	51%	12.29
Croatia			24.45	31%	7.75
Cyprus			24.45	45%	11.20
Czechia			24.45	50%	12.11
Denmark	23.33	40%	24.45	26%	15.90
Estonia	1.94	3%	24.45	57%	13.82
Finland	61.09	36%	24.45	43%	32.77
France	44.04	35%	24.45	21%	20.73
Germany			24.45	44%	10.81
Greece			24.45	46%	11.54
Hungary			24.45	33%	7.97
Iceland	29.45	29%	24.45	42%	18.61
Ireland	19.19	49%	24.45	42%	19.59
Italy			24.45	33%	8.18
Latvia	4.39	15%	24.45	25%	6.72
Lithuania			24.45	29%	7.11
Luxembourg			24.45	14%	3.47
Malta			24.45	41%	10.19
Netherlands			24.45	44%	10.86
Norway	53.35	62%	24.45	50%	45.65
Poland	0.07	4%	24.45	46%	11.31
Portugal	12.52	29%	24.45	34%	11.95
Romania			24.45	32%	7.61
Slovakia			24.45	49%	12.02
Slovenia	16.93	24%	24.45	36%	13.01
Spain	14.81	3%	24.45	34%	8.89
Sweden	112.09	40%	24.45	40%	54.54
United Kingdom	19.93	23%	24.45	26%	11.09

Notes: This table contains information on carbon taxes and ETS prices in Europe. All values are as of 2019. We show the carbon tax rate (in tCO2e) for the countries that have enacted such a tax, the share of emissions covered by the tax, the EU ETS price (in tCO2e), the country-specific ETS coverage and the coverage-weighted, overall effective carbon price. The data on carbon taxes are from Metcalf and Stock (2023). The ETS data are from euets.info, which sources information from the European Union Transaction Log.

effective carbon prices across European countries as of 2019. Effective carbon prices tend to be relatively low in Eastern European countries such as Romania or Hungary, with prices of about 7 euros per tCO2e. In countries without a carbon tax but a greater ETS coverage, like Germany as a major economy, the carbon price is approximately 11 euros per tCO2e. Effective carbon prices tend to be the highest in Scandinavian countries due to the higher carbon tax rates in these countries. For instance, the price in Sweden is about 55 euros and the price in Norway is close to 46 euros per tCO2e. Figures A-1 to A-3 in the Appendix illustrate the variation in European carbon prices over time during our sample period. We can see that the level differences across countries tend to persist and that there is substantial time-series variation in

prices separately as the policy variable.

country-specific carbon prices.

European carbon prices have been found to significantly reduce emissions in the policy-enacting countries, whereas the evidence on the economic impacts and mechanisms behind reduced domestic emissions is less clear (see, e.g., Martin et al., 2016). A potential explanation for these findings is that firms shift some of their emission-intensive operations abroad where climate regulation is less stringent. Policymakers are concerned about such potential carbon leakage, and anecdotal survey evidence suggests that managers consider reallocating activities geographically to avoid environmental taxes (see Figure A-4 in the Appendix for some suggestive evidence). Developing countries in particular are attractive destinations for firms to reallocate their emissions, as these countries generally have less stringent environmental policies in place and are not expected to tighten their regulatory stance in the foreseeable future. Does this intuition hold up in the data? There are several complications that arise when trying to answer this question empirically.

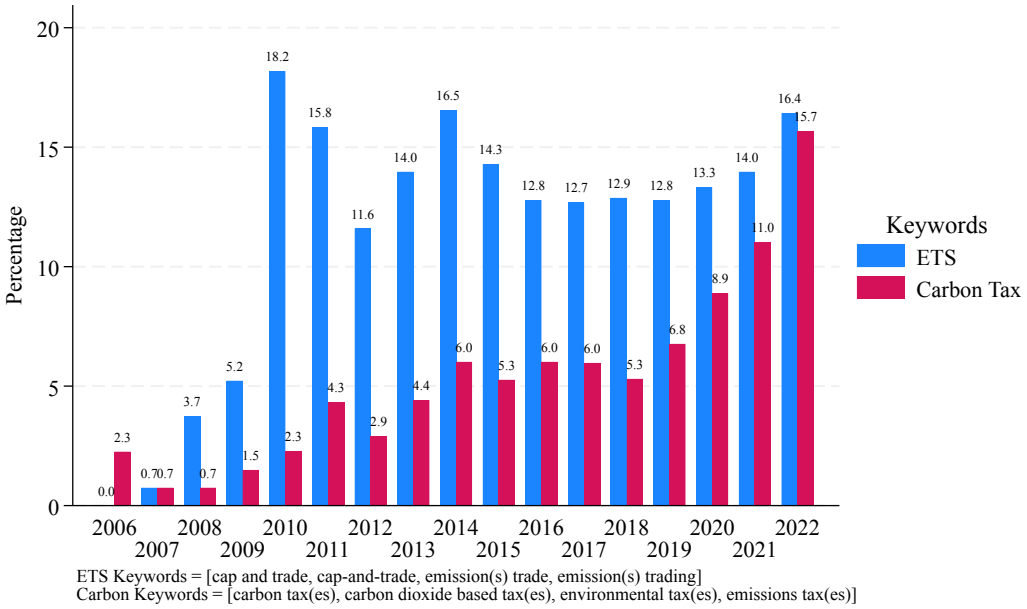
First, the enacted carbon prices are in the majority of countries still far from estimates of the social cost of carbon (Rennert et al., 2022; Bilal and Känzig, 2024). At these moderate prices, firms may not perceive the policies as stringent enough to warrant potentially costly adjustments in global supply chains and resource allocations. To verify that multinational firms view carbon policies as a material cost to their business, we conduct a textual analysis of disclosures by U.S. firms included in our sample. Specifically, we conduct a keyword search to identify whether firms discuss emissions trading systems (ETS) or carbon taxes in their annual reports, which are required to disclose cash-flow-relevant factors affecting the business. We then analyze the qualitative discussion in 10-K filings using sentiment analysis to assess whether these disclosures reflect perceived risk.

The results in Figure 1 show an increasing trend in the share of firms discussing carbon policies as a business risk, with more than 15 percent of our sample firms making such disclosures in 2022.[5] As accounting rules require firms to disclose their exposure to regulatory risk if such risk is financially material enough to affect shareholders' investment decisions (e.g., Matsumura et al., 2022; Sautner et al., 2023), this evidence suggest that firms have clear financial incentives to take action to avoid higher regulated carbon prices, including shifting operations

[5] 10-K full-text reports are available in machine-readible format on the EDGAR database from 2006. We observe similar patterns when we produce these statistics for the universe of 10-K reports published by all U.S. firms in the period 2006-2022. Unsurprisingly, the annual average share of disclosing firms ranges from 2 to 4 percent given that the full sample also excludes many firms from low-carbon intensity industries and firms with little or no operational footprint in (European) countries with carbon policies in place.

to jurisdictions with lax or no environmental policies.

Figure 1: FINANCIAL MATERIALITY OF CARBON POLICIES FOR MULTINATIONAL FIRMS



Notes: This figure plots the annual share of our sample's publicly listed U.S. multinational firms that mention emission trading schemes (ETS, left blue bars) or carbon taxes (right pink bars) as a financial risk to their operations in their annual reports (Form 10-Ks). The sample includes 139 firms in the mining, quarrying, and oil and gas extraction as well as manufacturing industries (2-digit NAICS codes 21, 31, 32 and 33).

Second, carbon prices are not set in isolation. Policymakers may take economic considerations into account when deciding on climate policies. The variation in the climate policy stance across European countries documented above, coupled with the varying firms' exposure to these policies, is the identifying variation we are going to exploit. The idea is to compare the outcomes of operations by multinationals that are significantly exposed to carbon prices to similar multinationals that are not. Working with data at the firm level has the advantage that we can flexibly control for a wide range of potential confounding factors using fixed effects. Reassuringly, our carbon price exposure measure is strongly associated with a greater extent and likelihood of firms' public disclosures of financial risks due to carbon taxes or ETS, as proxied by the textual transition risk measures discussed above and presented in Figure 1 (see Section 4.2 for the formal validation tests).

Third, to operationalize our approach, we require data on the ownership network of multinational firms as well as a way to measure emissions at their subsidiaries in Africa. This is a challenge because high-quality emissions data at the subsidiary level is largely unavailable. One option is voluntary survey data. However, this may be subject to underreporting concerns, selection bias and measurement error. Therefore, we propose a novel approach that

allows us to directly measure leakage, as we explain in detail in the next section.

3 Multinationals' Carbon Footprint in Developing Countries

We construct a dataset on multinational firms that contains detailed information on their ownership network and financials. Most importantly, we propose a new approach to proxy emissions at the subsidiary level that is particularly well suited for Africa and other developing countries.

Subsidiary Networks and Financials of Multinational Firms. To construct an ownership network of parent and subsidiary firms, we use data from the Bureau Van Dijk Orbis historic database.[6] Following previous work by De Simone and Olbert (2022), Hoopes et al. (2023), and Coppola et al. (2021), our approach allows us to identify ultimate parent companies as well as their majority-owned subsidiaries across the organizational hierarchy and across the world, including tax havens and developing countries. We briefly describe here the construction of the data set. For more information, see, for example, De Simone and Olbert (2022).

To build the ownership tree, we first identify ultimate parents. These are defined as enterprises that either publish consolidated financial statements or that have no shareholder owning more than 50% of the company (level 0). We then identify all firms that are owned by an ultimate owner with a share exceeding 50% (level 1). In the next step, we identify all firms that are owned with a share exceeding 50% by a level 1 firm, and associate these with the ultimate parent of the level 1 firm. Moreover, we identify firms that are owned by various direct parents that belong to the same ultimate parent which hold a joint share exceeding 50%. This procedure is repeated until we have constructed the full ownership tree.

The Orbis data also contains information on multinationals' financials. In particular, we use financial information from the annual consolidated financial statements filed by the multinational firms' parent entities in their headquarters countries as well as financial information from the annual subsidiary-level unconsolidated financial statements filed by the multinational firms' subsidiaries incorporated in different European countries. Such data is available for subsidiaries in Europe due to the financial reporting regulation requiring public and private corporations to prepare and disclose unconsolidated financial accounts (Breuer, 2021; Kim

[6] In particular, we use historical snapshots of company ownership information from Orbis. The Orbis database includes detailed information on over 400 million companies worldwide. For most companies, Orbis provides ownership links for subsidiaries and shareholders.

and Olbert, 2022).[7] We use subsidiary-level unconsolidated financial data to measure multinational firms' exposure to European countries' carbon policies through their operations in a given European country and to examine investment responses in those countries (see Section 4.2 for details on the exposure design). However, importantly, financial information, let alone emissions data, is largely unavailable for subsidiaries in developing countries.

Building a Dataset of Multinationals' African Subsidiary Locations. A key challenge is how to measure activity and greenhouse gas emissions at a multinational subsidiary location in developing countries. Our key idea is to proxy emissions at the subsidiary level by measuring how emissions in the close geographical vicinity change over time. This approach is destined to work particularly well in Africa, where emissions are not as densely distributed as in Europe.

To this end, we gather information on subsidiary locations of multinational firms in Africa in a large-scale hand-collection effort. To keep the hand-collection manageable we focus on sectors with significant climate policy exposure: manufacturing as well as mining, quarrying, and oil and gas extraction sectors (NAICS codes 31, 32, 33 and 21). Specifically, we restrict our attention on multinational firms from around the world with their main operations in these sectors. We further expand on the sectoral coverage by including multinationals that are EU ETS account holders.[8] While many of these firms operate in the sectors we originally focus on, some of them are classified under other NAICS codes.

For multinationals headquartered and with parent entities incorporated outside of Europe, we restrict the sample to ultimate parents who have at least one subsidiary in Europe in order to ensure exposure to European carbon prices.[9]

In total, this starting sample consists of 1,899 multinational firms, of which 419 firms are covered by the EU ETS. This includes 223 firms from the U.K., 179 firms from France, 248 firms from Italy, 217 firms from the U.S., 129 from Germany, 180 from Canada, 95 firms from Japan, and 32 firms from China (see Table A-1 in the Appendix for a detailed list by headquarters country). For these firms, we georeference the exact locations of all their majority-owned

[7] Data on multinationals' financial information is sourced from the Orbis Generics flatfiles as of February 2023.

[8] This is possible due to efforts by Letout (2021), linking the account holders to their Bureau Van Dijk - Orbis identifier. From our corporate ownership structures based on the Orbis database, we can identify the ultimate parent of any firm present in the Letout (2021) dataset. We focus on EU ETS account holders in Germany, United Kingdom, France, Italy, Spain, Netherlands, and Belgium.

[9] As our focus is on carbon leakage from developed to developing countries, we exclude ultimate owners based in Africa. Specifically, we drop 1 from Mauritius, 1 from Nigeria, 25 from South Africa, and 1 from Zimbabwe.

subsidiaries in African countries using information from Google and Google maps.[10]

We start the hand collection for 13,135 African subsidiaries that are covered in the Orbis ownership files and owned by the multinational firms of our starting sample. We successfully collect geo-locations for 7,544 African subsidiaries in total. Restricting the sample to multinationals with available subsidiary-level financial data in European countries to construct our exposure measure results in 777 unique multinational firms from 36 countries worldwide with 4,688 unique African subsidiaries across 48 African countries.[11] In Table A-2, we tabulate the observations of the final sample by multinational firms' headquarter countries and African subsidiaries' countries. The same multinational firms have 12,631 unique subsidiaries in European countries with non-missing unconsolidated financial statement information. We use these European subsidiaries as the unit of observation in supplementary tests on the mechanisms behind carbon leakage (Section 4.3).

Panel (i) in Figure 2 shows the geo-coded locations of the African subsidiaries in our sample. We can see that in many countries, subsidiary locations are concentrated in the capitals and large cities on the coasts. For some economically more developed countries, such as South Africa, the spatial distribution is more dispersed.

Measuring Subsidiary-level Greenhouse Gas Emissions. Having collected the subsidiary location data, we combine this information with spatial emissions data. We use the Emission Database for Global Atmospheric Research (EDGAR) by Crippa et al. (2022). EDGAR provides high-quality emissions data across space, at a resolution up to 0.1 degree $\times$ 0.1 degree (approximately 11 km $\times$ 11 km at the equator). The dataset is maintained jointly by the European Commission Joint Research Centre and the Netherlands Environmental Assessment Agency and is frequently used in scientific assessments, including those conducted by the Intergovernmental Panel on Climate Change (IPCC).

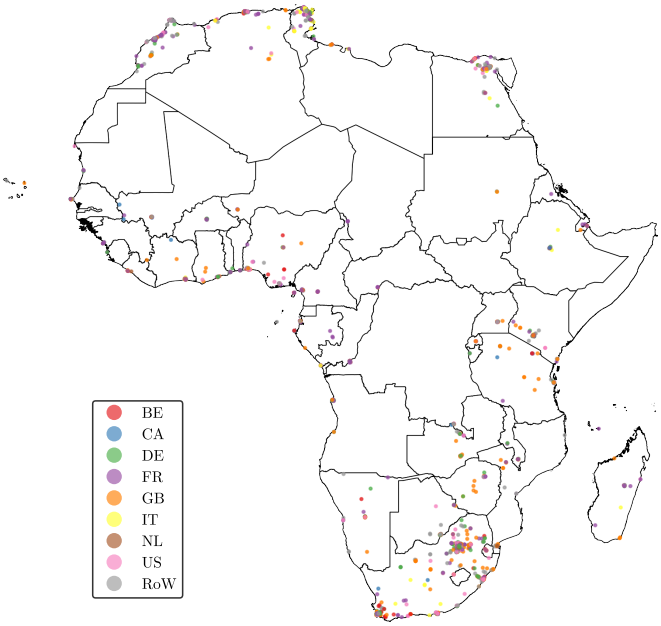
The emission statistics in EDGAR are estimated bottom-up from standard annual statistics of fuel, products, waste, crops, or livestock at the country level. The database then uses spatial data on population, roads, agricultural fields, and firm locations to disaggregate the national statistics at the local level. Emissions from a specific sector are attributed to a particular cell by

[10] For some entities, Orbis provides address information, including zip codes and streets. However, this information is often missing, less reliable and not as accurate as hand-collecting the location data, in particular in the case of developing countries. If the location we found is not an exact address, we use the closest proxy, that is, coordinates of the street, suburb, or city.

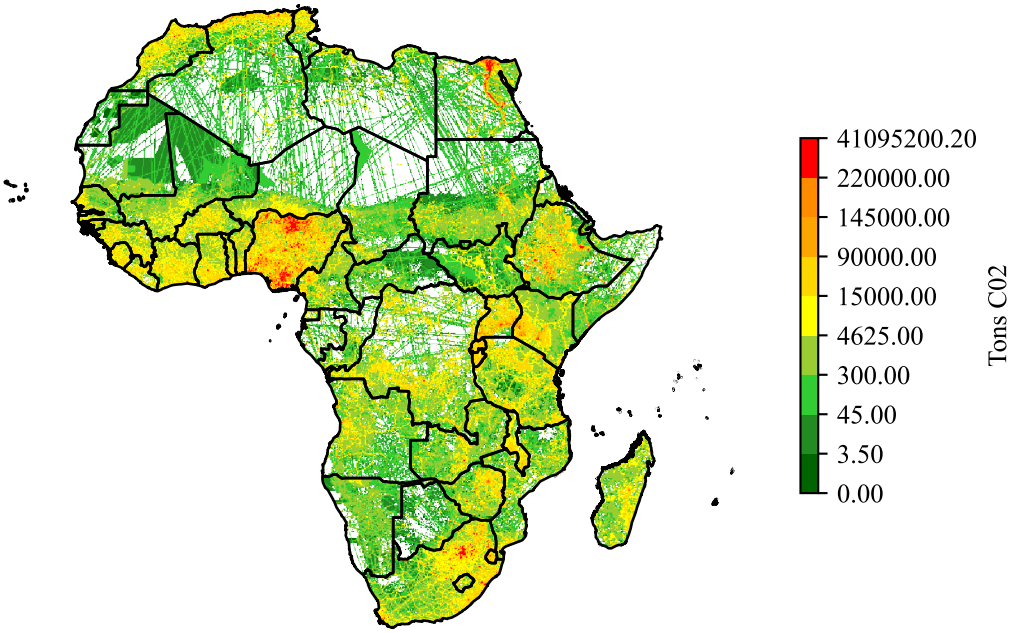
[11] We drop Seychelles because it is a high income country, South Sudan, because it gained independence during our sample period, and Mauritius because of its status as a tax haven.

Figure 2: PROXYING EMISSIONS AT AFRICAN SUBSIDIARIES WITH EDGAR

(i) SUBSIDIARY LOCATIONS OF MULTINATIONAL FIRM SAMPLE



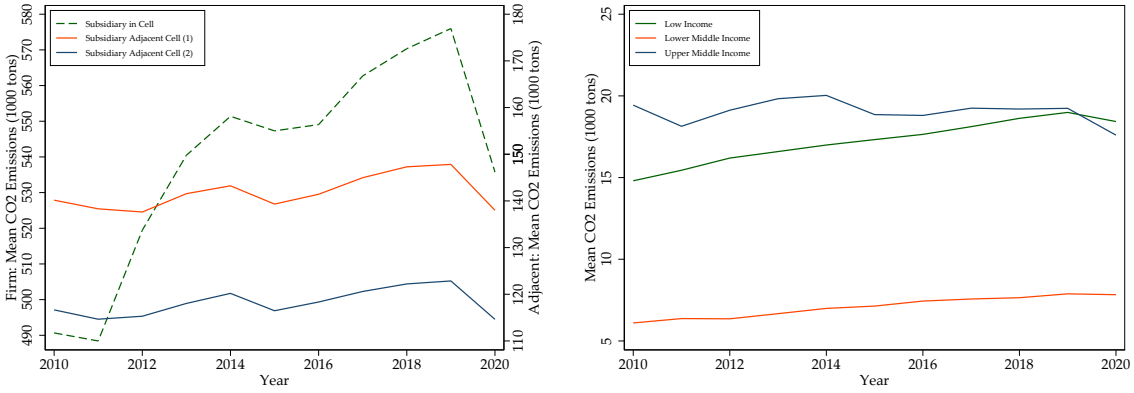
(ii) CO2 EMISSIONS ACROSS AFRICA



Notes: This figure illustrates how we measure emissions at African subsidiaries. Panel (i) shows the geographical distribution of 4,688 locations in our dataset with subsidiaries owned by firms from Belgium (103), Canada (37), Germany (576), France (1263), Great Britain (757), Italy (191), Netherlands (95), the US (690) and the rest of the world (976). Panel (ii) shows the geographical distribution of CO2 emissions in Africa at the 0.1×0.1 grid cell level based on data from EDGAR v7.0 for the year 2015. The color coding corresponds to the level of CO2 emissions.

Figure 3: DEVELOPMENT OF CO2 EMISSIONS AT GRID-CELL LEVEL

(i) FIRMS' SUBSIDIARIES AND ADJACENT CELLS **(ii)** AVERAGE BY COUNTRY INCOME GROUP



Notes: This figure plots the mean level of CO2 emissions from 2010 to 2020. In panel (i), the green line shows emissions in grid-cells where we observe multinational firm subsidiary presence, the orange and blue line show emissions in respectively up to one or up to two adjacent grid cells without multinational firm subsidiary presence (see Figure A-5 for a visualization). In panel (ii) we plot mean CO2 emissions over grid cells in low income countries (green), lower middle income countries (orange) and upper middle incom countries (blue).

calculating the share of the proxy associated with that sector that is located in that same cell relative to the country's total. For more details, see Janssens-Maenhout et al. (2013). We use the total emissions of all sectors, including short-cycle emissions.

Panel (ii) in Figure 2 visualizes the distribution in estimated emissions (total tons of CO2) from the EDGAR database across the African continent at the 0.1 $\times$ 0.1 grid cell level for the year 2015. We can see that emissions vary substantially both within and across countries. Generally, emissions are higher in densely populated areas. Emissions are particularly high in Nigeria and parts of South Africa and Egypt.

Equipped with the EDGAR data, we are able to proxy emissions around the subsidiaries of European multinationals. The measurement, however, crucially hinges upon the quality of the emissions data. Therefore, we perform a number of validation checks.

First, we explore the time-series variation in the EDGAR data at the grid-cell level. Specifically, Panel (i) of Figure 3 plots average CO2 values across grid cells in which our approach located a multinational firm subsidiary (green dashed line), as well as across adjacent grid cells without a subsidiary. The orange solid line shows averages for all grid cells that are the immediately closest neighbors, while the blue solid line depicts averages for the next two adjacent grid cells.[12]

We observe trends broadly in line with expectations based on economic activity and as-

[12]Figure A-5 in Appendix D.1 visualizes how we select these adjacent grid cells.

sociated emissions from multinational operations. Starting from a level of approximately 490 thousand tons of CO_2 per cell in 2010—at the beginning of our sample period and in the aftermath of the global financial crisis—emissions in subsidiary-location grid cells exhibit strong growth beginning in 2012. This growth moderates in the following years, peaks in 2019, and dips in 2020, consistent with the economic slowdown during the COVID-19 pandemic.

In contrast, adjacent grid cells without a localized multinational subsidiary exhibit relatively stable emission levels and weaker year-on-year variation, suggesting that CO2 trends in these areas are less influenced by changes in economic activity. The grid cells immediately adjacent to subsidiary-location cells have about 30 thousand tons more CO2 than the second-tier adjacent cells, consistent with a spatial gradient in economic activity and emissions that weakens with distance from multinational firm operations.

Panel (ii) of Figure 3 plots average CO2 emissions across all grid cells, with the sample split by country income groups in Africa. As expected, the trends appear more stable due to averaging across thousands of grid cells in multiple countries. We observe the highest levels and greatest variation in the group of upper-middle-income countries, reflecting their relatively more advanced economies. Emission growth over the sample period is strongest in low-income countries, consistent with these countries experiencing catch-up growth and associated increases in emissions. Interestingly, average CO2 emissions at the grid-cell level are higher in low-income countries than in lower-middle-income countries. This is likely driven by the latter group's larger geographic size, which results in a greater number of rural or natural-area grid cells with minimal economic activity and thus lower emission levels in the EDGAR data.

Despite observing these plausible time trends across grid-cells, a remaining concern is that these trends might be entirely driven by changes in national CO2 emissions from official statistics, which the EDGAR database then disaggregates using localized but relatively static spatial weights. If this were the case, our analysis would effectively rely only on the correlation between African country-level changes in CO2 emissions and average carbon price changes in Europe—rather than capturing within-country spatial variation linked to multinational firm presence. We mitigate this concern by the inclusion of yearly fixed effects separately for each African country in our main specifications, as detailed in Section 4.2, which absorb all country-level time-series variation. To further validate that our analysis leverages meaningful within-country variation, we regress the EDGAR grid-cell CO2 values on the country-year fixed effects and examine the residual variation. We find that this residual variation remains

substantial—even after including grid-cell fixed effects —confirming that our data contain rich within-country, within-year variation in emissions (see Figure A-6 in Appendix D.1).

In Appendix D.1, we conduct two additional tests. First, we study how well the EDGAR data aligns with emissions data from other sources at the country level. Specifically, we compare annual changes in EDGAR CO2 emissions to the same annual changes in CO2 emissions data from the Worldbank. The two series are very highly correlated, with a correlation coefficient above 0.75 even after controlling for changes in GDP. This is reassuring, but for our purposes we are also interested in how accurate the emissions data is across space. To this end, we correlate the EDGAR emissions data with nighttime luminosity data at the grid-cell level. We would expect these two series to be positively correlated, to the extent that higher luminosity is a proxy for higher economic activity which in turn is associated with higher emissions. This is indeed what we find. The correlation between the two measures is approximately 0.67.[13]

Summary Statistics. We focus our analysis on the period from 2010 to 2020. We start the sample after the global financial crisis and stop with the outbreak of the Covid-19 pandemic to avoid any confounding effects of these large shocks.[14] In Table 2, we report summary statistics for the main variables in our analyses. Panel A shows statistics for our sample of local African grid cell observations, which we use to study the local emission responses in Africa. Panel B displays financial information on multinational firms' European subsidiaries. Panel C shows statistics for equivalent variables based on multinational firms' consolidated financial statements, capturing firms' total worldwide assets in a given year. Finally, Panel D shows summary statistics for our the African countries that we focus on in our macro-level analyses.

In our sample of African subsidiaries in Panel A, average annual CO2 emissions are approximately 540,000 tCO2, measured based on the 0.1×0.1 degrees grid cell the multinational firms' subsidiaries are located in. The grid cells' average exposure to European carbon policies via the multinational firms active in the grid cells is 6.95 and 7.27 measured using fixed tangible or total assets, respectively. Note that these measures are exposure-weighted versions of the effective carbon price as tabulated for the year 2019 in Table 1. The corresponding standard de-

[13] As an additional comparison, we consider spatial emission data from Climate TRACE, which rely on different methodologies to track GHG emissions, including satellite data and estimation based on national statistics. There are challenges measuring emissions using satellites, in particular related to spectral, spatial and temporal resolution. Indeed, we find that there is a notable share of missing values in the data and in many populated cases, emissions do not change on a year-to-year basis. Furthermore, the data is only available from 2015. Nevertheless, for the overlapping sample, we find a cell-level correlation with EDGAR emissions of 0.4.

[14] Excluding the year 2020 from our analysis does not change our inferences.

Table 2: SUMMARY STATISTICS

	Obs.	Mean	Median	Min	Max	SD
Panel A	African Grid cell-level Tests					
CO2 0.1×0.1 (tons m)	7,381	0.54	0.17	0.00	45.16	2.09
Carbon Policy Exp. (FTanA)	7,227	6.95	5.42	1.03	54.16	5.42
Carbon Policy Exp. (TA)	7,381	7.27	5.43	1.03	54.35	6.07
Envir. Perf. Index 2010	7,315	34.54	34.60	24.40	44.30	4.69
Employment 0/1	118,968	0.58	1.00	0.00	1.00	0.49
Anemia 0/1	31,868	0.40	0.00	0.00	1.00	0.49
Share Children Coughing	50,210	0.10	0.00	0.00	1.00	0.26
Panel B	Multinational Firms' European Subsidiary-level Tests					
Fixed Tan. Assets (Uncons., USD m)	54,652	70.70	5.58	0.00	15,363.28	448.35
Total Assets (Uncons., USD m)	54,649	645.34	34.65	0.00	232,487.39	4,967.62
Employees (Uncons. th.)	46,419	0.53	0.12	0.00	152.99	3.11
Country-Carbon Policy Exp. (FTanA)	54,652	0.37	0.05	0.00	16.17	0.89
Carbon Policy Exp. (FTanA)	54,397	8.06	5.28	0.76	54.62	8.25
Panel C	Multinational Firm-level Tests					
Fixed Tan. Assets (Cons., USD m)	7,413	5,892.29	739.08	0.00	259,651.00	17,602.44
Total Assets (Cons., USD m)	7,413	22,875.89	3,976.60	3.75	747,793.00	54,099.76
Employees (th.)	6,911	35.47	11.83	0.00	671.21	59.32
Carbon Policy Exp. (FTanA)	7,413	7.25	4.99	0.76	54.62	7.71
Panel D	African Country-level Tests					
CO2 Country (tons m)	561	53.49	16.15	0.27	604.41	109.25
Carbon Policy Exp. (Macro, Trade)	561	6.05	5.22	1.25	19.68	3.21
Carbon Policy Exp. (Macro, Firms)	561	7.29	6.38	1.10	20.73	4.00
GDP Growth	543	4.06	4.26	-50.34	86.83	6.29
GDP (USD bn)	545	44.30	11.60	0.24	509.37	90.13
Exports (USD bn)	510	12.81	4.61	0.08	146.37	22.51
Population (m)	561	22.03	11.94	0.18	203.30	31.89

Notes: This table presents summary statistics for the variables used in the different regression samples throughout the analyses. In the different panels, variables and samples are categorized based on the level of the unit of observation for the sample period 2010-2020. Panel A shows statistics for grid cell-level observations, including emissions from the EDGAR database, the environmental performance index, and health outcomes from DHS surveys at the individual respondent level. Panel B shows statistics for multinational firms' consolidated financial data. Panel C shows statistics for multinational firms' subsidiary financial data in European countries. Panel D shows aggregate data at the country level for the sample of African countries. The multinational firms' unconsolidated and consolidated financial data and corporate ownership panel data are from the BvD Orbis Generics flatfiles update as of February 2023.

Data Sources: CO2 emissions are taken from EDGAR. EPI data are from `https://epi.yale.edu/downloads`. The data on carbon taxes are from Metcalf and Stock (2023). The ETS data are from euets.info. The multinational firms' consolidated and subsidiaries' unconsolidated financial data as well as corporate ownership panel data are from the BvD Orbis Generics flatfiles update as of February 2023. Macroeconomic variables are based on data from the World Bank.

viations are 5.42 and 6.07, suggesting that our sample's multinational firms exhibit substantial heterogeneous exposure to the European environmental policy stance. To facilitate the interpretation of coefficient estimates, we use standardized versions of the carbon policy exposure variables in the regressions (with mean zero and a standard deviation of one). Panel B shows that the mean multinational firms' European subsidiary reports approximately 70.7 million USD in unconsolidated fixed tangible assets and 645.34 million USD in unconsolidated total assets and has 530 employees. Panel C shows that the mean sample firm reports 5,892 million USD in consolidated fixed tangible assets and 22,876 million USD in consolidated total assets and has approximately 35,470 employees worldwide.

In Panel D, we show some country-level statistics for our sample of low- and middle-income countries. We can see that there is large heterogeneity in the CO2 emissions of African countries that are not high income, with small countries like Comoros emitting less than one million tons of CO2 per year.

4 Searching for Carbon Leaks to Developing Countries

How does stricter environmental regulation of European firms affect emissions at their subsidiaries in Africa? As we discussed, carbon policies not only incentivize multinational firms to reduce their emissions in their home country, but they may also trigger the offshoring of emission-intensive activities to countries with little or no regulation. Is this channel present in the data? To assess this, we perform two empirical exercises. We start our analysis with a simple motivational event study analysis to motivate our approach before turning to our baseline shift-share design that leverages the exposure of European multinationals' to European carbon prices.

4.1 A Simple Event Study Analysis

To motivate our empirical design, we first perform a simple event study analysis. We focus on France, which introduced a moderate but salient carbon tax in 2014, and compare this to Germany, which did not have such a tax in place during our sample period. The 2014 introduction of a French carbon tax provides a plausible policy shock for this exercise. Although climate and energy policy issues were publicly debated, the business sector unlikely expected a direct carbon tax: a prior attempt of a carbon contribution (tax) in 2010 was withdrawn un-

der President Sarkozy, and continued opposition during François Hollande's early presidency suggested little prospect of revival. Yet in 2014, the government unexpectedly embedded a carbon component into the existing domestic energy tax (TICPE), marking a significant policy shift. Enabled by falling oil prices, growing climate concern, and institutional support from the newly established Committee for Ecological Taxation, the reform avoided legal hurdles by building on an existing tax. It targeted emissions from transport and heating, excluding electricity due to France's low-carbon nuclear supply. The tax began at 7 euros per tCOe, with a trajectory toward 100 euros by 2030, and included redistributive measures to enhance political feasibility.[15]

The idea then is to compare subsidiaries that are owned by a French parent firm to subsidiaries that are owned by a multinational headquartered in Germany. In particular, we look at Edgar grid cells that have French but no German subsidiaries (treated), and compare these with grid cells that have German but no French subsidiaries (control).

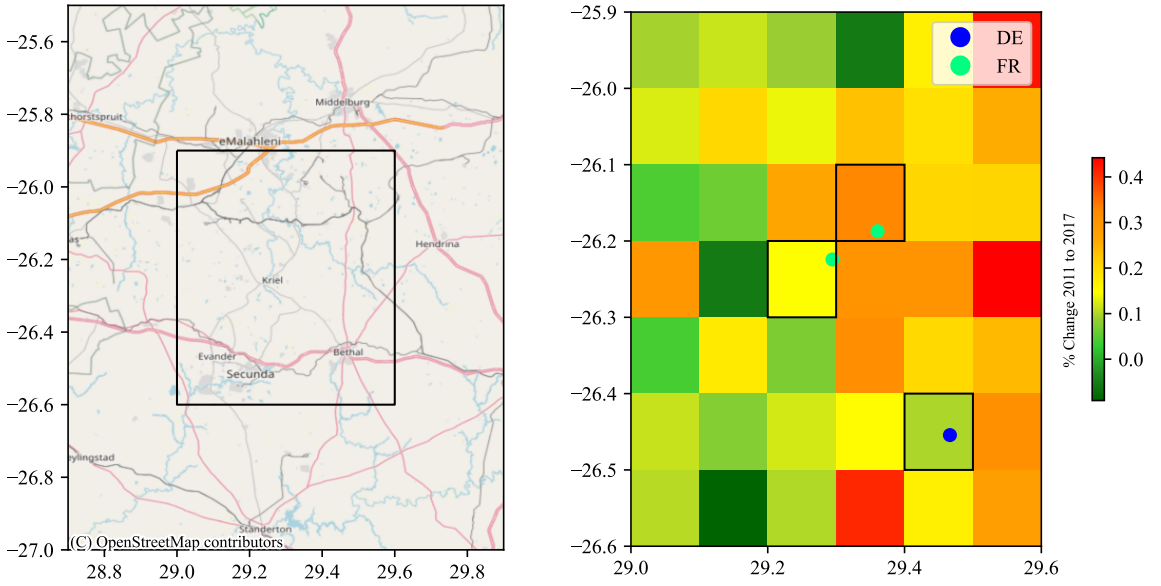
Two implicit assumptions underpin this approach. First, we assume that treated (control) multinational firms maintain a significant portion of their business operations, including production activities and employment, in their home countries and are thus affected (unaffected) by the tax in France (Germany). To support this assumption, we further specifically compare firms that have at least 75% of their European subsidiary-level assets in their home country (Germany or France). Second, we assume that treated and control multinational firms are comparable along many dimensions, including their business models, exposure to changes in regulation (except for the French carbon tax), and their operational footprint in Africa. We argue that this assumption is institutionally plausible, as France and Germany share a long border and exhibit similar economic and regulatory characteristics when compared to other EU member states. We are not aware of any other policy trends or macroeconomic factors that should affect French multinational firms systematically differently than German peers in the same industries starting in 2014. We further provide support for this assumption by estimating pre-treatment period differences between treated and control firms.

Figure 4 illustrates our difference-in-differences setting with a simple example. Displayed are two subsidiaries in South Africa that are relatively close to each other. Importantly, however, one is owned by a French multinational firm while the other subsidiary belongs to a

[15] In 2018, the government under president Macron suspended a planned carbon tax increase amid the Yellow Vest protests, a major social and political backlash against environmental fiscal policy. As a result, the tax rate never exceeded 44.60 euros.

Figure 4: AN EXAMPLE OF TWO MULTINATIONAL FIRM SUBSIDIARIES IN SOUTH AFRICA

(i) ZOOM AREA **(ii)** SUBSIDIARY CO2 EMISSIONS



Notes: This figure illustrates the mechanism of carbon leakage. Panel (i) shows a map of South Africa where the black box highlights the region that we zoom into in panel (ii). Panel (ii) shows subsidiaries of a French and a German multinational firm. The black bounding box is of size 0.1×0.1. Cell color indicates the percentage change in CO2 emissions from 2011 to 2017 based on the color coding in the legend on the right.

German multinational. The left panel shows the area on the map under consideration, while the right panel zooms in and displays the change in emissions from 2011 to 2017 across space. The green dots show the locations of the French subsidiaries and the blue dot shows the location of the German subsidiary. Relevant grid-cells are surrounded with a black box. We can see that grid-cells where the French-owned South African subsidiaries operate, whose parent has become subject to a carbon tax, display a stronger increase in emissions as compared to the grid-cell with German subsidiary presence. This evidence is consistent with carbon leakage effects. Of course, this represents only one example. Do we observe these leakage effects more systematically across a wider range of cases?

To formally examine the effect of the French carbon tax on emissions at African subsidiaries of French multinational firms, we consider the following event-study regression framework:

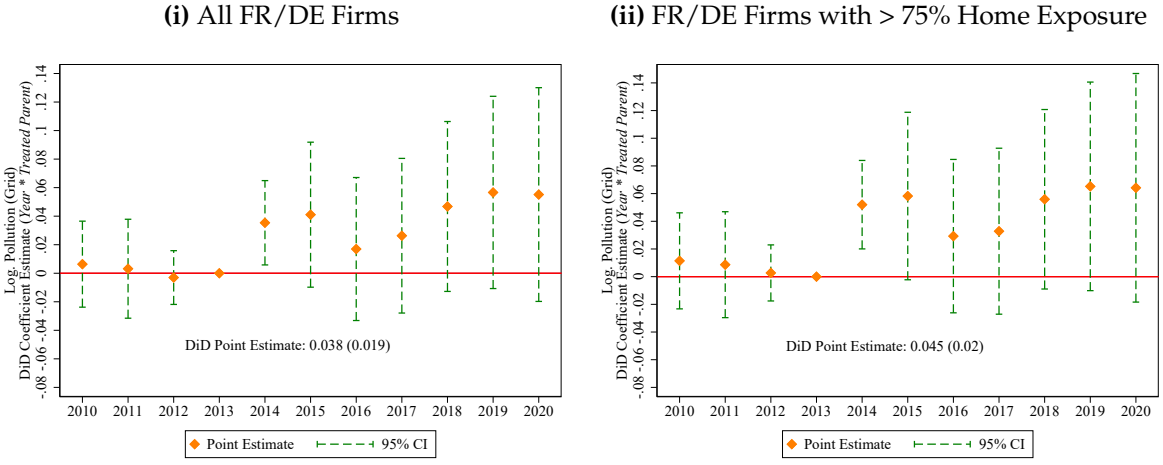
$$\ln(\text{CO2}_{g(c)t}) = \alpha_{g(c)} + \kappa_c \times \delta_t + \sum_{r \neq -1} \beta_t \times \mathbf{1}[r = t] \times \text{Treat}(S)_{g(c)} + \epsilon_{g(c)t}, \tag{1}$$

where $\ln(\text{CO2}_{g(c)t})$ is the log-level of pollution at time t in grid cell g located in country c. We include cell fixed effects, $\alpha_{g(c)}$, and country-year fixed effects, $\kappa_c \times \delta_t$. $\text{Treat}(S)_{g(c)}$ is a binary treatment indicator equal to one if the set of subsidiaries S located in cell $g(c)$ includes

subsidiaries of multinational firms with their headquarters in France and no subsidiaries with headquarters in Germany. Conversely, if it contains German but no French subsidiaries it is 0 (France introduced a carbon tax in 2014). We exclude grid cells in which both German and French-owned subsidiaries are located for cleaner estimation. For inference, we use Conley spatial HAC standard errors to account for spatial dependence in a linearly decreasing manner up to 100km (Conley, 1999). Of interest are the coefficients β_t over time, where the relative event years r measure the distance to the year of the carbon tax introduction in the treatment country. Coefficients on β_t should be insignificant before treatment to ensure parallel trends.

Figure 5 shows the results of the event study regression. We can see that after the introduction of the French carbon tax in 2014, CO2 emissions at French-owned African subsidiaries increase significantly and steadily over time. Reassuringly, we find little evidence for pre-trends: the point estimates in the pre-treatment period are relatively close to zero and not statistically significant. This finding supports our assumptions that treated and control firms are comparable and that their subsidiary-level emissions in Africa would have evolved similarly absent the introduction of the carbon tax in France.

Figure 5: FRENCH CARBON TAX AND MULTINATIONAL FIRMS' EMISSIONS IN AFRICA



Notes: This figure displays the results from the event study model in equation (1), estimating the effect of the introduction of a carbon tax in France on CO2 emissions of multinational firms' subsidiaries in Africa. We consider grid cells that contain either French (treated) or German (untreated) multinational subsidiaries, but not both. Germany did not introduce a carbon tax in the sample period and has no carbon tax in place as of 2023. The coefficient estimate on the *Post* × *Treated* indicator from the corresponding difference-in-differences model is also reported in the figure. The dependent variable is the log of CO2 emitted in grid cells of size 0.1 × 0.1 where firm subsidiaries are located. In panel (i) we consider all French and German subsidiaries, in panel (ii) we restrict the sample to firms which have an exposure of > 75% to the domestic market based on their total assets. Confidence intervals are reported based on Conley spatial HAC standard errors.

In terms of magnitudes, our estimates suggest that African subsidiaries with French parents increase their emissions by approximately 4-6 percent more than those of German sub-

sidiaries after two years and more than 5-6 percent after four years. To gauge the overall impact, we also run a difference-in-differences specification which estimates the difference in the change of local emissions between treated and control subsidiary-locations over the entire sample period. We also report these estimates in Figure 5. Consistent with the event-study evidence, our estimates suggest that carbon subsidiary-level emissions increased by close to 4 percent following the introduction of a carbon tax in parent firm's home country. This is a non-negligible effect, especially when considering that the carbon tax rate was only 7 euros per tCO2e at introduction in 2014.[16]

We run several tests based on alternative specifications and report the results in Table A-4 in the Appendix. We find similar results, albeit smaller estimates, when we include only year fixed effects. Consistent with the idea that the incentive to relocate emission-intensive activities to Africa in response to a carbon tax increases in domestic exposure, we find relatively larger point estimates as we impose higher share of the firms' European subsidiary-level assets being located in their home country in specifications that include country $\times$ year fixed effects.

4.2 A Shift-share Design Based on the Exposure to European Carbon Prices

In the previous section, we have seen tentative evidence for carbon leakage based on a simple and transparent event study design in the context of the French carbon tax. In this section, we study potential carbon leakage effects more broadly in our full sample of multinationals and their subsidiaries. Specifically, we are interested in how effective carbon prices in Europe affect multinational firms' emissions in Africa. There are two identification concerns that complicate the estimation of a causal effect. First, carbon prices may be endogenous, influenced by factors like lobbying, economic performance, or other regional policies and shocks that are correlated with firm outcomes. Second, there was limited variation in carbon prices over our sample of interest. To confront these challenges, we adopt a shift-share design, leveraging multinationals' exposure to European carbon prices.

Measuring the Exposure to European Carbon Prices. Based on our data on European subsidiaries, we can precisely measure the exposure of a multinational to European carbon pricing policies. Importantly, our exposure measure takes both ETS prices and carbon taxes into account. We construct the exposure measure as follows.

[16]Subsequently, from 2015 to 2019, it rose slowly but steadily and reached a level of 44.6 euros per tCO2e at the end of our sample.

First, we measure the extent to which a multinational firm operates in a given European country. We do this by looking at unconsolidated fixed tangible or total assets at the level of the firm's subsidiaries incorporated in the country of interest, d, relative to the total value of assets in the set of European countries, D:

$$w_{id} = \left(\sum_{t=2007}^{2009} \frac{\text{Assets}_{idt}}{\sum_{d \in D} \text{Assets}_{idt}} \right) / 3 \tag{2}$$

To ensure that we capture assets related to CO2-intensive production, we focus on the assets of subsidiaries in the mining, quarrying, and oil and gas extraction as well as manufacturing industries (NAICS codes 21, 31, 32 and 33).

We interpret w_{id} as the exposure weight of multinational firm i to regulations in country d. To mitigate the concern that this exposure may change in response to changes in regulation, we measure the weight as an average over the three years prior to our sample (Goldsmith-Pinkham et al., 2020; Borusyak et al., 2024).[17]

Using these exposure weights, the firm-specific carbon policy exposure measure then takes the form:

$$\text{CarbonPolicyExp}_{it} = \sum_{d \in D} w_{id} \times \text{cprice}_{dt}, \tag{3}$$

where w_{md} are the exposure weights computed as described above and cprice_{dt} is the carbon price in European country d in year t, capturing both national carbon taxes and ETS prices. As discussed in Section 2, we express the carbon prices in real coverage-weighted terms, i.e. deflating them using the relevant GDP deflator and weighting by the country-specific emission coverage of the policy as in Metcalf and Stock (2023).

To validate the assumption that the exposure measure $\text{CarbonPolicyExp}_{it}$ captures changes in firms' perceived financial costs due to carbon policies, we relate it to the environmental policy risk disclosures that we obtained for the subsample of U.S. public firms (see Figure 1). Table 3 reports results from regressing different disclosure variables on our carbon policy exposure measure, when controlling for firm and year fixed effects. We document that a one-standard deviation increase in the carbon policy exposure is associated with firms mentioning approximately an additional 0.98 environmental-policy related words per thousand words in

[17] Orbis provides subsidiary ownership information from 2007, allowing us to use data from three pre-sample period years.

Table 3: FIRMS' EUROPEAN CARBON POLICY EXPOSURE AND POLICY RISK DISCLOSURES

	(1)	(2)	(3)	(4)	(5)
	CO2 Policy Words/1k Words	CO2 Policy Risk Disclosure (%)			
Carbon Policy Exp. (FTanA)	0.98*	4.87*			
	(0.5356)	(2.4668)			
Carbon Policy Exp. (FTanA)$_{t-1}$			6.13**		
			(2.9420)		
Carbon Policy Exp. (FTanA)$_{t-2}$				13.58***	
				(5.1534)	
Carbon Policy Exp. (FTanA)$_{t-3}$					12.35**
					(4.7530)
Obs.	1,612	1,612	1,502	1,399	1,295
Adj. R2	0.595	0.751	0.800	0.856	0.904
Firm FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes

Notes: This table reports results from regressing measures of public U.S. firms' environmental policy-related disclosures on the firm-level exposure variable *Carbon Policy Exp.* using OLS. The dependent variable in Column 1 is the number of keywords related to ETS or carbon taxes disclosed in a firm's annual 10-K report, scaled by the total number of words disclosed in the same report (times 1,000). The dependent variable in Column 2 is an indicator equal to one if a firm mentions an ETS or carbon tax keyword and the respective qualitative disclosure is classified as a business risk. The indicator is multiplied by 100 to facilitate an interpretation of regression results in percentage terms. The variable of interest, *Carbon Policy Exp.*, is defined above. The sample includes 139 publicly listed U.S. firms as in Figure 1. The *Carbon Policy Exp.* variable is standardized for ease of interpretation of the regression coefficients. Standard errors are clustered at the firm level. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. *Data Source*: Firm-level qualitative disclosures are taken from the text-based information in the firms' 10-K accessible via the EDGAR API. The multinationals firms' unconsolidated financial data and corporate ownership panel data are from the BvD Orbis Generics flatfiles update as of February 2023. The data on carbon taxes are from Metcalf and Stock (2023). The ETS data are from euets.info.

the disclosed annual report (Column (1)). Column (2) suggests that the likelihood that a firm mentions carbon policies as a risk to their business increases by almost 5 percentage points for every one standard deviation increase in the exposure variable in the same year. We observe that this association becomes stronger as we increase the lag between the year in which we measure the exposure, consistent with firms more transparently disclosing environmental policy-related financial risk to their investors once the firms have been subject to carbon policies in the past.

Identification Strategy. Based on our novel multinational firm-level exposure measure, we can estimate the impact of European carbon policies on local CO2 emissions around multinational firms' African subsidiaries using the following specification:

$$\ln(\text{CO2}_{g(c)t}) = \alpha_g + \delta_t + \beta \text{CarbonPolicyExp}_{gt-1} + \epsilon_{g(c)t}, \tag{4}$$

where $\ln(\text{CO2}_{g(c)t})$ denotes the log of CO2 emissions at time t in grid cell g, located in African country c. Because multiple subsidiaries (s), owned by different multinational firms (i), can

be located in the same grid cell, the grid-cell-level exposure to European carbon policies, $CarbonPolicyExp_{gt-1}$, is defined as the average of the firm-level exposures of all multinational firms with subsidiaries in that grid cell.[18] To account for the relative importance of a given local grid cell to overall emissions, we weight observations by the grid cell's CO2 emission levels at the beginning of the sample period (following Donaldson and Hornbeck (2016) who weight their estimates regarding the impact of railroads on land value by the initial land value). For inference, we use Conley spatial HAC standard errors to account for spatial dependence in a linearly decreasing manner up to 100km (Conley, 1999). In the simplest specification, we include grid-cell and year fixed effects. In additional specifications, we also include other fixed effects such as African country by year fixed effects to control more flexibly for potential confounding factors.

This design exploits variation in the exposure of multinational firms—active in a given local area in Africa—to changes in European carbon prices, and is conceptually similar to a reduced-form shift-share regression (Borusyak et al., 2022, 2024). It leverages the interaction between firms' pre-determined asset locations across European countries (which determine its exposure to those countries' carbon policies) and time-series variation in carbon prices across these countries. The key identifying assumption is that the shifts in carbon prices are assigned at random across multinationals, conditional on the controls, and influence firms' emissions in Africa only by affecting their propensity to reallocate emission-intensive activities, without directly altering the attractiveness of locating or operating in specific regions in Africa.

Table 4 reports the results. To aid the interpretation, the carbon policy measures are standardized to have a mean of zero and standard deviation of one. We can see that grid cells with subsidiaries owned by multinationals with higher exposure to European carbon policies exhibit greater local CO2 emissions, consistent with multinational firms increasing their emissions at African subsidiaries relatively more as they are exposed to higher carbon prices due to the firms' operations in Europe. These effects are statistically and economically significant. Column (1) suggests that a one standard deviation increase in a grid cell's average carbon policy exposure—measured via multinational subsidiary locations in Europe—is associated with a 12.28 to 12.91 percent increase in emissions around African subsidiaries, depending

[18] We calculate the grid cell average as $\text{CarbonPolicyExp}_{gt-1} = \frac{1}{|K_g|} \sum_{i \in K_g} \text{CarbonPolicyExp}_{it-1}$ where K_g is the set of subsidiaries in grid-cell g. See Equation 3 for the definition of firm-level exposure. As discussed below, for supplementary analyses we also construct an alternative sample where the unit of observation is the individual subsidiary location, which implies that some grid cells appear multiple times in the regressions.

on whether exposure is calculated using European subsidiaries' unconsolidated fixed tangible assets (Panel A) or total assets (Panel B).

Table 4: FIRMS' EUROPEAN CARBON POLICY EXPOSURE AND LOCAL EMISSIONS IN AFRICA

	(1)	(2)	(3)
Panel A		ln(CO2)	
Carbon Policy Exp. (FTanA)	0.1159***	0.1003***	0.1248***
	(0.0309)	(0.0310)	(0.0353)
Obs.	7,227	7,227	7,128
R2	0.021	0.014	0.027
Panel B		ln(CO2)	
Carbon Policy Exp. (TA)	0.1215***	0.1161***	0.1417***
	(0.0270)	(0.0292)	(0.0318)
Obs.	7,381	7,381	7,282
R2	0.025	0.021	0.038
Grid Cell FE	Yes	Yes	Yes
Year FE	Yes		
African Region × Year FE	No	Yes	
African Country × Year FE	No	No	Yes

Notes: This table reports results from estimating equation 4 using OLS. The dependent variable is the logarithm of CO2 (tons) emitted in a grid cell based on data from EDGAR. The independent variable *Carbon Policy Exp.* is measured as of year $t-1$ and is akin to a shift-share instrument measuring a firm's exposure to European countries' effective carbon prices as described in Section 2. To calculate exposure, we use a multinational firm's average share of total European unconsolidated assets in the period 2007-2009 in a given European country (for details see equation 4). *Carbon Policy Exp. (FTanA)* (Panel A) and *Carbon Policy Exp. (TA)* (Panel B) refer to exposure measures based on multinational firms' subsidiaries' unconsolidated fixed tangible or total assets, respectively, as explained in equation 3. The shift is the level of the carbon price in a European country. In Europe, we include the former EU 28 member countries (EU27 + Great Britain) and measure exposure based on subsidiaries operating in the mining, quarrying, oil and gas extraction, or manufacturing industries (NAICS codes 21, 31, 32, and 33). It is standardized for ease of interpretation of the regression coefficients. Regressions are weighted by the initial (2010) level of CO2 emissions in a cell. *Parent Country Controls* refer to the multinational firm's headquarter country's natural logarithms of GDP and population as well as the ratio of net FDI outflows to GDP. African Region fixed effects relate to the following groupings: Eastern Africa, Middle Africa, Northern Africa, Southern Africa, Western Africa. Standard errors account for spatial dependence in a linearly decreasing manner up to 100km (as discussed by Conley, 1999). * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.
Data Source: CO2 emissions are taken from EDGAR. The multinational firm unconsolidated financial data and corporate ownership panel data are from the BvD Orbis Generics flatfiles update as of February 2023. The data on carbon taxes are from Metcalf and Stock (2023). The ETS data are from euets.info. Macroeconomic variables are based on data from the World Bank.

Threats to Identification. In the baseline specifications in Column (1) of Table 4, we have included grid cells and year fixed effects to control for time-invariant characteristics to the local area in which a given set of subsidiaries operate. These fixed effects also span the characteris-

tics of the parent companies, as well as global trends. Further, the baseline results are robust to the exposure measure used: using unconsolidated total or fixed tangible assets to measure exposure produces very similar results (Panels A versus B).

A potential concern with regards to identification relates to *time-varying* confounding factors. These could come in the form of varying trends across African countries. For instance, British multinationals may have more subsidiaries in their former colonies. While the selection of subsidiary locations is controlled for by our grid cell fixed effects, this could still pose a threat to identification if the development in these countries differs systematically from other African countries over time. Similarly, varying trends in European countries could be a concern, as European multinationals may be unequally exposed to the business cycle in countries that have a more stringent climate policy stance. Furthermore, even within the same country, multinationals may be differentially affected by industry-specific developments.

In Columns (2) and (3) of Table 4, we address these potential concerns by examining the robustness of our results to the inclusion of different sets of fixed effects. To address the concern of varying trends across African regions, we include African region-by-time fixed effects (Column (2)). The point estimates remain stable and are still highly statistically significant. In an even more restrictive specification in Column (3), we include African country-by-year fixed effects, which yields a design that compares the emissions of subsidiaries in the same country and year, owned by multinational parent firms with differential exposures to carbon policies in Europe. Again, we document a consistent effect size, which remains highly significant at conventional levels.

To account for even more granular time trends that could bias our inferences, we construct an alternative sample in which the unit of observation is the individual subsidiary. A caveat of this approach is that multiple subsidiaries may be located in the same grid cell, implying that the same CO_2 outcome is used repeatedly in the regression and potentially linked to different values of multinational-level carbon policy exposure. This likely introduces some measurement noise. The advantage of this subsidiary-level design is that it allows us to control for trends specific to the parent firm's headquarter country, either by including macroeconomic control variables for the parent country or by adding parent country-by-year fixed effects. Table A-7 in the Appendix reports these additional tests, which broadly corroborate our main findings.[19]

[19]We also estimate separate regressions for the four NAICS codes 21, 31, 32, and 33. We find significant effects

Overall, these results demonstrate that our evidence of carbon leakage within multinational firm networks is robust to the inclusion of flexible controls for potential time-varying confounders.

Effect dynamics - Short and long differences estimations. A natural question concerns the timing of the effects we document—specifically, how quickly multinational firms' exposure to higher carbon prices in Europe translates into increased emissions at the level of their African subsidiaries, which ultimately drive the observed increases in grid-cell level CO_2 emissions. To shed light on this question, we estimate a short- and long-run differences design, regressing changes in grid-cell level CO_2 emissions on lagged changes in exposure to European carbon prices, progressively increasing the time horizon over which these differences are computed. To stay close to our more stringent specifications in Table 4, we include country-by-year fixed effects.

Table 5 presents the results. Intuitively, the estimated effects increases as the time horizon over which changes are measured increases. For example, the coefficient in Column (1) suggests that a one standard deviation increase in exposure over one year is associated with a 6.2 percent increase in grid-cell level CO_2 emissions in the subsequent year. This effect increases to approximately 10 percentfor the two-year difference (Column (2)), increases modestly to 12.9 percent for the three-year difference (Column (3)), and then only slightly increases further for the four-year difference (Column (4)). These patterns are consistent with a significant reallocation response in the short run that is strongest after three years and then stabilizes.

Heterogeneous Firm Responses Along African Countries' Environmental Policy Stance. An underlying assumption behind our inferences is that firms are willing to incur the costs of reallocating activity to outsource pollution to avoid European carbon policies. If this assumption holds, we would expect our main results to vary based on African countries' environmental policy stance. Specifically, if African countries enact environmental policies that raise the cost of CO2-intensive production, we would not expect to observe significant leakage effects. To test this prediction, we estimate our baseline model after splitting the sample based on African countries' rank in the Envrionmental Performance Index (EPI) from Wolf et al. (2022). The index proxies at a national scale how close countries are to established envi-

across all sectors, with the strongest effects observed in mining and oil and gas (21), as well as industries related to agriculture and textiles (31), and chemicals and non-metallic mineral products manufacturing (32).

Table 5: FIRMS' EUROPEAN CARBON POLICY EXPOSURE AND LOCAL EMISSIONS IN AFRICA - DYNAMICS

	(1)	(2)	(3)	(4)
	Δ ln(CO2)			
	$t - t_{-1}$	$t_{+1} - t_{-1}$	$t_{+2} - t_{-1}$	$t_{+3} - t_{-1}$
Δ Carbon Policy Exp. (FTanA)	0.0622**	0.0979***	0.1217***	0.1260***
	(0.0277)	(0.0369)	(0.0441)	(0.0412)
Obs.	5,832	5,184	4,536	3,888
R2	0.003	0.012	0.024	0.034
African Country × Year FE	Yes	Yes	Yes	Yes

Notes: This table reports results from regressing changes in grid-cell level CO_2 emissions on lagged changes in exposure to European carbon taxes at the grid-cell level. The dependent variable is the difference in the logarithm of CO_2 emissions (in tons) at the grid-cell level between $t-1$ and t, $t+1$, $t+2$, or $t+3$, in Columns (1) to (4), respectively. The independent variable, *Carbon Policy Exp.*, is the difference in our measure of carbon policy exposure (defined in Section 4.2) between $t-2$ and $t-1$, t, $t+1$, or $t+2$, in Columns (1) to (4), respectively. Regressions are weighted by the initial (2010) level of CO2 emissions in a cell. Standard errors account for spatial dependence in a linearly decreasing manner up to 100km (as discussed by Conley, 1999). * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.
Data Source: CO2 emissions are taken from EDGAR. The multinational firm unconsolidated financial data and corporate ownership panel data are from the BvD Orbis Generics flatfiles update as of February 2023. The data on carbon taxes are from Metcalf and Stock (2023). The ETS data are from euets.info. Macroeconomic variables are based on data from the World Bank.

ronmental policy targets. Table A-3 in the Appendix lists the 2010 values in EPIs by African sample country.

In Table 6, we document predictably larger effects with an effect size of close to 20 percent in the subsample of African countries with a median or below-median EPI as of 2010, the beginning of our sample period. The estimated coefficient for the subsample of African countries with an above-median EPI is notably smaller. This distinction is even more pronounced if we focus on the lowest and highest quintile. The point estimate when restricting the sample to the lowest quintile is 0.27, and is statistically significant at conventional levels. For the highest quintile, it is substantially smaller (0.02) and not significant. The smaller effect size suggests that multinational firms avoid European carbon taxes by exporting emissions to the least regulated jurisdictions which are mostly in Sub-Saharan Africa.

Splitting the sample based on income highlights that multinational firms shift their emissions mainly to low income countries. Splitting the sample based on World Bank income groups (Columns (1) and (2) of Table 6), we find a higher point estimate (0.09) when looking only at low and lower middle income countries as compared to upper middle income countries (0.06). Splitting the sample based on GDP per capita PPP, a similar pattern emerges, though it is much more pronounced. The point estimate for countries below the median income level is

Table 6: CARBON LEAKAGE AND AFRICAN COUNTRIES' ENVIRONMENTAL STANCE

	(1)	(2)	(3)	(4)
Panel A:	ln(CO2)			
Countries' Closeness to Environ. Policy Targets	$<$ median	$\geq$ median	Lowest Quintile	Highest Quintile
Carbon Policy Exp. (FTanA)	0.1810*	0.1090***	0.2666**	0.0192
	(0.0945)	(0.0358)	(0.1166)	(0.0417)
Obs.	2,563	4,664	1,573	880
R2	0.035	0.020	0.070	0.001
Grid Cell FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Panel B:	ln(CO2)			
African Countries' Income Group	Low and Lower Middle	Upper Middle	$<$ median 2010 GDP/pc	$\geq$ median 2010 GDP/pc
Carbon Policy Exp. (FTanA)	0.0943*	0.0637**	0.2284***	0.0755***
	(0.0492)	(0.0319)	(0.0884)	(0.0253)
Obs.	4,587	2,607	3,157	3,971
R2	0.011	0.009	0.066	0.012
Grid Cell FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes

Notes: This table reports results from estimating our main specification from Column 1 of Table 4 for different sub-samples. Panel A splits the sample according to how close a country is to environmental policy targets. In Column (1), the sample only includes grid-cells where the Environmental Performance Index (EPI) value as of 2010, assigned based on the country in which a grid cell is located, is below the median EPI value of grid-cells. In Column (2), the sample only includes grid-cells with an above-median Environmental Performance Index (EPI) value as of 2010. In Column (3), and Column (4) we consider only grid-cells in the lowest and highest quintiles of EPI in 2010, respectively. Panel B splits the sample based on income level. Columns (1) and (2) use the income group classification from the World Bank, separating low and lower middle, and upper middle income countries. Column (3) and (4) split the sample according to whether a grid-cell GDP PPP per capita, assigned based on the country in which a grid cell is located, is below or above the median level. The *Carbon Policy Exp.* variable is standardized for ease of interpretation of the regression coefficients. Regressions are weighted by the initial (2010) level of CO2 emissions in a cell. Standard errors account for spatial dependence in a linearly decreasing manner up to 100km (as discussed by Conley, 1999). * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.
Data Source: CO2 emissions are taken from EDGAR. The multinational firms' unconsolidated financial data and corporate ownership panel data are from the BvD Orbis Generics flatfiles update as of February 2023. The data on carbon taxes are from Metcalf and Stock (2023). The ETS data are from euets.info. Macroeconomic variables are based on data from the World Bank. EPI data are from `https://epi.yale.edu/downloads`.

almost three times as large.

Additional Analyses. We conduct a range of robustness checks to validate our inferences and report the results in the Appendix.

Table A-5 demonstrates that our findings are robust to alternative definitions of the carbon policy exposure measure. Specifically, the results remain robust when we (i) include all subsidiaries of a multinational firm regardless of their industry classification, (ii) apply a log-

arithmic transformation to the exposure variable, (iii) winsorize the exposure measure, or (iv) use employment rather than assets as the weighting factor in constructing exposure. Additionally, we separately construct two distinct policy exposure measures based on (i) carbon taxes and (ii) EU Emissions Trading System (ETS) prices, and include both in a single regression. The results indicate that the main effects are primarily driven by variation in national CO_2 taxes across European countries, with ETS price variation playing a more limited role. This suggests that the cross-country heterogeneity in carbon tax regimes provides particularly useful identifying variation for our empirical design. We interpret these result as evidence that national carbon taxes are they key driving force in shaping firms' responses to environmental policies.

Table A-6 demonstrates the robustness of our main results to alternative sample restrictions. Specifically, we show that the estimates remain stable when (i) excluding observations from South Africa, (ii) dropping the pandemic year 2020, (iii) weighting grid cells by average rather than initial CO_2 emissions, and (iv) winsorizing the CO_2 emission proxies derived from the EDGAR dataset.

4.3 Within-firm Mechanisms

After documenting evidence consistent with multinational firms increasing emissions at African subsidiaries in response to more stringent climate policies for their European operations, our aim is to shed more light on the within-firm mechanism to corroborate our findings. To this end, we exploit information from corporate disclosures using multinational firms' subsidiary-level unconsolidated and firm-wide consolidated financial statement data. We focus on those multinationals that own the African subsidiaries included in our main specifications in Section 4.2. We examine these firms' investment at the level of their subsidiaries in European countries where carbon taxes are imposed as well as their worldwide consolidated investment.

European Subsidiary-level Economic Activity. Prior work and aggregate statistics suggest that firms have taken measures to reduce overall (i.e., worldwide) emissions in response to higher carbon taxation. This can occur through a decline in heavily polluting production activities, overall changes to a firms' scope, or the use of greener production technologies. Our evidence suggests that firms more exposed to carbon taxes in Europe increase emissions at their African subsidiaries. Thus, our findings suggest that firms reallocate activity from highly

regulated European markets to developing countries in Africa. To further corroborate this inference, we turn to analyzing European subsidiaries at the firm level.

We estimate a specification similar to equation (4) using observations on the European subsidiaries of our sample's multinational firms. Specifically, we look at subsidiaries in the mining, quarrying, and oil and gas extraction as well manufacturing industries (NAICS 21, 31, 32, 33). In these tests, a firms' individual subsidiary serves as the unit of observation and the carbon policy exposure defined at the firm level as in equation (3). As outcomes, we look at fixed tangible assets to proxy for physical investment (i.e., production), total assets to proxy for total activities and corporate size, and the number of employees. Our baseline tests uses the full sample of subsidiaries active in relevant sectors in the former 28 European Member State countries (i.e., EU27 plus the United Kingdom). We include year fixed effects and subsidiary fixed effects, which also subsume parent firm fixed effects.

Furthermore, we examine the effect separately for subsidiaries located in European countries that have an effective carbon price of above or below 10. This sample split allows us to test whether firms engage in carbon leakage by reducing economic activity in European countries where the carbon prices are highest and to test whether carbon leakage might occur within Europe by firms reallocating activity to countries with low carbon prices.

We start by relating the different measures of economic activity to a country-specific carbon policy exposure measure ($\text{CountryCarbonPolicyExp}_{it}$). This measure is a variant of our main measure, $\text{CarbonPolicyExp}_{it}$, multiplying a subsidiary's countries' carbon price in a given year to a firm's subsidiaries' assets in this country scaled by the sum of all European assets. As a result, this variable measures a subsidiaries' treatment intensity to changes in the specific country's carbon price by weighting the country-specific carbon price by a firms' economic presence in the same country. As a comparison, we also consider our main overall exposure measure from the previous section. In this way we can gauge to the importance of domestic carbon policies relative to carbon policies in the entire geographic bloc.

Table 7 shows the results. We can see that subsidiaries of multinationals with a greater exposure to European carbon prices reduce their fixed tangible assets in Europe. This is true for the exposure to domestic carbon prices, but the effect is even more pronounced when we look at the overall exposure measure. The overall effect appears to be driven by a strong reduction of fixed tangible assets and employees located countries with relatively high carbon tax prices (Column (4)). These countries mostly have a domestic carbon tax in place in addition

Table 7: THE EFFECT ON MULTINATIONALS' ECONOMIC ACTIVITY IN EUROPEAN COUNTRIES

	(1)	(2)	(3)	(4)
	All EU 28	All EU 28	CO2 Price ≤10	CO2 Price >10
Panel A	ln(Fixed Tan. Assets)			
Country-Carbon Policy Exp. (FTanA)	-0.0264**			
	(0.0105)			
Carbon Policy Exp. (FTanA)		-0.1035*	-0.0507	-0.1181*
		(0.0599)	(0.0834)	(0.0716)
Obs.	54,625	54,379	26,245	28,065
Adj. R2	0.937	0.937	0.942	0.933
Panel B	ln(Total Assets)			
Country-Carbon Policy Exp. (FTanA)	0.0037			
	(0.0210)			
Carbon Policy Exp. (FTanA)		-0.0154	0.0016	0.0344
		(0.0459)	(0.0706)	(0.0598)
Obs.	65,951	65,323	29,325	35,940
Adj. R2	0.932	0.932	0.935	0.931
Panel C	ln(Employees)			
Country-Carbon Policy Exp. (FTanA)	-0.0113			
	(0.0127)			
Carbon Policy Exp. (FTanA)		-0.0480	-0.0128	-0.0443
		(0.0292)	(0.0402)	(0.0440)
Obs.	51,846	51,554	26,548	24,927
Adj. R2	0.949	0.949	0.949	0.949
Sub. FE	Yes	Yes	Yes	Yes
Firm HQ Country × Year FE	Yes	Yes	Yes	Yes

Notes: This table reports results from estimating a variant of equation 4 using OLS with multinational firms' European subsidiaries as the unit of observation. The dependent variable is the logarithm of the sample firms' subsidiary-level unconsolidated fixed tangible assets (Panel A), total assets (Panel B), or the number of employees (Panel C). Columns (1) and (2) include observations from subsidiaries in all former EU 28 (i.e., EU 27 and the Great Britain) countries, Column (3) from EU 28 countries with low (less than or equal to 10 EUR/tCO2e) effective carbon prices, and Columns (4) from EU 28 countries with relatively high carbon prices of above 10 EUR/tCO2e. In Column (1), the independent variable *Country-Carbon Policy Exp.* measures a firms' exposure to a given European country's carbon policy in year $t-1$. The variable is defined as a multinational firms' share of unconsolidated fixed tangible assets in the country in which the outcome variable is observed multiplied by that country's effective carbon price in year t. In Columns (2)-(4), the independent variable *Carbon Policy Exp.* is our main exposure measure in year $t-1$ as used in Table 4. The *Carbon Policy Exp.* variables are standardized for ease of interpretation of the regression coefficients. Standard errors are clustered at the multinational firm level. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Data Source: The multinational firms' unconsolidated financial data and corporate ownership panel data are from the BvD Orbis Generics flatfiles update as of February 2023. The data on carbon taxes are from Metcalf and Stock (2023). The ETS data are from euets.info.

to the EU-wide ETS. This suggests that in response to an increase in the exposure to European carbon prices, multinationals reduce their operations given the strong results for fixed tangible assets in Panel A, particularly in countries that are directly affected by the regulation. The effect on total assets is less conclusive. This is perhaps not too surprising, as total assets could capture alternative uses of corporate resources, such as capital raised for future R&D or acquisitions, and they may also include assets that are not directly linked to the company's primary operational activities. On the other hand, fixed tangible assets are generally closely tied to the core operational activities of a business, which for our sample of firms will likely be emission-intensive production facilities. Finally, we also document an economically sizable decrease in the number of employees at European subsidiaries of more exposed firms, which is again concentrated in countries that are directly affected by regulations that induce higher carbon prices. However, the employment effects are estimated with less precision, likely due to measurement error arising from rounding in some of the employment figures reported in Orbis Bajgar et al. (2020).

In terms of economic magnitudes, the documented effect sizes are substantial. A one standard deviation increase in the climate policy exposure leads to a fall in fixed tangible assets by 10 percent. Our results quantitatively similar when accounting for country-year trends, though we loose precision for the point estimates (see Table A-8 in the Appendix). Overall, these findings point to significant carbon leakage from Europe to the developing world through the reallocation of capital and economic activity.

Consolidated Firm-level Investment and Emissions. What impact do stricter climate policies have on multinational corporations when assessed at a consolidated, worldwide level? Our evidence so far suggests that firms with greater exposure to European carbon policies allocate relatively more emissions, likely through an increase in activity, to subsidiaries in other countries, including Africa. This seems to come at the expense of economic activity in Europe where regulators impose higher carbon prices. However, multinational firms with substantial carbon policy exposure may also lose market share to competitors with less or no such exposure. Further, reallocating activity within firm boundaries in response to carbon policies does not necessarily imply a change in firms' global investment and emissions, which is of the broader relevance to assess policy effectiveness. Thus, it is interesting to study the total effect on firm-wide activity is.

Table 8: EFFECTS ON ECONOMIC ACTIVITY AT THE CONSOLIDATED FIRM LEVEL

	(1)	(2)
Panel A	ln(Fixed Tan. Assets)	
Carbon Policy Exp. (FTanA)	-0.0763	-0.1070*
	(0.0572)	(0.0648)
Obs.	7,413	7,303
Adj. R2	0.953	0.955
Panel B	ln(Total Assets)	
Carbon Policy Exp. (FTanA)	-0.0330	-0.0678
	(0.0383)	(0.0461)
Obs.	7,452	7,342
Adj. R2	0.980	0.982
Panel C	ln(Employees)	
Carbon Policy Exp. (FTanA)	-0.0334	-0.0181
	(0.0479)	(0.0504)
Obs.	6,938	6,840
Adj. R2	0.961	0.962
Firm FE	Yes	Yes
Year FE	Yes	
Firm HQ Country × Year FE	No	Yes

Notes: This table reports results from estimating a variant of equation 4 using OLS with multinational firms' at the consolidated level as the unit of observation. The specifications are based on the main model in Column (1) of Table 8 and include multinational firm parent country by year fixed effects. Standard errors are clustered at the multinational firm level. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.
Data Source: The multinational firms' unconsolidated and consolidated financial data and corporate ownership panel data are from the BvD Orbis Generics flatfiles update as of February 2023. The data on carbon taxes are from Metcalf and Stock (2023). The ETS data are from euets.info.

We build on our analysis at the European subsidiary level (Table 7) by relating consolidated firm-level activity measures to carbon policy exposure. In addition to the baseline specification with firm and year fixed effects, we include firm-headquarter-country-by-year fixed effects to account for potential confounders such as country-specific policies or macroeconomic shocks that may correlate with the climate policy environment in a multinational's home country. This allows us to isolate variation in exposure stemming from differences in carbon policy stringency across European countries.

Table 8 presents the results. While the point estimates are negative, they are largely statistically insignificant. The estimates suggest a decline in economic activity—proxied by assets and employment—with the most pronounced effects observed for fixed tangible assets. This

pattern is consistent with the notion that firms bear a substantial share of environmental tax burdens, which reduces the after-tax return on investment and, in turn, leads to lower investment and potentially the divestment of emission-intensive assets (Jacob and Zerwer, 2024; Ecker and Keeve, 2023). However, these effects are smaller in magnitude and less precisely estimated than those observed at the level of European subsidiaries.

The finding that consolidated firm-level activity does not decline significantly—or declines less than at the subsidiary level—combined with the more substantial drop in activity at European subsidiaries, provides additional, indirect evidence of carbon leakage. These results remain robust when restricting the identifying variation to multinationals from the same headquarter country, in the same year, and within the same industry (untabulated).

4.4 Local Economic Effects: Employment and Health Outcomes

Emission-intensive activities typically accelerate climate change. Further, higher emissions at the local level in Africa may correlate with elevated pollution levels, adversely affecting the quality of life and health outcomes of local communities. However, the associated increase in economic activity may also benefit the local population by contributing to higher income levels, for instance, through additional employment opportunities if multinational firms expand their local operations. In this section, we build on our grid-cell level analysis from Section 4.2 and examine the relationship between local communities' employment and health outcomes and carbon leakage.

Specifically, we use survey data from the Demographic and Health Survey (DHS). The georeferenced dataset spans several waves of surveys and includes, among other variables, information on employment and a broad range of health outcomes for local populations in Africa. The DHS program has been active since 1984, operating in more than 90 countries. The surveys are repeated cross-sections of a nationally representative sample. As of 2025, there were a total of nine survey waves. To link DHS survey responses to our firm-level carbon price exposure measure, we focus on 34 African countries in which we observe subsidiaries of multinational firms. Between 2010 and 2021, these countries participated in one, two, or three DHS waves. For most countries, the majority of responses were collected in two to four separate years with intermittent gaps.

Consistent with the approaches in Hjort and Poulsen (2019) and Hoopes et al. (2023), we use as a proxy for employment whether the respondent is currently working (DHS variable

v714). For health outcomes, we use anemia status (item v457) and the share of children reported to have had a cough in the past two weeks (item h31 divided by b5).[20]

To assess the impact of European carbon prices on individual outcomes, we construct grid cells of size 0.1×0.1 degrees to generate overlapping grids with the analysis from Section 4.2. Analogous to our main analyses, the key independent variable is the level of carbon policy exposure in each cell, calculated as the average exposure across subsidiaries. We then match each respondent to a grid cell based on their location. Consequently, the unit of observation is the individual respondent. On average, we observe 633 respondents across the 360 cells in the 34 countries. Since we do not have panel data, we do not include grid cell fixed effects, but instead use country and year or country-by-year fixed effects to compare local employment and health responses to subsidiaries' increased exposure to higher European carbon prices within the same country, controlling for general year trends, or within the same country and year. We study both contemporaneous and lagged relationships to allow time for potential local economic and health effects to be observable in the survey data following increases in emissions-intensive activities by multinational firms in a given area.

Table 9 presents the results of our analysis. Panel A suggests a positive relationship between local subsidiaries' exposure to European carbon prices—previously shown to induce higher local emissions—and local employment. While the coefficient is estimated with some error, its statistical significance increases when we lag the exposure variable by three years. Notably, this result is robust to the inclusion of country-by-year fixed effects. In economic terms, the effect is modest: a one standard deviation increase in carbon policy exposure increases the probability of being employed by approximately 0.6 to 0.7 percentage points (relative to an overall employment probability of 58.2%). However, the standard deviation of average employment rates across grid-cell observations is 13 percentage points, and 5 percentage points when residualizing on country-year fixed effects, as in our specifications in Column (4) of Table 9. Against this benchmark, an increase in local employment rates associated with multinational firms' carbon leakage into an area is economically meaningful. Hence our results suggest that increased economic activity may translate into higher employment rates over the

[20] Anemia is a condition in which an individual lacks enough healthy red blood cells or hemoglobin to carry oxygen. It has been linked to the prevalence of air pollution (Datt et al., 2023). The DHS distinguishes between not anemic, mild, moderate, or severe anemia. We create a binary variable indicating whether an individual is anemic or not. As an additional proxy for health outcomes, we use the share of children with a recent cough as an indicator of adverse health effects, since industry-related air pollution has been linked to dry cough in children (Bergstra et al., 2018).

Table 9: FIRMS' EUROPEAN CARBON POLICY EXPOSURE AND LOCAL EMPLOYMENT AND HEALTH OUTCOMES IN AFRICA

	(1)	(2)	(3)	(4)
Panel A	Employment (0/1)			
Carbon Policy Exp. $(FTanA)_{t-1}$	0.0061*			
	(0.0035)			
Carbon Policy Exp. $(FTanA)_{t-2}$		0.0064*		
		(0.0035)		
Carbon Policy Exp. $(FTanA)_{t-3}$			0.0068*	0.0072**
			(0.0036)	(0.0033)
Obs.	118,968	118,968	118,968	118,968
R2	0.000	0.000	0.000	0.000
Panel B	Anemia (0/1)			
Carbon Policy Exp. $(FTanA)_{t-1}$	-0.0025			
	(0.0046)			
Carbon Policy Exp. $(FTanA)_{t-2}$		-0.0021		
		(0.0044)		
Carbon Policy Exp. $(FTanA)_{t-3}$			-0.0016	-0.0015
			(0.0045)	(0.0046)
Obs.	32,408	32,408	32,408	32,407
R2	0.000	0.000	0.000	0.000
Panel C	Share Children Coughing			
Carbon Policy Exp. $(FTanA)_{t-1}$	-0.0022			
	(0.0021)			
Carbon Policy Exp. $(FTanA)_{t-2}$		-0.0017		
		(0.0019)		
Carbon Policy Exp. $(FTanA)_{t-3}$			-0.0010	-0.0002
			(0.0019)	(0.0017)
Obs.	56,321	56,321	56,321	56,320
R2	0.000	0.000	0.000	0.000
Country FE	Yes	Yes	Yes	
Year FE	Yes	Yes	Yes	
Country × Year FE	No	No	No	Yes

Notes: This table reports results from estimating a specification akin to equation 4 using OLS. The unit of observation is a respondent to the DHS survey. To each respondent we assign a level of *Carbon Policy Exp.* based on the average *Carbon Policy Exp.* we calculated for ultimate parents to subsidiaries in a 0.1 × 0.1 grid cell in which the individual is located (for details regarding the construction of the exposure measure see section 2). The dependent variable is either a binary measure of employment, a binary measure of anemia, or the share of children coughing. Standard errors account for spatial dependence in a linearly decreasing manner up to 100km (as discussed by Conley, 1999). * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.
Data Source: Survey responses are taken from the Demographic and Health Survey Program. The multinational firm unconsolidated financial data and corporate ownership panel data are from the BvD Orbis Generics flatfiles update as of February 2023. The data on carbon taxes are from Metcalf and Stock (2023). The ETS data are from euets.info.

long term.

We do not find a statistically significant impact on health outcomes. While higher pollution levels could potentially worsen anemia and respiratory issues among children, such effects may emerge with a delay beyond the three-year window we examine. Moreover, higher income levels resulting from increased employment could improve health outcomes, making the net long-term effects harder to predict. Additionally, since baseline emission levels in these African communities may be relatively low, the increases of less than 10% documented in Section 4.2 may not be large enough in absolute terms to significantly impact local health outcomes.

5 Carbon Leakage at the Macro Level

We have seen robust evidence for carbon leakage at the firm level. However, carbon leakage effects are not bound within firms. Further, an important question for global climate policy is whether within-firm carbon leakage leads to higher aggregate emissions abroad, or whether it is offset by reductions in local firms' pollution due to crowding out by multinational activities. A natural question is thus: are these leakage effects also present at the macro level? Furthermore, we have focused so far on carbon leakage from Europe to Africa. An important question is to what extent such leakage effects are representative for potential leakage to other regions in the world.

To answer these questions, we estimate the impact of European carbon prices on country-wide emissions in foreign developing countries. We exploit the fact that different countries are differentially exposed to European effective carbon prices depending on how much they export to a country with a higher or lower carbon price. The idea is that in a country with a relatively higher price on CO2 emissions, it is costlier to produce carbon intensive commodities and, as a consequence, these commodities will be increasingly imported from abroad. This might happen either due to outsourcing or offshoring of production.

We construct a panel of 125 countries that are not part of the World Bank high-income economies. We exclude high-income countries because our focus is on developing countries and higher income countries are also less likely to be destinations for carbon leakage. The sample includes countries in Africa (51), America (23), Asia (35), Europe (8) and Oceania (8). Out of these, 24 are low income, 53 lower middle income, and 48 upper middle income. We

include data on different macro indicators such as GDP, population and emissions. The macro variables are from the World Bank while we source the emissions data again from EDGAR. To construct the exposure to European carbon policies, we leverage data on European imports from Eurostat.[21]

Country-level Research Design using an Aggregate Exposure Measure. We employ again a shift-share design and construct the exposure measure in the following way:

$$w_{cd} = \left(\sum_{t=2007}^{2009} \frac{\text{EX}_{cdt}}{\sum_{d \in D} \text{EX}_{cdt}} \right) /3, \tag{5}$$

where w_{ct} is the exposure weight of country c to the carbon price of country d in Europe at time t. It is calculated by dividing EX_{cdt}, the value of exports of c to d at time t by the total value of exports of country c at time t to the set of European countries D we use. To mitigate the concern that this exposure may change in response to changes in regulation, we measure the weight as an average over the three years prior to our sample, as for our firm-level exposure measure.

To validate the instrument and to connect the macroeconomic analysis to our firm-level tests in Section 4.1, we also calculate an alternative exposure weight using the share of multinational firm subsidiaries operating in an African country c and headquartered in the respective European country d. For this exercise, we exploit the full sample of multinational firms with ownership data in the Orbis database.

Using these exposure weights, the shift-share instrument then takes the form:

$$CarbonPolicyExp_{ct} = \sum_{d \in D} w_{cd} \times \text{cprice}_{dt}, \tag{6}$$

where cprice_d is the carbon price in European country d that is weighted by w_{cd}. We then estimate the impact of European carbon prices on CO2 emissions for the years 2010 to 2020 in the following way:

$$\ln(\text{CO2}_{ct-1}) = \alpha_c + \delta_t + \boldsymbol{X}_{ct}\theta + \beta CarbonPolicyExp_{ct-1} + \epsilon_{ct}. \tag{7}$$

[21] We focus on SITC-codes 2, crude materials, inedible, except fuels; 3, mineral fuels, lubric. and related mtrls.; 5, chemicals and related products; 6, manufactured goods classif. by material; 7, machinery and transport equipment; 8, miscellaneous manufactured articles, consistent with the NAICS codes that we are focusing on.

Here, $CO2_{ct}$ is the level of emissions of country c at time t as measured in tons of CO2, α_i are country fixed effects, δ_t are year fixed effects, and $\boldsymbol{X}_{ct-1}$ is a vector of control variables.[22] We are interested in the coefficient β which tells us how responsive aggregate emissions in a given country are to changes in the climate policy stance in Europe.

Table 10: CARBON LEAKAGE TO AFRICA AT THE MACRO LEVEL

	(1)	(2)	(3)	(4)	(5)	(6)
	ln(CO2 Country)					
	All Africa		Low Income		All Africa	
Carbon Policy Exp. (Macro, Trade)	0.0332*		0.0382**		0.0504**	
	(0.0184)		(0.0141)		(0.0237)	
Carbon Policy Exp. (Macro, Firms)		0.0464***		0.0281*		0.0707***
		(0.0171)		(0.0158)		(0.0188)
ln(GDP)					0.1730	0.1870
					(0.1833)	(0.1792)
GDP Growth					-0.0004	-0.0005
					(0.0008)	(0.0008)
ln(Exports)					0.0658**	0.0517*
					(0.0287)	(0.0277)
ln(Population)					0.5045	0.5459
					(0.6236)	(0.5771)
Obs.	561	561	220	220	508	508
Adj. R2	0.997	0.997	0.997	0.997	0.997	0.997
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes				
African Region × Year FE			Yes	Yes	Yes	Yes

Notes: This table reports results from estimating equation 7 using OLS. The dependent variable is the natural logarithm of the level of total CO2 emissions in a country based on data from EDGAR. The full sample in Columns (1) and (2) and (5) and (6) consists of 51 African countries over the period 2010-2020. Columns (3) and (4) restrict the sample to African countries in the low income group category according to the Worldbank definition. For our independent variable, we use a shift-share instrument where the weight is constructed as either the share of exports of an country to a European country or the share of multinational firm subsidiaries operating in an African country that have their headquarter in a European country (for details see equation 5). In Europe, we include the EU27 + Great Britain. The shift is the lagged level of the carbon price in a European country. African Region fixed effects relate to the following groupings: Eastern Africa, Middle Africa, Northern Africa, Southern Africa, Western Africa. Standard errors are clustered at the country level. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.
Data Source: CO2 emissions are taken from EDGAR. The trade shares are taken from Eurostat and the level of the carbon price is discussed in section 2. Control variables are based on data from the World Bank.

Country-level Results. We first focus on the set of African countries to examine how the leakage effects discussed in Section 4.2 and identified at the local grid cell level relate to aggregate effects for entire countries. Table 10 presents the results of estimating equation 7 for the set of 51 African countries. The estimates suggest that an increase in the carbon policy

[22] We include African country-level GDP Growth and the natural logarithms of GDP, Exports and Population. A concern with including controls for economic activity is that this activity could also be directly affected by European carbon taxes through carbon leakage, leading to a bad controls issue. To mitigate this concern, we lag the control variables by one year and first show our results without control variables.

Table 11: CARBON LEAKAGE TO LOWER-INCOME COUNTRIES AT THE MACRO LEVEL

	(1)	(2)	(3)	(4)	(5)	(6)
	ln(CO2 Country)					
Panel A	All Dev. Countris		Upper Middle Income		Lower Middle Income	
Carbon Policy Exp. (Macro, Trade)	0.0155	0.0055	-0.1036	-0.1239	0.0233	-0.0012
	(0.0300)	(0.0275)	(0.0810)	(0.0985)	(0.0473)	(0.0597)
Obs.	1,386	1,386	528	451	583	517
Adj. R2	0.996	0.997	0.997	0.998	0.998	0.998
Panel B	Lower Middle and Low Income		Low Income		Low Income (Africa)	
Carbon Policy Exp. (Macro, Trade)	0.0248	0.0107	0.0294	0.0364**	0.0374**	0.0382**
	(0.0259)	(0.0249)	(0.0294)	(0.0142)	(0.0146)	(0.0141)
Obs.	847	792	264	242	220	220
Adj. R2	0.996	0.996	0.980	0.994	0.997	0.997
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes		Yes		Yes	
Region × Year FE		Yes		Yes		Yes

Notes: This table reports results from estimating equation 7 using OLS. The dependent variable is the natural logarithm of the level of total CO2 emissions in a country based on data from EDGAR. The full sample consists of 125 countries over the period 2010-2020. For our independent variable, we use a shift-share instrument where the weight is constructed as the share of exports of an country to a European country (for details see equation 5). In Europe, we include the EU27 + Great Britain. The shift is the lagged level of the carbon price in a European country. Standard errors are clustered at the country level. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. *Data Source*: CO2 emissions are taken from EDGAR. The trade shares are taken from Eurostat and the level of the carbon price is discussed in section 2. Control variables are based on data from the World Bank.

exposure by one standard deviation leads to an increase in emissions by 3.3 to approximately 7 percent, depending on the specification. Using the exposure measure based on trade relationships or multinational firms' subsidiary locations produces similar results. This illustrates that multinationals' subsidiary networks are informative for the carbon policy exposure, even at the macro level. Notably, our results are robust to controlling for year or year by region fixed effects. Our results are further robust to excluding middle income countries (Columns (3) and (4)) as well as to separately South Africa, excluding countries in Northern Africa, excluding major oil and gas producing countries and excluding counties with a small population (untabulated).

How do these effects look like for the broader sample of developing countries? Table 11 shows the results for different country samples. We can see that a higher carbon policy exposure leads to an increase in emissions. However, the effect is not statistically significant when estimated on our full set of countries in Columns (1) and (2) of Panel A. When focusing on low income countries, we document a substantial and statistically significant increase in emissions. An increase in the carbon policy exposure by one standard deviation leads to an increase in

emissions by 2.9 to 3.6 percent (Columns (3) and (4) in Panel B). The estimated effect is very similar to the average effect estimated for our entire sample of African countries in Table 10. When restricting the sample to African countries classified as low income countries, we continue to find robust results (Columns (5) and (6) in Panel B). This confirms our notion that low income countries are prime destinations for potential carbon leakage. Further, our findings alleviate concerns about external validity and suggests that studying carbon leakage effects to Africa is informative about leakage effects more broadly.

The estimated effects at the macroeconomic level may appear large as they suggest an up to four percent increase in emission for a standard deviation increase in European carbon prices by one EUR/tCO2e. However, our macro shift-share analysis does not only capture the intensive margin of carbon leakage within multinational firms, as examined in Section 4.2, but also carbon leakage may also happen along the extensive margin within multinational firms, as well as outside multinational ownership networks.

To illustrate the magnitude of change of our instrument over time, we give two examples for the case where we use trade shares. The standardized instrument increased from -0.83 in 2015 to -0.04 in 2018 for Algeria, hence approximately 0.79 standard deviations; for Kenya, it increased from -0.15 to 0.3 over the same time period. This is to say that changes in the level of taxation of carbon emissions in Europe do have a meaningful impact on CO2 emissions in Africa.

Discussion. Collectively, our results present a consistent narrative: multinational firms respond to increases in European carbon prices by reducing economic activity, and likely emissions, in Europe while reallocating some of this activity to less developed countries in Africa. This phenomenon appears significant enough to manifest at the macroeconomic level, as African countries with higher investment and trade ties to European countries raising carbon prices experience larger increases in emissions. Interpreting these findings with a policy perspective requires considering the economic magnitude of carbon leakage to developing countries relative to changes in European and global emissions and their broader implications. Moreover, it is important to consider potential positive impacts on local economic outcomes, as documented in our study by showing a small increase in employment.

Turning to carbon leakage, our findings indicate that while leakage to developing countries is detectable, it is unlikely to significantly undermine the global emissions-reduction impact of

European carbon policies. This is because, although the relative firm-level effects in Africa are noticeable, the total increase in CO2 emissions in Africa remains relatively small compared to the reductions in emissions in Europe driven by higher carbon prices, as estimated, for example, in Metcalf and Stock (2023). Our ongoing work aims to more directly compare these total effects to quantify leakage rates and better inform the cost-benefit trade-offs of climate policies.

At the firm level, we find that higher European carbon price substantially reduce domestic investment. Specifically, a one-standard-deviation increase in carbon prices, equivalent to approximately EUR 7 per CO2e, results in a 2.7 percent decline in fixed tangible asset investment in a given country (based on results reported in Column (1) of Table 7). For context, average carbon prices ranged from EUR 6 to EUR 60 per CO2e across European countries by the end of our sample period. This economic magnitude is comparable to the effect of a 2-percentage-point increase in corporate income tax rates, based on the semi-elasticities documented in prior literature (Mooij and Ederveen, 2008; Lester and Olbert, 2024). However, unlike corporate tax hikes, carbon policies are also associated with positive effects on patenting and R&D (Aghion et al., 2016; Brown et al., 2022), indicating potential innovation benefits that would likely benefit the European economy.

The observation that carbon leakage to developing countries is economically small but detectable raises questions about the costs of policies designed to mitigate such leakage, especially as leakage appears correlated with increased economic activity in Africa. Our work in progress aims to quantify the economic consequences of reallocating emission-intensive activities to Africa, including effects on wealth as well as country-level GDP growth, and trade. These measures are particularly relevant for policymakers considering the distributional consequences of climate policies in the context of the UN Sustainable Development Goals.

6 Conclusion

In this paper, we study the complex relationship between climate policies in developed countries and their spillover effects on the developing world. Specifically, we look into potential carbon leakage effects from Europe to Africa. Europe has introduced different policies to mitigate climate change, including the carbon market and national carbon taxes, providing interesting policy variation.

We document substantial leakage within multinational European firms' ownership networks. We find that subsidiary-level carbon emissions in Africa increase significantly when a parent becomes more exposed to higher carbon prices due to regulatory changes in Europe, indicating notable within-firm carbon leakage from Europe to Africa. We corroborate these findings using indirect evidence from unconsolidated and consolidated financial data on firms European and worldwide economic activity. In particular, we show that multinationals that are more exposed to European carbon taxes reduce their operations in Europe, but the firms' activity at the consolidated level remains largely unchanged – consistent with the existence of carbon leakage effects. We confirm these results at the macro level, where we document a significant increase in aggregate emissions in African countries after an increase in the exposure to European carbon prices. We document a similar increase in emissions in other low-income countries but no significant impact on higher income countries.

Carbon leakage at least partially undermines the effectiveness of national carbon pricing policies. However, developing countries benefit economically from such policies due to the increase in economic activity such as local employment. Thus, policymakers should also take development considerations into account when designing policies to prevent carbon leakage.

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Appendix

Carbon Leakage to Developing Countries

Diego R. Känzig
Julian Marenz
Marcel Olbert

This version: July 9, 2025

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A - Data and Summary Statistics

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A Data and Summary Statistics

Table A-1: MULTINATIONAL FIRM PARENT SAMPLE - DATASET CONSTRUCTION

	NAICS Code						
Country	21	31	32	33	Other	Total	ETS Firms
Australia	29	2	5	7	0	43	2
Austria	1	0	0	4	0	5	2
Belgium	4	14	13	18	8	57	19
Bermuda	7	3	1	2	0	13	1
Brazil	0	1	1	3	0	5	1
Canada	154	1	15	10	0	180	2
Cayman Islands	2	3	0	2	0	7	0
China	1	1	7	23	0	32	2
Croatia	0	1	0	0	0	1	1
Cyprus	2	1	0	0	0	3	0
Denmark	0	4	2	4	0	10	2
Estonia	0	0	0	1	0	1	0
Finland	0	1	3	11	0	15	5
France	9	36	29	73	32	179	49
Germany	0	3	21	68	37	129	58
Greece	0	0	2	4	0	6	1
Hong Kong	0	0	0	4	0	4	0
Iceland	0	0	0	2	0	2	0
India	0	6	23	25	0	54	7
Ireland	8	3	5	9	0	25	5
Italy	8	46	51	104	39	248	45
Japan	0	5	22	68	0	95	20
Jordan	0	0	1	0	0	1	0
Korea, Republic of	0	0	1	9	0	10	1
Kuwait	1	0	1	0	0	2	0
Malaysia	2	1	2	2	0	7	1
Mexico	0	1	2	0	0	3	2
Netherlands	7	4	7	15	11	44	23
New Zealand	0	1	0	1	0	2	0
Norway	2	1	1	6	0	10	2
Pakistan	0	1	0	0	0	1	0
Poland	1	0	0	1	0	2	1
Portugal	1	0	2	1	0	4	2
Russia	3	0	0	1	0	4	0
Saudi Arabia	0	1	1	2	0	4	0
Serbia	0	0	0	1	0	1	0
Singapore	0	3	1	7	0	11	1
Spain	7	32	24	39	29	131	39
Sweden	2	4	2	20	0	28	12
Switzerland	1	6	11	13	0	31	7
Taiwan	0	2	3	34	0	39	0
Thailand	0	3	0	0	0	3	0
Turkey	0	2	0	1	0	3	0
United Kingdom	104	15	34	40	30	223	54
United States of America	13	23	46	133	2	217	52
Virgin Islands	3	0	0	1	0	4	0
Total	372	231	339	769	188	1899	419

Notes: This table tabulates the number of unique ultimate parent firms by headquarters country that that we include in our sample to start the dataset construction. The NAICS codes correspond to the following industries: Mining, quarrying, and oil and gas extraction (21) and manufacturing (31, 32, 33). The number of ETS firms refers to the multinational firms we identified based on the data provided by Letout (2021).

Table A-2: MULTINATIONAL PARENT FIRM AND SUBSIDIARY COUNTRIES - ANALYSIS SAMPLE

Parent Country	Algeria	Angola	Benin	Botswana	Burkina Faso	Cameroon	Central Afr. R.	Chad	Congo	Congo, DR	Ivory Coast	Egypt	Equatorial Guinea	Eswatini	Ethiopia	Gabon	Ghana	Guinea	Kenya	Lesotho
Australia	0	1	0	0	0	0	0	0	0	2	0	1	0	0	0	0	1	0	1	0
Austria	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Belgium	2	1	0	2	0	0	0	0	0	1	1	4	0	1	1	0	1	0	2	0
Bermuda	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	2	0
British Virgin Islands	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Canada	0	0	0	0	1	0	0	0	0	2	6	0	0	0	2	2	0	0	2	0
Cayman Islands	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	1	0
China	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	2	0
Croatia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Denmark	0	0	0	1	0	1	0	0	1	0	3	0	0	0	0	3	0	0	2	0
Estonia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Finland	2	0	0	0	0	1	0	0	0	0	1	3	0	0	1	1	0	0	4	0
France	66	16	12	9	13	27	4	4	14	8	45	81	6	2	4	22	4	11	26	3
Germany	15	6	3	6	2	3	0	0	0	2	11	57	0	0	2	0	3	1	20	0
Greece	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	2	0
Hong Kong	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Iceland	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
India	1	0	0	1	0	2	0	0	0	0	1	4	0	0	1	0	0	0	3	0
Ireland	0	0	0	1	0	0	0	0	0	0	0	7	0	0	0	0	0	0	2	0
Italy	8	1	0	1	0	0	0	0	2	0	8	11	0	0	2	1	0	1	3	0
Japan	1	0	0	3	0	0	0	0	0	0	1	18	0	0	0	0	0	1	9	0
Korea, Rep	1	1	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0
Mexico	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0
Netherlands	1	1	0	2	0	0	0	0	0	0	2	9	1	1	0	0	2	0	5	0
Norway	1	1	1	0	0	1	0	0	1	0	0	4	0	0	1	0	1	0	1	0
Poland	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Portugal	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Russian Federation	0	0	0	1	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0
Saudi Arabia	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Singapore	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spain	4	4	0	0	1	1	0	0	0	0	2	6	1	0	0	2	0	0	3	0
Sweden	2	2	0	6	2	2	0	0	1	2	1	15	0	0	0	0	2	0	7	0
Switzerland	13	6	0	1	1	4	0	0	0	2	7	29	0	0	2	1	1	2	6	0
United Kingdom	11	9	1	13	4	7	2	0	3	6	15	36	0	6	2	5	7	1	34	2
United States	21	9	0	12	1	6	0	0	1	2	10	70	5	5	0	4	4	0	25	3
Total	152	61	17	62	25	56	6	4	23	27	117	367	13	15	18	41	26	17	165	8
In %	3.4%	1.4%	0.4%	1.4%	0.6%	1.2%	0.1%	0.1%	0.5%	0.6%	2.6%	8.2%	0.3%	0.3%	0.4%	0.9%	0.6%	0.4%	3.7%	0.2%

Notes: This table tabulates the final number of African subsidiary observations used to measure multinational firms' local emissions in African countries. The horizontal columns show the distribution by African country. The vertical lines show the distribution by multinational firm parent headquarter country.

Table A-2: MULTINATIONAL PARENT FIRM AND SUBSIDIARY COUNTRIES - ANALYSIS SAMPLE (CONTINUED)

Parent Country	Liberia	Libya	Madagascar	Malawi	Mali	Mauritania	Morocco	Mozambique	Namibia	Nigeria	Sao T. and Pr.	Senegal	South Africa	Tanzania	Togo	Tunisia	Uganda	Zambia	Zimbabwe	Total	In %
Australia	0	0	0	0	0	0	0	1	0	2	0	1	38	1	0	0	0	2	0	51	1.1%
Austria	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	5	0.1%
Belgium	0	0	0	1	0	0	7	1	3	7	0	0	52	3	0	7	3	2	0	102	2.3%
Bermuda	0	0	0	0	0	0	1	1	0	0	0	0	2	0	0	0	0	0	0	8	0.2%
British Virgin Islands	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	3	0.1%
Canada	0	0	0	0	8	0	1	0	0	1	0	1	11	1	0	1	0	0	0	39	0.9%
Cayman Islands	1	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	9	0.2%
China	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	5	0.1%
Croatia	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0.0%
Denmark	1	0	0	1	0	0	0	0	0	1	0	0	9	1	0	0	0	0	1	25	0.6%
Estonia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0.0%
Finland	0	0	0	0	0	1	3	2	0	2	0	1	16	1	0	3	0	2	0	44	1.0%
France	4	1	19	5	13	6	232	14	12	42	0	32	267	9	9	116	9	8	10	1,185	26.4%
Germany	1	0	9	2	1	1	48	6	9	9	0	6	271	6	6	25	2	3	5	541	12.0%
Greece	0	0	0	0	0	0	0	0	0	4	0	0	2	0	0	1	0	0	0	10	0.2%
Hong Kong	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	4	0.1%
Iceland	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	2	0.0%
India	0	0	0	0	0	0	2	2	1	4	0	0	33	0	0	2	0	4	0	61	1.4%
Ireland	0	0	1	0	0	0	2	5	0	0	0	0	8	0	0	0	0	0	0	26	0.6%
Italy	0	1	2	0	0	1	11	3	2	8	0	2	59	0	0	58	2	0	0	187	4.2%
Japan	1	0	1	0	0	0	11	1	1	7	0	2	83	7	0	8	1	2	1	159	3.5%
Korea, Rep	0	0	0	0	0	0	1	0	1	4	0	0	5	1	0	2	0	0	0	20	0.4%
Mexico	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0.0%
Netherlands	2	0	0	1	0	0	12	1	1	7	0	0	36	1	0	4	0	2	0	91	2.0%
Norway	0	0	0	0	0	0	1	1	0	2	0	0	10	0	0	0	0	0	0	26	0.6%
Poland	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0.0%
Portugal	0	0	0	0	0	0	0	2	0	0	1	0	0	1	0	4	1	0	0	14	0.3%
Russian Federation	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	5	0.1%
Saudi Arabia	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	6	0.1%
Singapore	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	2	0.0%
Spain	0	1	1	0	1	1	34	2	3	1	0	3	25	0	0	10	0	0	0	106	2.4%
Sweden	0	0	0	0	2	0	11	2	4	5	0	1	64	5	0	0	1	5	5	147	3.3%
Switzerland	0	0	1	1	2	0	10	5	1	16	0	3	46	2	1	10	1	2	1	177	3.9%
United Kingdom	8	0	13	1	3	0	27	20	15	57	0	8	354	19	2	13	13	14	17	748	16.6%
United States	7	0	1	2	1	1	59	6	6	65	0	7	295	2	1	27	5	6	12	681	15.2%
Total	25	3	48	14	31	11	473	75	60	245	1	67	1,708	61	19	291	38	52	52	4,494	100.0%
In %	0.6%	0.1%	1.1%	0.3%	0.7%	0.2%	10.5%	1.7%	1.3%	5.5%	0.0%	1.5%	38.0%	1.4%	0.4%	6.5%	0.8%	1.2%	1.2%	100.0%	

Notes: This table tabulates the final number of African subsidiary observations used to measure multinational firms' local emissions in African countries. The horizontal columns show the distribution by African country. The vertical lines show the distribution by multinational firm parent headquarter country.

Table A-3: ENVIRONMENTAL PERFORMANCE INDEX BY AFRICAN COUNTRY

Country	EPI as of 2010	Rank
Zimbabwe	44.3	1
Algeria	44.3	2
Zambia	42.0	3
Botswana	41.5	4
Gabon	41.4	5
Malawi	40.9	6
Central African Republic	40.8	7
Tunisia	40.3	8
Congo, Democratic Republic of the	36.8	9
Egypt	35.6	10
Eswatini	35.4	11
Kenya	34.7	12
South Africa	34.6	13
Ivory Coast	34.3	14
Ethiopia	34.2	15
Uganda	33.8	16
Senegal	33.4	17
Madagascar	33.1	18
Mali	32.7	19
Congo	32.3	20
Sao Tome and Principe	32.3	21
Cameroon	32.1	22
Ghana	32.0	23
Togo	31.6	24
Burkina Faso	31.4	25
Namibia	31.1	26
Guinea	30.6	27
Tanzania, United Republic of	29.4	28
Morocco	29.0	29
Lesotho	29.0	30
Mozambique	28.6	31
Equatorial Guinea	28.5	32
Chad	27.6	33
Mauritania	27.4	34
Nigeria	27.4	35
Benin	27.3	36
Liberia	26.3	37
Angola	24.4	38
Libya		

Notes: This table lists the value of the Environmental Performance Index (EPI) as of 2010 for the African sample countries. EPI data are from https://epi.yale.edu/downloads and published by Wolf et al. (2022). The index provides a gauge at a national scale of how close countries are to established environmental policy targets.

B Institutional Details

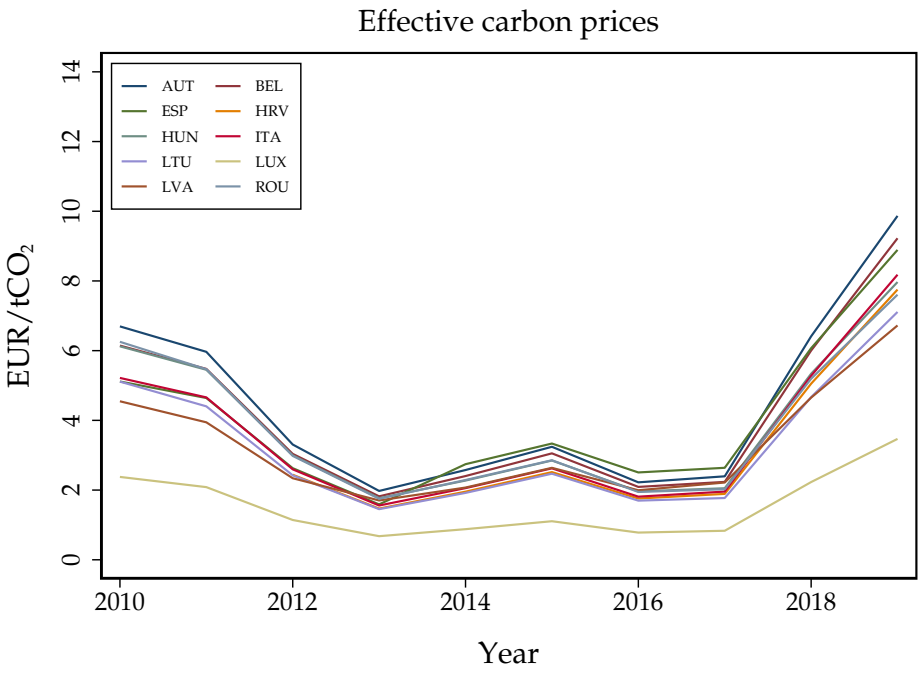
B.1 Carbon Prices in Europe

In this appendix, we provide some more detail on carbon prices in Europe. Carbon taxes were first enacted in Europe with Finland leading the way in 1990. Following an early wave of carbon tax enactments primarily in the Nordic countries, more countries enacted carbon taxes and currently sixteen European countries have carbon taxes in place. Our data on carbon prices is from Metcalf and Stock (2023), which sources the data from the World Bank.

The EU ETS was launched in 2005 as the cornerstone of the EU's policy to combat climate change. The first phase (2005-2007) served as a pilot to establish the system and its market mechanisms, often criticized for over-allocating emissions allowances which weighed down on prices. The second phase (2008-2012) coincided with the Kyoto Protocol commitment period; it aimed to tighten emissions caps and improve the robustness of the system, but issues like the continued surplus of allowances persisted. The third phase (2013-2020) introduced significant reforms including a centralized allocation of allowances and a shift from free allocation to auctioning to better reflect market principles and reduce surpluses. These phases progressively helped refine the system, setting the stage for more ambitious climate goals in subsequent phases. Not all European countries were part of the system from the start. For instance, Norway, Iceland, and Liechtenstein only joined in January 2008. Data on the EU ETS is available from the European Union Transaction Log through euets.info.

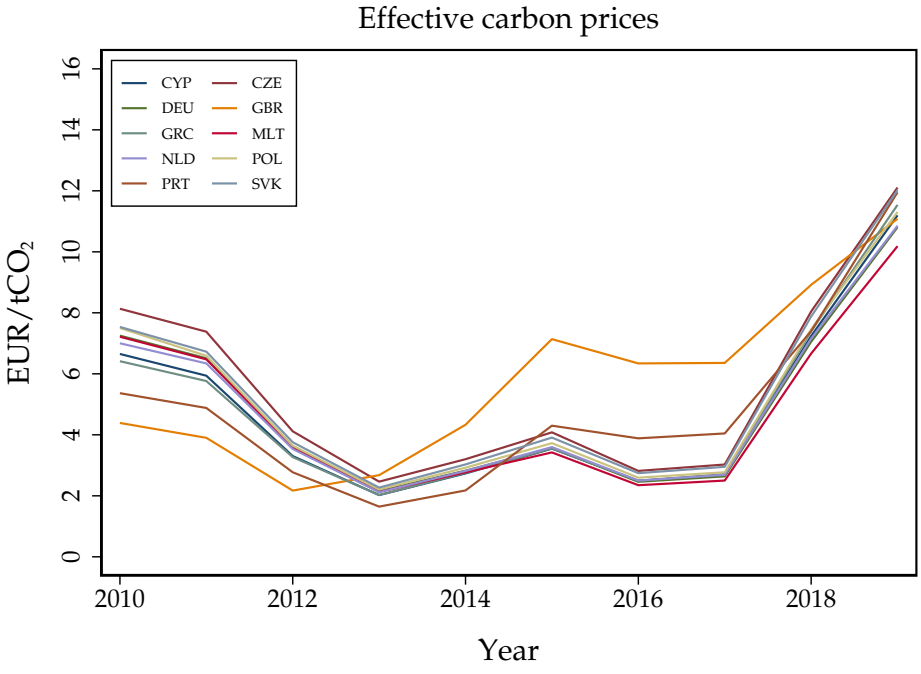
Based on this data, we construct effective carbon taxes for the European countries in our sample as the coverage-weighted sum of carbon tax rates and EU ETS prices. In Figures A-1-A-3, we display the variation in effective carbon prices over time. We split the countries into three groups according to their effective carbon price in 2009: a first group with relatively low carbon prices, a second group with average carbon prices, and a third group with high carbon prices. We can see that while there is quite a bit of variation in carbon prices over time, the differences across countries tend to persist and do not change as much.

Figure A-1: EFFECTIVE CARBON PRICES IN LESS STRINGENT COUNTRIES



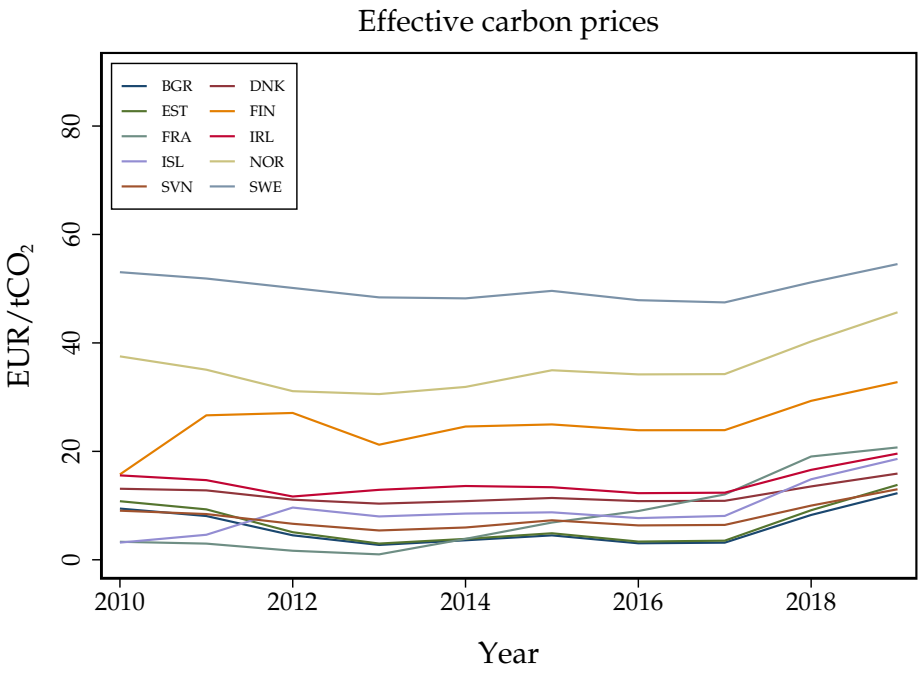
Notes: This figure shows effective European carbon prices in real 2018 euros for countries with relatively low average carbon prices. Carbon taxes and ETS prices are deflated with the GDP deflator as of 2018 and converted into euros using the 2018 exchange rate, where applicable. We weight the carbon prices by their coverage in 2019 and compute effective carbon prices as the coverage-weighted sum of carbon tax rates and ETS prices.

Figure A-2: EFFECTIVE CARBON PRICES IN COUNTRIES WITH AVERAGE CARBON STANCE



Notes: This figure shows effective European carbon prices in real 2018 euros for countries with common average carbon prices. Carbon taxes and ETS prices are deflated with the GDP deflator as of 2018 and converted into euros using the 2018 exchange rate, where applicable. We weigh the carbon prices by their coverage in 2019 and compute effective carbon prices as the coverage-weighted sum of carbon tax rates and ETS prices.

Figure A-3: EFFECTIVE CARBON PRICES IN MORE STRINGENT COUNTRIES

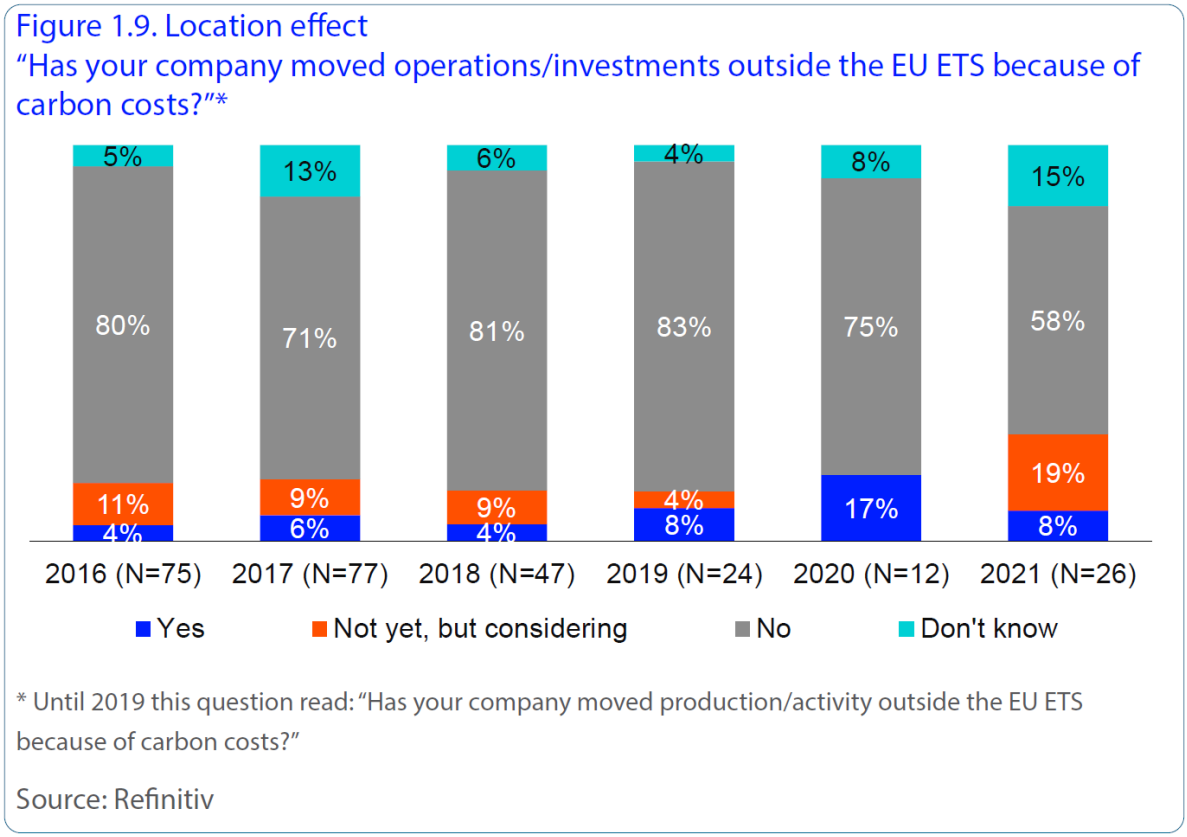


Notes: This figure shows effective European carbon prices in real 2018 euros for countries with relatively high average carbon prices. Carbon taxes and ETS prices are deflated with the GDP deflator as of 2018 and converted into euros using the 2018 exchange rate, where applicable. We weight the carbon prices by their coverage in 2019 and compute effective carbon prices as the coverage-weighted sum of carbon tax rates and ETS prices.

B.2 Carbon Leakage

As motivating evidence for the presence of carbon leakage we below present results from a survey conducted by Refinitiv. Clearly, offshoring business as a reaction to an increase in the price of emitting carbon is a consideration for firm executives.

Figure A-4: CARBON LEAKAGE: SURVEY EVIDENCE



C Supplementary and Robustness Tests

C.1 Main Results - Alternative Specifications

Table A-4: FRENCH CARBON TAX AND FIRMS' EMISSIONS IN AFRICA - DID ESTIMATES

	(1)	(2)	(3)	(4)	(5)	(6)
	ln(CO2)					
Treat × Post	0.0295***	0.0381**	0.0169	0.0387**	0.0088	0.0454**
	(0.0098)	(0.0191)	(0.0424)	(0.0176)	(0.0543)	(0.0202)
Domestic Asset Cutoff	All FR/DE	All FR/DE	> 50%	> 50%	> 75%	> 75%
Obs.	2,310	2,310	1,705	1,705	1,100	1,100
R2	0.002	0.006	0.001	0.006	0.000	0.006
Grid Cell FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
African Country × Year FE	No	Yes	No	Yes	No	Yes

Notes: This table reports results from a difference-in-difference specification, estimating the effect of the introduction of a carbon tax in France on grid-cell CO2 emissions in Africa. The treatment group are grid-cells that contain subsidiaries of multinational firms with headquarters in France, but not no subsidiaries with headquarters in Germany. The control group consists of grid-cells that contain multinational firms with headquarters in Germany, but not in France. The models complement the results reported in Figure 5 based on equation (1) by varying the fixed effects structure and sample.

Table A-5: ALTERNATIVE MEASURES OF EUROPEAN CARBON POLICY EXPOSURE

	(1)	(2)	(3)	(4)	(5)
			ln(CO2)		
Carbon Policy Exp.	0.1009***	0.1141***	0.1250***	0.1254***	
	(0.0373)	(0.0260)	(0.0354)	(0.0346)	
CO2 Tax Exp.					0.0868***
					(0.0242)
ETS Price Exp.					0.0527*
					(0.0297)
Exposure Definition:	All subsidiary industries in Europe	logarithmic Exp.	Winsorized	Empl.-weighted	CO2 taxes and ETS Prices
Obs.	7,491	7,128	7,128	7,051	7,128
R2	0.018	0.022	0.027	0.022	0.020
Grid Cell FE	Yes	Yes	Yes	Yes	Yes
African Country × Year FE	Yes	Yes	Yes	Yes	Yes

Notes: This table reports results from estimating equation 4 using OLS. The specifications are based on the main model in Column (3) of Table 4 and vary by the definition of the carbon policy exposure measure and sample composition as indicated in the table. Column (1) uses to calculate the exposure measure all subsidiary industries in Europe. Column (2) uses a log transformation of the *Carbon Policy Exp.* as our independent variable (not standardized). Column (4) winsorizes our independent variable at 1% and 99%. Column (5) separates the carbon tax from the ETS price when constructing the carbon policy exposure measure. In Column (1), (3), (4), and (5) we standardize the independent variables for ease of interpretation of the regression coefficients. Regressions are weighted by the initial (2010) level of CO2 emissions in a cell. Standard errors account for spatial dependence in a linearly decreasing manner up to 100km (as discussed by Conley, 1999). * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.
Data Source: CO2 emissions are taken from EDGAR. The multinational firm unconsolidated financial data and corporate ownership panel data are from the BvD Orbis Generics flatfiles update as of February 2023. The data on carbon taxes are from Metcalf and Stock (2023). The ETS data are from euets.info.

Table A-6: ALTERNATIVE SPECIFICATION CHOICES

	(1)	(2)	(3)	(4)	(5)
			ln(CO2)		
Carbon Tax Exp. (FTanA)	0.1614***	0.1142***	0.0678*	0.1089***	0.0706***
	(0.0531)	(0.0330)	(0.0386)	(0.0360)	(0.0273)
Outcome or Sample Variation	No Cells in South Africa	Pre Covid (<2020)	Weighted by mean CO2	ln(CO2) win. at [1;99]	ln(CO2) win. at [5;95]
Obs.	4,928	6,480	7,128	7,128	7,128
R2	0.043	0.022	0.006	0.022	0.012
Grid Cell FE	Yes	Yes	Yes	Yes	Yes
African Country × Year FE	Yes	Yes	Yes	Yes	Yes

Notes: This table reports results from estimating equation 4 using OLS. The specifications are based on the main model in Column (3) of Table 4. Columns (1) excludes cells located in South Africa. Column (2) drops 2020 from our estimation as the Covid pandemic had a global impact starting in that year. Column 3 weights cells by their mean CO2 level over the whole sample instead of their value at the beginning of the sample. Column (4) and Column (5) winsorize our outcome variable at the 1%, 99% level and 5%, 95% level respectively. The *Carbon Policy Exp.* variable is standardized for ease of interpretation of the regression coefficients. Regressions are weighted by the initial (2010) level of CO2 emissions in a cell. Standard errors account for spatial dependence in a linearly decreasing manner up to 100km (as discussed by Conley, 1999). * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.
Data Source: CO2 emissions are taken from EDGAR. The multinational firm unconsolidated financial data and corporate ownership panel data are from the BvD Orbis Generics flatfiles update as of February 2023. The data on carbon taxes are from Metcalf and Stock (2023). The ETS data are from euets.info.

Using African subsidiaries as the unit of observation. To account for even more granular time trends that could bias our inferences, we construct an alternative sample in which the unit of observation is the individual subsidiary and run additional tests using EDGAR data on grid-cell level CO2 emissions reported below.

Relative to our main design discussed in Section 4.2, the empirical design has the following specification. Instead of the grid-cell level carbon policy exposure measure, we use the exposure measure at the multinational firm level as defined in equation (3). We then estimate the impact of European carbon policies on local CO2 emissions around multinational firms' African subsidiaries using the following specification:

$$\ln(\text{CO2}_{s(i)t}) = \alpha_s + \delta_t + \beta \text{CarbonPolicyExp}_{it-1} + \epsilon_{s(i)t}, \tag{8}$$

where $\ln(\text{CO2}_{s(i)t})$ is the log-level of pollution at time t around subsidiary s owned by multinational firm i. In the simplest specification, we include subsidiary and year fixed effects. In additional specifications, we also include other fixed effects such as country by year fixed effects to control more flexibly for potential confounding factors.

Compared to our main design, the subsidiary-level observations used here are unweighted, and multiple subsidiaries—either from the same or different multinational firms—may be located within the same African grid cell.

As discussed in Section 4.2, we use this design to run several supplemental tests that allow for the inclusion of several sets of fixed effects as reported in Table A-7.

Table A-7: ALTERNATIVE EMPIRICAL DESIGN: AFRICAN SUBSIDIARY-LEVEL ANALYSIS OF EUROPEAN CARBON POLICY EXPOSURE

	(1)	(2)	(3)	(4)
Panel A	ln(CO2)			
Grid Size:	0.1 × 0.1	0.1 × 0.1	0.25 × 0.25	0.25 × 0.25
Carbon Policy Exp. (FTanA)	0.0299***		0.0260***	
	(0.0072)		(0.0060)	
Carbon Policy Exp. (TA)		0.0254***		0.0233***
		(0.0069)		(0.0061)
Obs.	50,149	51,568	50,182	51,601
Adj. R2	0.003	0.002	0.004	0.003
Subsidiary FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Panel B	ln(CO2)			
Grid Size:	0.1 × 0.1	0.1 × 0.1	0.1 × 0.1	0.1 × 0.1
Carbon Policy Exp. (FTanA)	0.0188***	0.0102**	0.0139*	0.0107***
	(0.0059)	(0.0041)	(0.0082)	(0.0041)
Obs.	50,149	50,116	50,116	49,841
Adj. R2	0.001	0.001	0.000	0.001
Subsidiary FE	Yes	Yes	Yes	Yes
Year FE			Yes	
African Region × Year FE	Yes		No	
African Country × Year FE	No	Yes	No	Yes
Parent Country × Year FE	No	No	Yes	No
Parent Country Controls	No	No	No	Yes

Notes: This table reports results from estimating equation 8 using OLS. The dependent variable is the logarithm of the mean level of CO2 emitted in grid cells around the firm location based on data from EDGAR. Columns (1) and (2) of Panel A and all Columns in Panel B include grid cells that have their center inside a cell around the subsidiary location of 0.1 × 0.1 degrees. Columns (3) and (4) of Panel A use 0.25 × 0.25 degrees. GPS coordinates are in longitude and latitude based on the World Geodetic System 1984. The independent variable *Carbon Policy Exp.* is measured as of year $t-1$ akin to a shift-share instrument measuring a firm's exposure to European countries' effective carbon prices as described in Section 2. The *Carbon Policy Exp.* variable is standardized for ease of interpretation of the regression coefficients. The weight is a multinational firm's average share of total European unconsolidated assets in the period 2007-2009 in a given European country (for details see equation 4). *Carbon Policy Exp. (FTanA)* and *Carbon Policy Exp. (TA)* refer to the exposure measures based on multinational firms' subsidiaries' unconsolidated fixed tangible or total assets, respectively, as explained in equation 3. In Europe, we include the former EU 28 member countries (EU27 + Great Britain) and measure exposure based on subsidiaries operating in the mining, quarrying, oil and gas extraction, or manufacturing industries (NAICS codes 21, 31, 32, and 33). The shift is the level of the carbon price in a European country. *Parent Country Controls* refer to the multinational firm's headquarter country's natural logarithms of GDP and population as well as the ratio of net FDI outflows to GDP. Standard errors account for spatial dependence in a linearly decreasing manner up to 100km (as discussed by Conley, 1999). * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.
Data Source: CO2 emissions are taken from EDGAR. The multinational firm unconsolidated financial data and corporate ownership panel data are from the BvD Orbis Generics flatfiles update as of February 2023. The data on carbon taxes are from Metcalf and Stock (2023). The ETS data are from euets.info. Macroeconomic variables are based on data from the World Bank.

Table A-8: THE EFFECT ON MULTINATIONALS' ECONOMIC ACTIVITY IN EUROPEAN COUNTRIES - ROBUSTNESS TO SUBSIDIARY COUNTRY-YEAR TRENDS FIXED EFFECTS

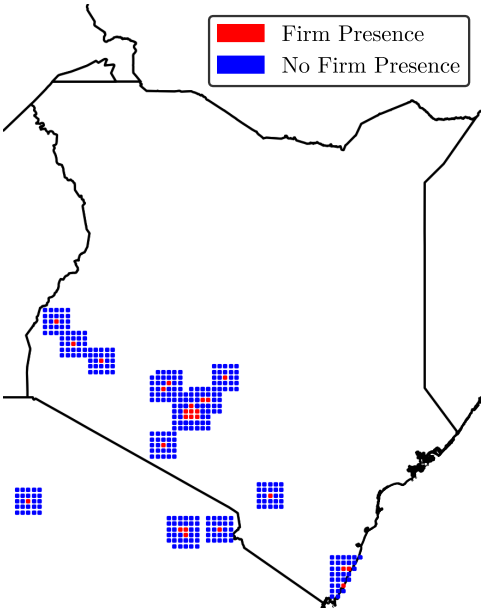
	(1)	(2)	(3)	(4)
	All EU 28	All EU 28	CO2 Price ≤10	CO2 Price >10
Panel A	ln(Fixed Tan. Assets)			
Country-Carbon Policy Exp. (FTanA)	-0.0266**			
	(0.0121)			
Carbon Policy Exp. (FTanA)		-0.0950	-0.0533	-0.1377*
		(0.0608)	(0.0824)	(0.0736)
Obs.	54,620	54,374	26,243	28,065
Adj. R2	0.937	0.937	0.942	0.933
Panel B	ln(Total Assets)			
Country-Carbon Policy Exp. (FTanA)	0.0101			
	(0.0299)			
Carbon Policy Exp. (FTanA)		0.0065	-0.0054	0.0133
		(0.0454)	(0.0712)	(0.0606)
Obs.	65,948	65,320	29,321	35,940
Adj. R2	0.932	0.933	0.935	0.931
Panel C	ln(Employees)			
Country-Carbon Policy Exp. (FTanA)	0.0016			
	(0.0122)			
Carbon Policy Exp. (FTanA)		-0.0277	-0.0123	-0.0420
		(0.0280)	(0.0395)	(0.0414)
Obs.	51,838	51,546	26,540	24,927
Adj. R2	0.949	0.949	0.949	0.949
Sub. FE	Yes	Yes	Yes	Yes
Firm HQ Country × Year FE	Yes	Yes	Yes	Yes
Sub. Country × Year FE	Yes	Yes	Yes	Yes

Notes: This table reports results from estimating a variant of equation 4 using OLS with multinational firms' European subsidiaries as the unit of observation. The specifications are based on the main model in Column (1) of Table 7 and include European subsidiary country by year fixed effects. Standard errors are clustered at the multinational firm level. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.
Data Source: The multinational firm unconsolidated financial data and corporate ownership panel data are from the BvD Orbis Generics flatfiles update as of February 2023. The data on carbon taxes are from Metcalf and Stock (2023). The ETS data are from euets.info.

D Data Details and Validation

D.1 Validation of EDGAR CO2 Emissions Data

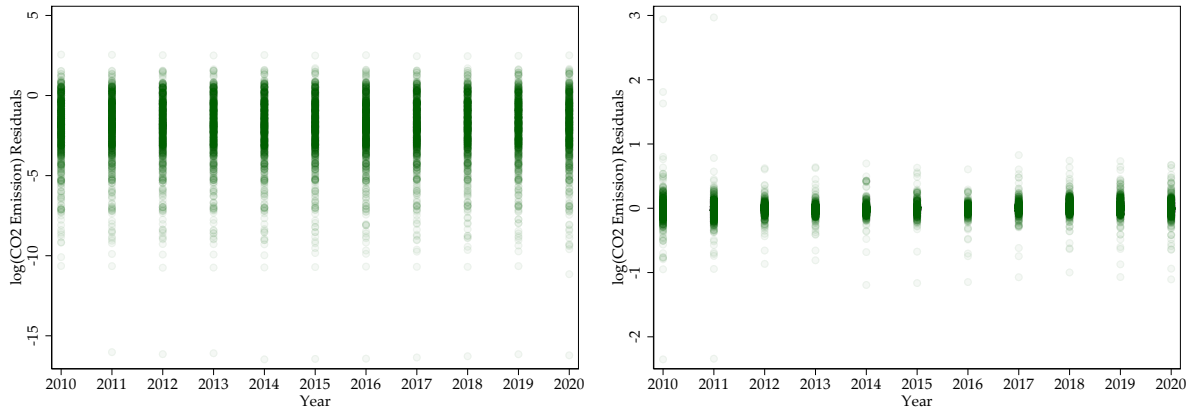
Figure A-5: FIRM GRID CELLS AND ADJACENT CELLS



Notes: This figure illustrates how we selected grid cells used in the time-series emission comparison in Figure 3 zooming in on Kenya. Red squares are grid cells that contain subsidiaries of multinational firms, blue squares do not.

Figure A-6: GRID CELL RESIDUAL VARIATION

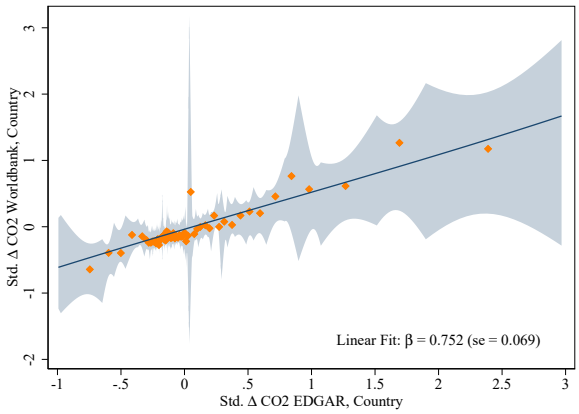
(i) COUNTRY × YEAR **(ii)** COUNTRY × YEAR AND CELL FE



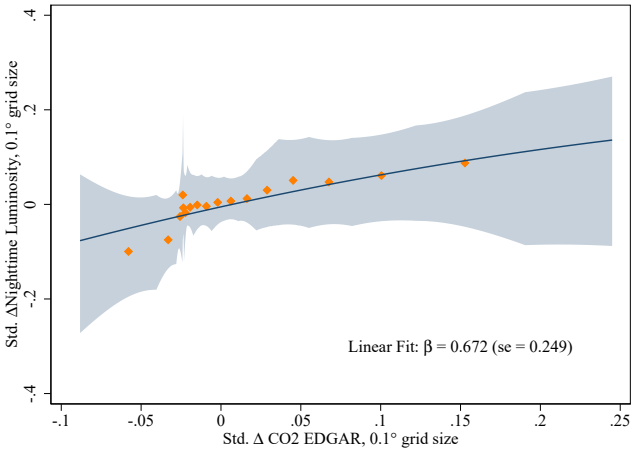
Notes: This figure shows the residual variation in the log of CO2 emissions in Edgar grid cells after conditioning on country × year fixed effects in panel (i), and on country × year fixed effects and cell fixed effects in panel (ii). In panel (ii) we omitted around 100 points that had residuals either larger than 5, or smaller than -5 for better visibility.

Figure A-7: VALIDATION OF EDGAR CO2 EMISSIONS DATA

(i) Correlation between EDGAR and World Bank CO2 data at the Country Level



(ii) Correlation between EDGAR CO2 Emissions and Nighttime Luminosity at the Grid-Cell Level



Notes: This figure presents a binscatter plot illustrating the relationship between CO2 emission data from EDGAR and CO2 emission data from the World Bank (Panel (i)) or measures of nighttime luminosity (Panel (ii). We implement a binscatter least squares estimations with robust inference using the methodology proposed in Cattaneo et al. (2023). We use canonical binscatter options with a piecewise constant, adding the sample average of the standardized change in *CO2 EDGAR* within each bin to the grid of evaluation points. The number of bins is selected via the data-driven procedure described in Cattaneo et al. (2023). The shaded area represents a 95% confidence band, calculated using first-order polynomials. A third-order polynomial fit of the regression function is added to the binned scatter plot. We also report the results of a linear fixed effects regressions within the graph. In Panel (i), we regress the standardized annual change in country-level values in *CO2 EDGAR* on the standardized annual change in *CO2 World Bank*, controlling for changes in the natural logarithm of country-level GDP and country and year fixed effects. Standard errors are clustered at the country-year level. We use a sample of 52 African countries with non-missing emissions data in both datasets from 1991-2020. In Panel (ii), we proceed analogously but use CO2 EDGAR emissions data at the 0.1×0.1 grid-size level for Sub-Saharan Africa (as in our main tests discussed in Section 4.1). We regress the standardized annual change in grid-cell-level values in *CO2 EDGAR* the standardized annual change in the same grid-cell-level nighttime luminosity measured by US Air Force Defense Meteorological Satellite Program (DMSP). We control for grid-cell and country-year fixed effects, and we drop observations with a standardized annual change of more than 1 standard deviation to mitigate the influence of extreme outliers likely reflecting measurement noise. Standard errors are clustered at the country-year level. We use a sample of approximately 30,000 unique grid cells in 51 Sub-Saharan African countries with non-missing information in both datasets from 2010-2020 as in our main tests.