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 reduce their domestic investment in Europe while worldwide investment remains unchanged – consistent with the notion that these firms shift some of their operations abroad. We confirm these results at the aggregate level, documenting a significant increase in economic activity and emissions in Africa. Policies to mitigate leakage should thus balance environmental concerns against development and equity considerations.

JEL classifications: F18, H23, Q52, Q54

Keywords: Climate policy, Multinational firms, Carbon leakage, Inequality, Economic development

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1 Introduction

The looming climate crisis is at the top of the global policy agenda. Governments around the world started to introduce policies to reduce carbon emissions via carbon taxes, emissions trading schemes, and other regulatory tools. 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. Based on a large hand collection effort, we construct a new dataset containing information on subsidiary locations of multinational firms. Using 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 operational exposure to European countries prime candidates for exploring the dynamics of 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 panel dataset includes more than 1,500 large multinational firms with almost 16,000 unique African subsidiaries and spans the period from 2010 to 2019. 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 empirical approach leverages variation in climate policies across European countries. To motivate our setting, we start with a simple differences-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 2.4 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 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 have complemented the ETS carbon market with national carbon taxes. These 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 effective carbon price measures which include coverage-weighted ETS prices and carbon tax rates.

To identify causal carbon leakage effects, we employ a shift-share design. We measure multinational firms' exposure to European carbon prices via the firms' average 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 2010-2019. Consequently, our resulting carbon policy exposure measure reflects the extent to which a multinational firm faces higher carbon prices due to regulation 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 the EU ETS.

Our estimates point to significant carbon leakage effects. Increasing the exposure to European carbon prices by one standard deviation increases emissions at African subsidiaries by more than 2 percent. Interestingly, these effects are broadly consistent with our simple event-study evidence. The results are robust along several dimensions, including varying the grid size around the subsidiaries in Africa, flexibly accounting for potential time-varying confounders using different sets of fixed effects, and using alternative definitions of our exposure measure. We also document that the carbon leakage effects are more pronounced in African countries 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 and employment 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 total investment or employment do not seem to change significantly, pointing to an increase in investment outside of Europe.[1] Consistent with this interpretation, we document no significant change in firm-wide emissions in response to higher European carbon policy exposures for the subset of multinational firms for which we observe worldwide emissions. 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.

Studying carbon leakage at the firm and firm-subsidiary levels allows us to credibly iden-

[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.

tify potential leakage effects. However, carbon leakage is a more general problem and may also occur outside firm boundaries. To address this issue, 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 and the presence of multinational firms headquartered in different European countries in a panel of 114 low- and middle-income countries. Based on this country-level shift-share design, we document a significant increase in aggregate emissions in low-income countries with greater exposure to climate policy in Europe. Specifically, a one-standard-deviation increase in a low-income country's aggregate exposure to European carbon policies is associated with an approximate 5 percent increase in country-wide emissions. Interestingly, we find leakage effects of very similar magnitude when we focus exclusively on African countries. While the estimated magnitudes are somewhat larger than the leakage effects we document within multinational firms, these findings still suggest that multinationals are a key contributor to aggregate carbon leakage. In fact, we find similar effects when we construct an alternative exposure measure based on the share of European subsidiaries operating in an African country.

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. Specifically, our results suggest that carbon leakage also comes with a reallocation of economic activity to developing countries, which likely 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; 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, Lyons, Schiffbauer and Tol, 2011; Fowlie, Holland and Mansur, 2012; Martin, De Preux and Wagner, 2014; Marin, Marino and Pellegrin, 2018; Dechezleprêtre, Koźluk, Kruse, Nachtigall and De Serres, 2019; Cui, Wang, Zhang and Zheng, 2021; Colmer, Martin, Muûls and Wagner, 2023; Brown, Martinsson and Thomann, 2022; Jacob and Zerwer, 2023; Erbertseder, Jacob, Taubenböck and Zerwer, 2023; Martinsson, Sajtos, Strömberg and Thomann, 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 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 (Greenstone, Leuz and Breuer, 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, 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, Jang, Kleimeier and Viehs, 2021; Dechezleprêtre, Gennaioli, Martin, Muûls and Stoerk, 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 two other recent studies that study potential leakage effects within firm ownership networks.[2] Cui, Wang, Wang, Zhang and Zheng (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, Chen, Liu, Serrato and Xu (2023) study a prominent energy

[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).

regulation affecting large Chinese manufacturers that are part of broader conglomerates. They show that regulated firms cut output and shifted some production to unregulated firms in the same conglomerate instead of improving their energy efficiency. Both 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 an influential 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).

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. 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, which were around 24.5 euros per tCO2e in 2019. While the ETS price is uniform, 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 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 car-

[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.

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 (2022). The ETS data are from euets.info, which sources information from the European Union Transaction Log.

bon 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 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 10 euros per tCO2e. Effective carbon prices tend to be the highest in Scandinavian countries due to the higher carbon tax

[4]In supplementary tests reported in the Appendix, we also show results when only using carbon taxes or ETS prices separately as the policy variable.

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. 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.

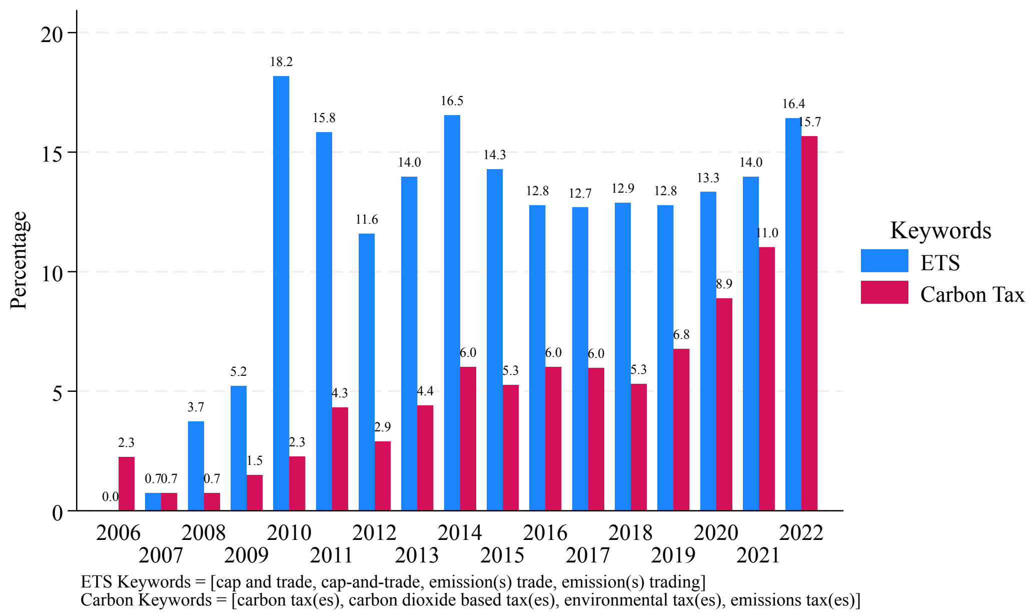
Identifying Assumptions. European carbon prices have been found to significantly reduce emissions in the policy-enacting countries, whereas the evidence on the economic impacts and mechanisms behind reduced domestic emissions is less clear (see e.g. Martin et al., 2014). A potential explanation for these 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, an underlying assumption is that firms expect the costs due to tighter carbon policies to be large enough to justify potentially costly changes in global supply chains and resource allocations. To verify that multinational firms view carbon policies as a cost to their business, we conduct a textual analysis of disclosures by U.S. firms included in our sample. Specifically, we use a keyword search to examine whether firms make qualitative disclosures about ETS or carbon taxes in their 10-K reports and use a sentiment analysis to assess whether these disclosures reflect 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, Prakash and Vera-Muñoz, 2022; Sautner, Van Lent, Vilkov and

[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.

Zhang, 2023), this evidence suggest that firms have clear financial incentives to take action to avoid higher regulated carbon prices, including shifting operations 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 well 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 multinationals that are significantly exposed to carbon taxes to similar multinationals that are not. Working at the firm level has the advantage that we can flexibly control for a selection of different fixed effects to account for a wide range of potential confounding factors. 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 (see Section 4.2).

Third, 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 in this paper that allows us to directly measure leakage, as we explain in detail in the following 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 e.g. 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.

Financials of Multinational Firms and Their European Subsidiaries. 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' sub-

[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.

sidiaries incorporated in different European countries. Fortunately, such data is available in Europe due to the financial reporting regulation requiring public and private corporations to prepare and disclose unconsolidated financial accounts (Breuer, 2021; Kim 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 country and to examine investment responses in those countries (see Section 4.2 for details on the exposure design). Importantly, financial information, let alone emissions data, is largely unavailable for subsidiaries in developing countries.

Building a Dataset of Multinational Firms' 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 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. We exclude ultimate owners based in Africa.[9]

In total, this starting sample consists of 1,519 multinational firms, of which 254 firms are covered by the EU ETS. This includes 183 firms from the U.K., 160 firms from France, 161 firms from Italy, 192 firms from the U.S., 121 from Germany, 130 from Canada, 86 firms from

[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] We drop 1 from Mauritius, 1 from Nigeria, 25 from South Africa, and 1 from Zimbabwe.

Japan, and 28 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 subsidiaries in African countries using information from Google and Google maps.[10]

We start the hand collection for 15,946 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 7,329 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 776 unique multinational firms from 36 countries worldwide with 4,519 unique African subsidiaries across 39 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 JRC Joint Research Centre and the Netherlands Environmental Assessment Agency (PBL) and is frequently used in scientific assessments, including those conducted by the Intergovernmental Panel on Climate Change (IPCC).

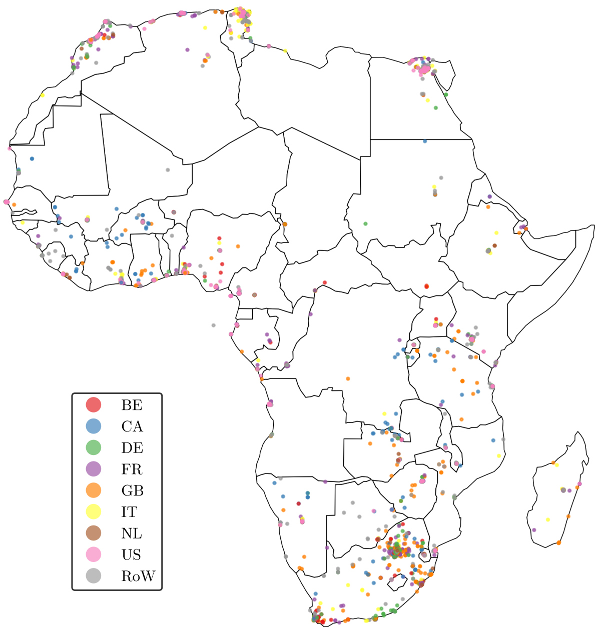
The emission statistics in EDGAR are estimated bottom-up from standard annual statistics

[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.

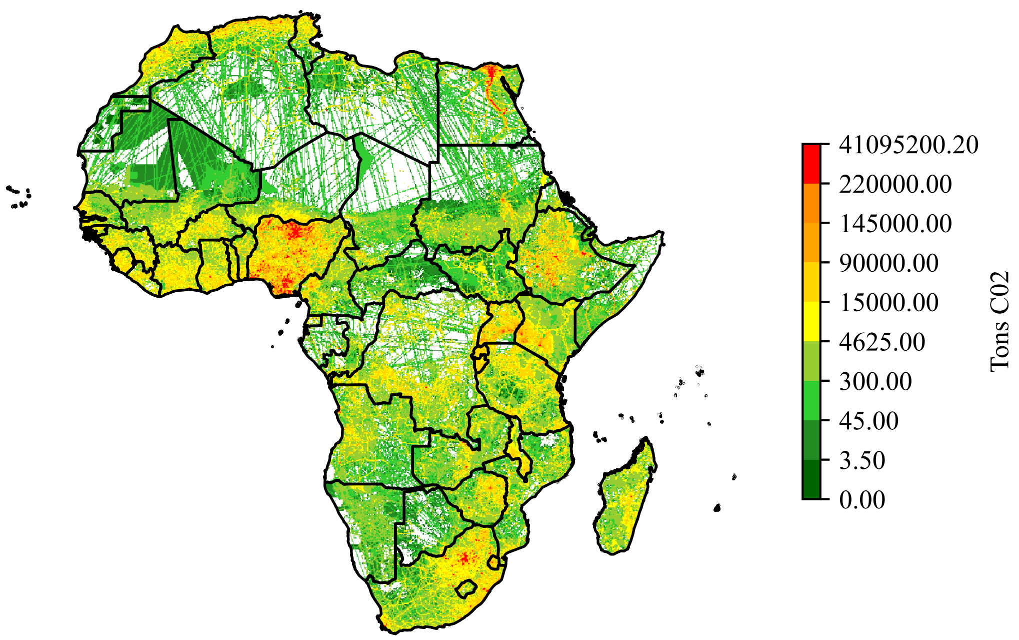
[11] We drop African countries in which we observe less than two multinational firm subsidiaries for which we can successfully merge geospatial data at the 0.1 $\times$ 0.1 degree grid level from EDGAR. This step results in a smaller number of African sample countries relative to the macro-level tests in Section 5 where we observe aggregate emissions for a panel of 49 African countries.

Figure 2: Proxying Emissions at African Subsidiaries

(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 7,329 firm locations in our dataset with subsidiaries from Belgium (160), Canada (350), Germany (771), France (1521), Great Britain (1240), Italy (336), Netherlands (208), the US (868) and the rest of the world (1,875). 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.

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 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 0.1×0.1 grid cell level for the year 2015. We can see that emissions vary a lot 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 (see Appendix D.1). 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.[12]

Worldwide Emissions of Multinationals at the Consolidated Level. We complement our firm-level consolidated financial information with information on firms' worldwide greenhouse gas (GHG) emissions from the S&P Trucost Environment Database. The Trucost database

[12] As an additional comparison, we consider spatial emission data from Climate TRACE, which rely on different methodologies to track GHG emissions. These methodologies differ by subsectors and include the use of machine learning, satellite data, and estimation based on shares of 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.

contains disclosed or estimated greenhouse gas emissions for publicly listed firms from around the world (Greenstone, Leuz and Breuer, 2023). Note that this information is only available for a smaller sample of public firms that file voluntary or mandatory sustainability reports or disclose emissions in their annual reports or sustainability reports.

Summary Statistics. We focus our analysis on the period from 2010 to 2019. We start the sample after the global financial crisis and stop before the outbreak of the Covid-19 pandemic to avoid any confounding effects of these large shocks. In Table 2, we report summary statistics for the main variables in our analyses. Panel A shows statistics for our sample of African subsidiaries, 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. We also show the total Scope 1 emissions for the subset of publicly listed firms covered in the Trucost database. Finally, Panel D shows summary statistics for our 114 low- and middle-income countries that we focus on in our macro-level analyses.

In our sample of African subsidiaries in Panel A, average annual CO2 emissions are 1,286 tCO2, measured based on the 0.1×0.1 degrees grid cell the multinational firm's subsidiary is located in. To mitigate the influence of outliers in the EDGAR data, we winsorize the respective variables in our main tests at the 2 and 98 percentiles. The subsidiaries' parent firms' mean exposure to European carbon policies is 6.59 and 7.04 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 deviations are 7.01 and 8.16, 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 Tax Policy Exp.* 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 65 million USD in unconsolidated fixed tangible assets and 628 million USD in unconsolidated total assets and has 530 employees. Panel C shows that the mean sample firm reports 7,148 million USD in consolidated fixed tangible assets and 30,353 million USD in consolidated total assets and has almost 40,000 employees worldwide. The mean public firm with available

Table 2: SUMMARY STATISTICS

	Obs.	Mean	Median	Min	Max	SD
Panel A	Multinational Firms' African Subsidiaries					
CO_2 0.1×0.1	41,760	1286.24	820.45	0.00	45157.83	2348.33
CO_2 0.25×0.25	45,190	927.44	743.32	0.05	7701.25	933.35
Carbon Policy Exp. (FTanA)	43,950	6.59	4.64	0.76	52.83	7.01
Carbon Policy Exp. (TA)	45,190	7.04	4.67	0.78	52.83	8.16
Envir. Perf. Index 2010	45,160	34.15	34.60	24.40	44.30	4.25
Panel B	Multinational Firms' European Subsidiaries					
Fixed Tan. Assets (Cons., USD m)	61,018	65.45	4.10	-0.00	15363.28	429.06
Total Assets (Cons., USD m)	66,529	627.65	27.36	0.00	232487.39	4838.64
Employees (th.)	49,169	0.53	0.11	0.00	153.00	3.14
Country-Carbon Policy Exp. (FTanA)	66,529	0.37	0.05	0.00	13.01	0.85
Carbon Policy Exp. (FTanA)	66,529	7.59	5.44	1.03	54.62	7.48
Panel C	Multinational Firms' Consolidated Statistics					
Fixed Tan. Assets (Cons., USD m)	6,036	7147.74	989.78	0.00	259651.00	19836.69
Total Assets (Cons., USD m)	6,051	30352.70	4885.83	0.00	1850772.52	91426.43
Employees (th.)	5,677	40.04	14.27	0.00	501.96	60.08
Scope 1 Emissions (th. tons)	1,912	5311.14	219.45	0.01	129292.42	15604.10
Scope 1+2 Emissions (th. tons)	1,912	6351.43	487.79	0.01	134948.50	16888.42
Scope 1 Em. Intensity	1,912	176.37	27.52	0.05	4990.00	422.38
Carbon Policy Exp. (FTanA)	6,051	6.97	5.21	1.03	54.62	6.90
Panel D	Country-level Statistics					
Carbon Policy Exp. (Macro, Trade)	1,105	6.23	5.37	1.25	26.79	3.38
Carbon Policy Exp. (Macro, Firms)	1,105	3.16	0.00	0.00	20.73	4.60
GDP Growth	1,105	3.87	4.15	-50.34	86.83	5.28
ln(Exports)	1,105	22.77	22.74	16.77	28.61	2.09
ln(Population)	1,105	16.16	16.24	11.14	21.07	1.85
CO_2 Country	1,105	241.22	26.50	0.06	12389.74	1130.41
GDP (USD m)	1,105	234.54	21.57	0.14	14296.34	1082.27

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 2010-2019. Panel A shows statistics for grid cell-level emissions from the EDGAR database. Panel B shows statistics for multinational firms' subsidiary financial data in European countries. Panel C shows statistics for multinational firms' consolidated financial data and reported Greenhouse Gas emissions from the S&P Trucost database. Panel D shows aggregate data at the country level.

greenhouse gas emission data in the Trucost database emits approximately 5.3 million tCO2e directly (Scope 1) per sample year at an intensity of approximately 176 tCO2 per million USD in revenue.[13]

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 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 pollution-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 idea is then to compare subsidiaries that are owned by a French parent firm to subsidiaries that are owned by a multinational headquartered in Germany as the relevant control group.

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, our main specifications include only firms with the largest share (80%) of their European subsidiary-level assets located in their

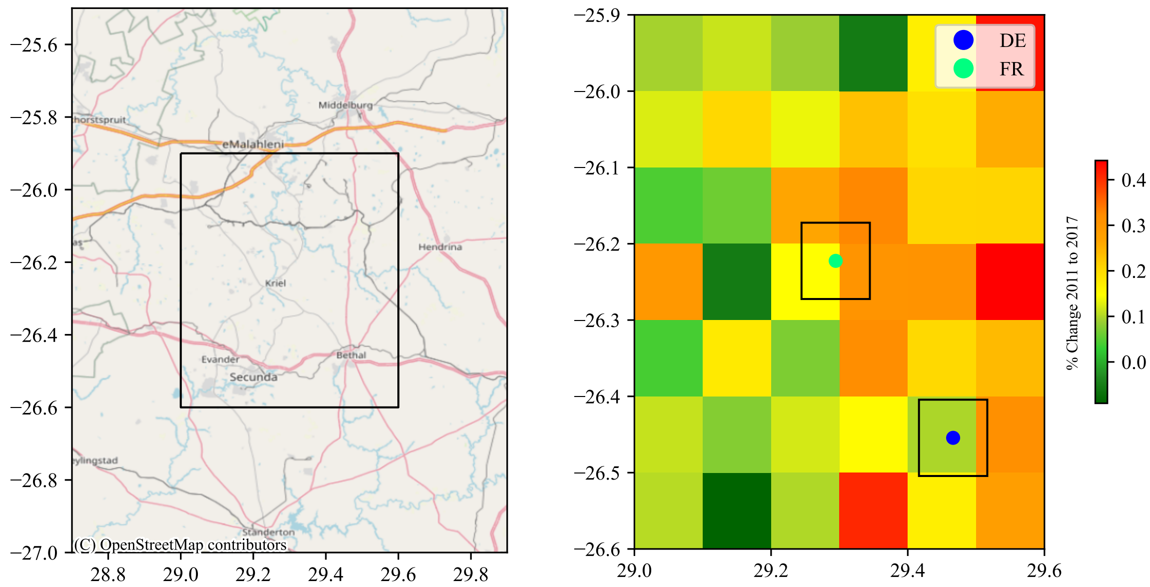
[13]The Trucost database normalizes the emission intensity metric by denominating emissions by firms' annual consolidated revenues in million USD (see https://www.spglobal.com/spdji/en/documents/additional-material/faq-trucost.pdf).

home country. 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 that should affect French multinational firms systematically differently than German peers starting in 2014. We further provide support for this assumption by estimating pre-treatment period differences between treated and control firms.

Figure 3: 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 colour indicates the percentage change in CO2 emissions from 2011 to 2017.

Figure 3 illustrates our differences-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 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 dot shows the location of the French and the blue dot shows the location of the German subsidiary. The black square around the firm is of size 0.1 × 0.1 degrees (approximately

11km × 11km). We can see that the French-owned South African subsidiary, whose parent has become subject to a carbon tax, displays a stronger increase in emissions than the German subsidiary. 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:

$$\ln(\text{CO2}_{s(i)t}) = \alpha_s + \delta_t + \sum_{r \neq -1} \beta_t \times \mathbf{1}\left[r = t\right] \times \text{Treat}_s(i) + \epsilon_{st}, \tag{1}$$

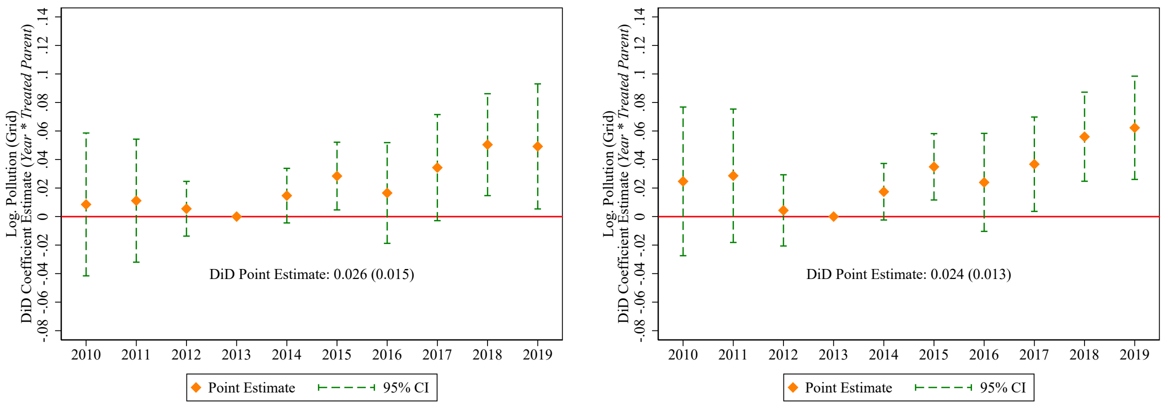
where $\ln(\text{CO2}_{s(i)t})$ is the log-level of pollution at time t in the grid cell(s) matched to subsidiary s owned by parent firm i. We include subsidiary (i.e. grid-cell) fixed effects, α_s, and year fixed effects, δ_t. $\text{Treat}_s(i)$ is a binary treatment indicator equal to one if the subsidiary is owned by a multinational firm headquartered in France (France introduced a carbon tax in 2014). $\text{Treat}_s(i)$ is equal to zero if the subsidiary is owned by a multinational firm headquartered in Germany. For inference, we use Conley spatial HAC standard errors to account for spatial dependence in a linearly decreasing manner up to 500km (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 4 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.

The results are robust to varying the grid size around the subsidiaries. Using a grid size of 0.1×0.1 or 0.25×0.25 yields very similar results, as can be seen in Panels (i) and (ii) of Figure 4. In terms of magnitudes, our estimates suggest that African subsidiaries with French parents increase their emissions by approximately 2 percent more than those of German subsidiaries after two years and more than 4 percent after four years. To gauge the overall impact, we

Figure 4: IMPACT OF FRENCH CARBON TAX ON MULTINATIONALS' EMISSIONS IN AFRICA

(i) Grid Size: 0.1 **(ii)** Grid Size: 0.25



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 at African subsidiaries of multinational firms with headquarters in France. The control group are African subsidiaries of multinational firms with headquarters in Germany. 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* $\times$ *Treated* indicator from the corresponding differences-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 (Panel i) or 0.25×0.25 (Panel ii) around the firm location based on data from EDGAR. We restrict the sample to firms which have an exposure of $> 80\%$ to the domestic market based on their total assets. Confidence intervals are reported based on Conley spatial HAC standard errors. We report results based on alternative samples in Figure A-5 in the Appendix.

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 4. Consistent with the event-study evidence, our estimates suggest that carbon subsidiary-level emissions increased by close to 3 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 about 7 euros per tCO2e at introduction in 2014.[14]

We run several tests based on alternative specifications and report the results in the Appendix. We find similar results, albeit estimated with less precision, when using the full sample of French and German multinationals irrespective of their home country asset exposure. 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 larger point estimates when restricting the sample to firms with more than 90 percent of their European subsidiary-level assets being located in their home country (Figure A-5). Finally, Table A-4 in the Appendix shows that our difference-in-differences inferences remain qualitatively unchanged after controlling for country-year fixed effects and using different samples.

[14]Subsequently, from 2015 to 2019, it rose slowly but steadily and reached a level of 44 euros per tCO2e at the end of our sample.

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 based on a shift-share design. 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.

A New Exposure Measure. To measure multinational firms' exposure to European carbon policies, we proxy to what extent a multinational is subject to effective European carbon prices via its operations in Europe. We construct the exposure measure as follows.

First, we measure the extent to which a multinational operates in a given European country. We do this by looking at unconsolidated total or fixed tangible assets in the country of interest 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 m 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).[15]

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. de-

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

flating them using the relevant GDP deflator and weighting by the country-specific emission coverage of the policy as in Metcalf and Stock (2023).

Table 3: FIRMS' EUROPEAN CARBON POLICY EXPOSURE AND 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 (2022). The ETS data are from euets.info. Macroeconomic variables are based on data from the World Bank.

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 0.97 environmental-policy related words per thousand words in 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.

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

$$\ln(\text{CO2}_{s(i)t}) = \alpha_s + \delta_t + \beta \text{CarbonPolicyExp}_{it-1} + \epsilon_{s(i)t}, \tag{4}$$

where $\ln(\text{CO2}_{s(i)t})$ is the log-level of pollution at time t around subsidiary s located 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.

This design leverages variation in the overall exposure of multinationals to European carbon prices. It exploits the interaction of a multinational firm's pre-determined exposure to different European countries' environmental policies based on the location of their assets with the time-series variation in these countries' carbon policies to arrive at a cost of emitting CO2 which affects multinational firms differentially.

Table 4 reports the results. We can see that multinationals with higher exposure to European carbon policies increase their emissions at African subsidiaries relatively more. These effects are statistically and economically significant. An increase in a multinationals firm's carbon policy exposure by one standard deviation leads to an increase in emissions around its African subsidiaries by 2.4 to 3.2 percent.

The results are robust along a number of dimensions. In particular, the results are robust to the exposure measure used: using unconsolidated total or fixed tangible assets to measure exposure produces very similar results, albeit the effects are a bit larger when we focus on fixed tangible asset exposure. This finding is consistent with fixed tangible assets more accurately proxying for firms' operations that cause carbon tax liabilities because accounting standards define fixed tangible assets as physical items used to produce products and services over a period of more than one year. Furthermore, we obtain consistent results when we vary the grid size to proxy subsidiary-level emissions.

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

	(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)	0.0312***		0.0267***	
	(0.0077)		(0.0062)	
Carbon Policy Exp. (TA)		0.0276***		0.0235***
		(0.0076)		(0.0064)
Obs.	40,640	41,760	43,950	45,190
Adj. R2	0.004	0.003	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)	0.0193***	0.0087**	0.0200**	0.0091**
	(0.0064)	(0.0038)	(0.0086)	(0.0038)
Obs.	40,640	40,640	40,640	40,390
Adj. R2	0.002	0.001	0.001	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 4 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 500km (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 (2022). The ETS data are from euets.info. Macroeconomic variables are based on data from the World Bank.

Threats to Identification. As we have seen above, our results are robust along a number of dimensions, including the grid size and definition of carbon tax exposure. In all our specifications, we have also included subsidiary and year fixed effects to control for time-invariant subsidiary specific characteristics, which also span the characteristics of the parent companies, as well as global trends.

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 subsidiary 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 Panel B of Table 4 we address these potential concerns by examining the robustness of our results subject 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 1). The point estimate of 0.02 is somewhat smaller than the baseline estimate of 0.03 but still highly statistically significant. In an even more restrictive specification in Column 2, we include African country by year fixed effects, which leads to a design in which we compare 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 smaller effect size which is still significant at conventional levels. To account for different trends in the parent country, we also include parent country-year fixed effects (Column 3). In our most restrictive specification, we again include African country by year fixed effects and control for a selection of macroeconomic variables in the parent firm countries. Again, we estimate somewhat smaller but robust results. The coefficient retains statistical significance if we include African country by year by industry fixed effects (results not tabulated). We also ran separate regression for the four NAICS codes, 21, 31, 32 and 33. The effect is strongest for industry classification 31 which manufacturing related to agriculture or animal produce. Overall, these results illustrate that our finding of carbon leakage effects within multinational firm networks is very robust and survives when controlling flexibly for potential time-varying confounders.

Heterogeneity in Firm Responses Based on 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 environmental policy targets. Table A-3 in the Appendix lists the 2010 values in EPIs by African sample country.

Table 5: CARBON LEAKAGE AND AFRICAN COUNTRIES' ENVIRONMENTAL STANCE

	(1)	(2)	(3)
		ln(CO2)	
Grid Size:	0.1 × 0.1	0.1 × 0.1	0.1 × 0.1
Carbon Policy Exp. (FTanA)	0.0379***	0.0170	0.0664***
	(0.0091)	(0.0117)	(0.0201)
Carbon Policy Exp. (FTanA) × EPI Quintile			-0.0140*
			(0.0073)
African Countries' Closeness to Environmental Policy Targets	≤ median	> median	Full Sample Quintile Groups
Obs.	29,260	11,380	40,630
Adj. R2	0.006	0.001	0.007
Subsidiary FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes

Notes: This table reports results from estimating sub-sample and cross-sectional tests based on our main specification from Column 1 of Table 4. In Column 1, the sample only includes African countries with a median or below-median Environmental Performance Index (EPI) value as of 2010. In Column 2, the sample only includes African countries with an above-median Environmental Performance Index (EPI) value as of 2010. In Column 3, we interact the main carbon policy exposure variable of interest, *Carbon Policy Exp.*, with the categorical variable *EPI Quintile* taking on values of 1 to 5 and grouping African countries based on their EPI as of 2010. The *Carbon Policy Exp.* variable is standardized for ease of interpretation of the regression coefficients. Standard errors account for spatial dependence in a linearly decreasing manner up to 500km (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 (2022). 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`.

In Table 5, we document predictably larger effects with an effect size of close to 4 percent in the subsample of African countries with a median or below-median EPI as of 2010, the beginning of our sample period. This coefficient is statistically highly significant. The estimated coefficient for the subsample of African countries with an above-median EPI is less than half as big and not statistically significant at conventional levels. While this could be due to the smaller sample size, the substantially smaller effect size clearly indicates that multinational firms avoid European carbon taxes by exporting emissions to the least regulated jurisdictions which are mostly in Sub-Saharan Africa. We corroborate this inference using an alternative specification in which we create quintiles based on countries' 2010 EPI and interact this quintile variable with our main policy exposure measure of interest (Column (3)).

Additional Analyses. We conduct several analyses to validate our inferences and report results in Tables A-5 and A-6 in the Appendix. Specifically, we show that our results are robust to using alternative definitions or our exposure measure, such as weighting by subsidiary assets in all industries and using employment as the weighting factor. We also demonstrate that our results are robust to excluding sample firms that are covered by the EU ETS. When studying ETS firms only and using an exposure measure that only captures ETS prices, we document smaller and statistically insignificant effect sizes. This is not too surprising as our empirical design leverages heterogeneity in effective carbon prices, which is much smaller when focusing on ETS prices only. Thus, the heterogeneity in national carbon taxes provides very useful variation for identification. The results are also unaffected if we do not winsorize the emissions proxies from EDGAR. Finally, our results are robust to excluding oil producing countries, such as Nigeria and Angola, or dropping subsidiaries in South Africa.

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 multinational firms' consolidated and subsidiary-level unconsolidated financial statement data. We examine investment in European countries as well as worldwide consolidated investment and overall emissions of multinationals affected by carbon taxes in our sample. We focus on those multinationals that own the African subsidiaries included in our main specifications in Section 4.2.

European Subsidiary-level Economic Activity. To this end, we begin by estimating a specification akin to equation (4) for our sample of European subsidiaries. As outcomes, we look at fixed tangible assets, total assets and the number of employees. 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, $\text{CarbonPolicyExp}_{it}$, as it multiplies 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 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 bloc.

Table 6 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 significantly. 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 subsidiaries located countries with relatively high carbon tax prices (Column (4)). These countries mostly have a domestic carbon tax in place in addition to the EU-wide ETS. This suggests that in response to an increase in the exposure to European carbon prices, multinationals reduce their operations, particularly in countries that are directly affected by the regulation. The effect on total assets also tends to be negative but not significant. This is perhaps not too surprising, as total assets 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. Finally, we also document a significant fall 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.

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 3 percent. Notably, our results are robust to accounting for country-year trends (see Table A-7 in the Appendix). Overall, these findings point to significant carbon leakage from Europe to

Table 6: The Effect on Multinationals' Economic Activity in Europe

	(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)	-0.0193**			
	(0.0081)			
Carbon Policy Exp. (FTanA)		-0.0304*	-0.0377	-0.0963**
		(0.0167)	(0.0250)	(0.0434)
Obs.	53,108	53,108	38,148	13,473
Adj. R2	0.934	0.934	0.942	0.943
Panel B	ln(Total Assets)			
Country-Carbon Policy Exp. (FTanA)	0.0018			
	(0.0129)			
Carbon Policy Exp. (FTanA)		-0.0118	0.0003	0.0477
		(0.0183)	(0.0176)	(0.0477)
Obs.	64,211	64,211	44,685	17,673
Adj. R2	0.925	0.925	0.927	0.949
Panel C	ln(Employees)			
Country-Carbon Policy Exp. (FTanA)	-0.0084			
	(0.0087)			
Carbon Policy Exp. (FTanA)		-0.0226***	-0.0165*	-0.0483
		(0.0080)	(0.0099)	(0.0324)
Obs.	46,738	46,738	32,558	12,661
Adj. R2	0.947	0.947	0.950	0.962
Sub. FE	Yes	Yes	Yes	Yes
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 (2022). The ETS data are from euets.info.

the developing world through the reallocation of capital and economic activity.

Consolidated Firm-level Investment and Emissions. How do these results look like at the consolidated, worldwide level? Our evidence so far suggests that firms with greater exposure to European carbon policies relocate operations at their European subsidiaries to subsidiaries in other countries, including Africa. However, multinationals with substantial carbon policy exposure may also lose market share to competitors with less or no such exposure. Thus, it is interesting to study the total effect on firm-wide activity is.

Table 7: THE EFFECT ON EMISSIONS AND ACTIVITY AT THE CONSOLIDATED LEVEL

	(1)	(2)	(3)
Panel A	ln(Fixed Tan. Assets)	ln(Total Assets)	ln(Employees)
Carbon Policy Exp. (FTanA)	-0.0199	-0.0050	-0.0052
	(0.0262)	(0.0202)	(0.0242)
Obs.	6,006	6,041	5,665
Adj. R2	0.959	0.978	0.954
Panel B	ln(Scope 1 Emissions)	ln(Scope 1+2 Emissions)	ln(Scope 1 Em. Intensity)
Carbon Policy Exp. (FTanA)	-0.0124	-0.0483	-0.0545
	(0.0785)	(0.0690)	(0.0727)
Obs.	1,906	1,906	1,906
Adj. R2	0.955	0.961	0.929
Firm FE	Yes	Yes	Yes
Year FE	Yes	Yes	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. In Panel A, the dependent variable is the logarithm of the multinational firms' consolidated fixed tangible assets (Column 1), total assets (Column 2), or the number of employees (Column 3) for our main firms with consolidated financial data in Orbis. In Panel B, the dependent variable is the log of Scope 1 Greenhouse Gas Emissions (Column 1), log of Scope 1 plus Scope 2 Greenhouse Gas Emissions (Column 2), or the log of Scope 1 Greenhouse Gas Emissions Intensity (Column 3). The independent variable *Carbon Policy Exp.* is our main exposure measure in year $t-1$ as used in Table 4. The *Carbon Policy Exp.* variable is 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 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 (2022). The ETS data are from euets.info. Macroeconomic variables are based on data from the World Bank. Firm-wide emissions are from the S&P Trucost Environment Database as of May 2023. Scope 1 Emissions of public firms in the Trucost database are primarily from mandatory and voluntary company disclosures of public firms (annual reports and sustainability/CSR reports).

We build on our tests at the European subsidiary level (Table 6) and relate the respective consolidated activity measures to the firms' carbon policy exposure. For the subsample of firms covered by the S&P Trucost database, we also estimate the effects on firms' worldwide GHG emissions. In particular, we consider scope 1 and 2 emissions as well as the emission intensity.

Table 7 shows the results. We can see that the effects are negative but largely insignificant. The estimates seem to point to a fall in economic activity as proxied by assets and employment, but the effects are relatively small and not statistically significant. In line with previous studies, we confirm that European carbon policies are successful at reducing emissions. However, the effects are again not statistically significant, likely driven by the fact that we only observe this data for a subset of public firms. These results turn out to be robust when we focus on variation from multinational firms from the same headquarters country in the same year (Table A-8 in the Appendix).

The finding that activity at the consolidated level does not fall significantly, coupled with the significant fall in activity at European subsidiaries provides further, indirect evidence on carbon leakage.

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. 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 emission in other 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 114 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 (48), America (19), Asia (33), Europe (8) and Oceania (6). Out of these, 20 are low income, 51 lower middle income, and 43 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.[16]

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:

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

where cprice_d is the carbon price in European country d that is weighted by w_{cd}. We can then estimate the impact of European carbon prices on CO2 emissions for the years 2010 to 2019 in the following way:

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

Here, CO2_{ct} is the level of emissions of country c at time t as measured in tons of CO2e, α_i

[16] We focus on SITC-codes 2, Crude Materials, Inedible, Except Fuels, 3, Mineral Fuels, Lubric. And Related Mtrls., 5, Chemicals And Related Products, N.E.S., 6, Manufactured Goods Classif. By Material, 7, Machinery And Transport Equipment, and 8, Miscellaneous Manufactured Articles, as these are the most relevant to our question.

are country fixed effects, δ_t are year fixed effects, and $\boldsymbol{X}_{ct}$ is a vector of control variables[17]. 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 8: CARBON LEAKAGE TO LOWER-INCOME COUNTRIES AT THE MACRO LEVEL

	(1)	(2)	(3)	(4)	(5)
			ln(CO2 Country)		
Sample:	Full	Full	Upper Middle	Lower Middle	Low Income
Carbon Policy Exp. (Macro, Trade)	0.025	0.026	0.007	-0.003	0.045***
	(0.02)	(0.02)	(0.08)	(0.05)	(0.01)
ln(GDP)	0.610***	0.625***	0.791***	0.191	0.323**
	(0.12)	(0.14)	(0.13)	(0.22)	(0.15)
GDP Growth	-0.001**	-0.001**	0.001	-0.000	-0.000
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
ln(Exports)	0.053**	0.077***	0.034	0.009	0.113***
	(0.03)	(0.03)	(0.08)	(0.03)	(0.04)
ln(Population)	0.229	0.149	-0.222	0.188	-0.440
	(0.18)	(0.24)	(0.42)	(0.45)	(0.38)
Obs.	1105	1095	367	436	185
Adj. R2	0.998	0.998	0.998	0.998	0.995
Country FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes				
Year $\times$ Region 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 consists of 114 countries over the period 2010-2019. 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.

Country-level Shift-share Design. Table 8 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. 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 4.5 percent. This confirms our notion that low income countries are prime destinations for potential carbon leakage. The results are robust to controlling for year or year by region fixed effects.

[17]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 also estimate the regression without control variables. We obtain qualitatively similar results, but the coefficients are measured less precisely.

Table 9: CABON LEAKAGE TO AFRICA AT THE MACRO LEVEL

	(1)	(2)	(3)	(4)
	ln(CO2 Country)			
Sample:	Africa	Africa	Africa	Africa
Carbon Policy Exp. (Macro, Trade)	0.039**	0.041**		
	(0.02)	(0.02)		
Carbon Policy Exp. (Macro, Firms)			0.053***	0.063***
			(0.02)	(0.02)
ln(GDP)	0.340*	0.279	0.350**	0.280
	(0.18)	(0.19)	(0.17)	(0.18)
GDP Growth	-0.000	-0.000	-0.000	-0.000
	(0.00)	(0.00)	(0.00)	(0.00)
ln(Exports)	0.041	0.060**	0.028	0.050*
	(0.03)	(0.03)	(0.03)	(0.03)
ln(Population)	0.236	0.529	0.116	0.566
	(0.53)	(0.61)	(0.52)	(0.56)
Obs.	463	463	463	463
Adj. R2	0.997	0.997	0.998	0.997
Country FE	Yes	Yes	Yes	Yes
Year FE	Yes		Yes	
Year × Region FE		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 48 African countries over the period 2010-2019. 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. 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.

How do these effects compare to leakage effects to African countries? To analyze this, we run our macro shift-share design on the subset of African countries. The results are shown in Table 9. The estimated effect is very similar to the average effect estimated for our entire sample of low-income countries. This finding alleviates concerns about external validity and suggests that studying carbon leakage effects to Africa is informative about leakage effects more broadly. Using the exposure measure based on multinational firms' subsidiary locations produces very similar results compared to using the trade-based measure. This illustrates that multinationals' subsidiary networks are informative for the carbon policy exposure, even at the macro level.

The estimated effects are somewhat larger compared to what we estimate at the firm level. This is maybe not too surprising since the firm-level results focus on the intensive margin of carbon leakage within multinational firms. The macro shift-share analysis suggest that this is a relevant margin but that carbon leakage may also happen along the extensive margin within multinational firms, as well as outside multinational ownership networks.

Our results are robust to excluding South Africa, excluding countries in Northern Africa, excluding major oil and gas producing countries and excluding counties with a small population.

To illustrate the magnitude of change of our instrument over time, we give two example for the case where we use trade shares. The standardised instrument increased from -0.889 in 2015 to -0.243 in 2018 for Algeria; for Kenya, it increased from -0.128 to 0.201 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.

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, including worldwide emissions, 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. 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

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Julian Marenz
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This version: May 17, 2024

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A Data and Summary Statistics

Table A-1: Multinational Parent Sample - Dataset Construction

	NAICS Code								NAICS Code						
Country	21	31	32	33	Other	Total	ETS Firms	Country	21	31	32	33	Other	Total	ETS Firms
Austria	1	0	0	3	0	4	0	Jordan	0	0	1	0	0	1	0
Australia	20	2	5	4	0	31	0	Japan	0	5	19	62	0	86	0
Belgium	2	12	7	14	6	41	16	Korea, Republic of	0	0	1	9	0	10	0
Bermuda	7	3	0	2	0	12	0	Kuwait	1	0	1	0	0	2	0
Brazil	0	0	1	3	0	4	0	Cayman Islands	1	3	0	2	0	6	0
Canada	112	1	10	7	0	130	1	Mexico	0	1	2	0	0	3	0
Switzerland	1	6	9	11	0	27	0	Malaysia	2	1	1	2	0	6	0
China	1	1	5	21	0	28	0	Netherlands	6	4	6	14	11	41	22
Cyprus	1	1	0	0	0	2	0	Norway	2	0	1	3	0	6	0
Germany	0	3	21	64	33	121	54	New Zealand	0	1	0	1	0	2	0
Denmark	0	3	2	1	0	6	0	Pakistan	0	1	0	0	0	1	0
Estonia	0	0	0	1	0	1	0	Poland	0	0	0	1	0	1	0
Spain	5	20	12	25	22	84	31	Portugal	1	0	2	1	0	4	0
Finland	0	1	3	11	0	15	0	Serbia	0	0	0	1	0	1	0
France	9	32	28	66	25	160	42	Russia	2	0	0	0	0	2	0
United Kingdom	80	13	28	34	28	183	51	Saudi Arabia	0	1	1	1	0	3	0
Greece	0	0	2	4	0	6	0	Sweden	1	3	2	17	0	23	0
Hong Kong	0	0	0	4	0	4	0	Singapore	0	3	0	4	0	7	0
Croatia	0	1	0	0	0	1	0	Thailand	0	2	0	0	0	2	0
Ireland	6	2	4	9	0	21	4	Turkey	0	1	0	1	0	2	0
India	0	4	20	21	0	45	0	Taiwan	0	2	3	20	0	25	0
Iceland	0	0	0	2	0	2	0	United States of America	10	21	43	116	2	192	0
Italy	5	29	32	67	28	161	33	Virgin Islands	3	0	0	1	0	4	0
								Total	279	183	272	630	155	1519	254

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 observations used in the African subsidiary-level tests by African subsidiary country (horizontally) and multinational firm parent country (vertically).

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 observations used in the African subsidiary-level tests by African subsidiary country (horizontally) and multinational firm parent country (vertically).

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

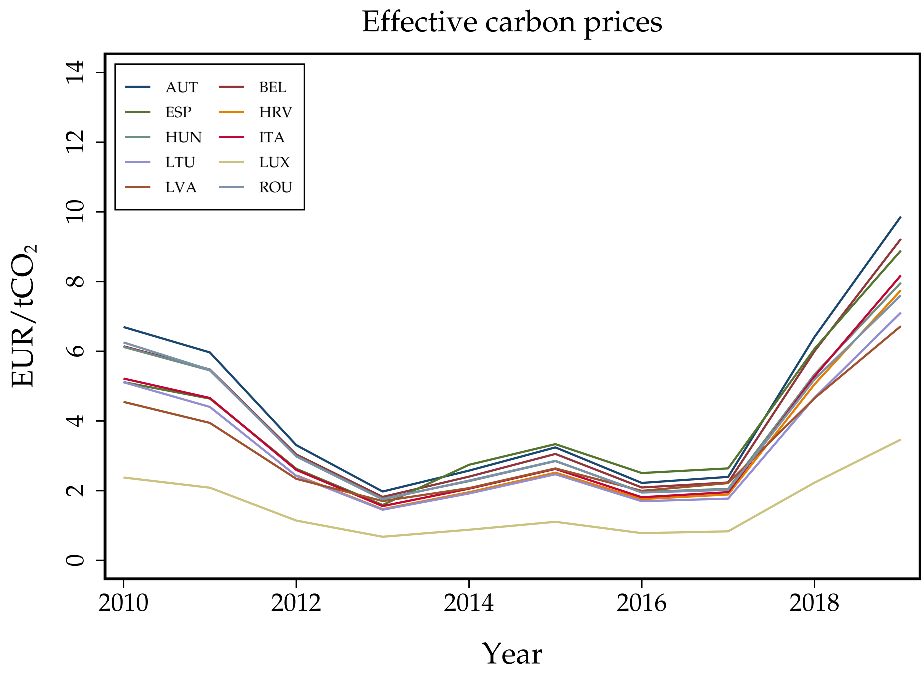
B.1 Carbon Prices in Europe

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.

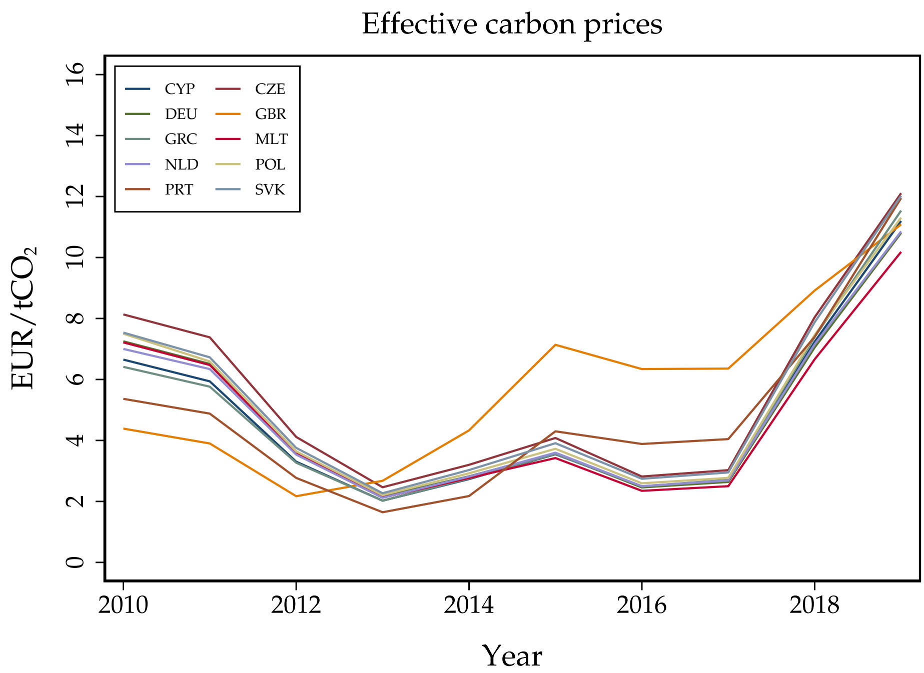
Based on this data, we construct effective carbon taxes for the European countries in our sample as the coverage-weighted sum of carbon tax rates and EU ETS prices. In Figures A-1-A-3, we display the variation in effective carbon prices over time. We split the countries into three groups according to 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



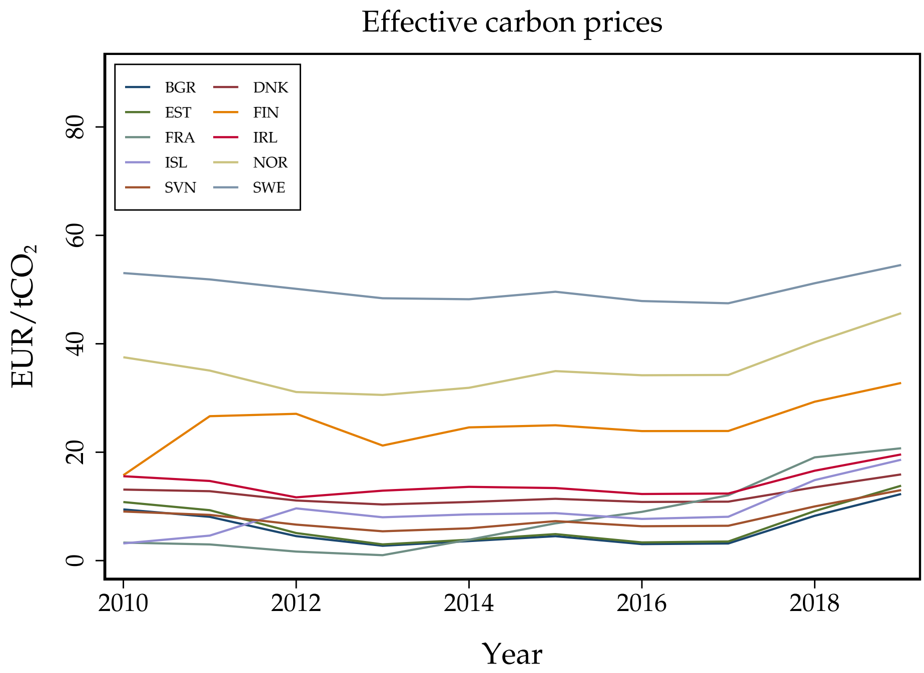
Notes: This figure shows effective European carbon prices in real 2018 euros for countries with relatively low average carbon prices. Carbon taxes and ETS prices are deflated with the GDP deflator as of 2018 and converted into euros using the 2018 exchange rate, where applicable. We weigh the carbon 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-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

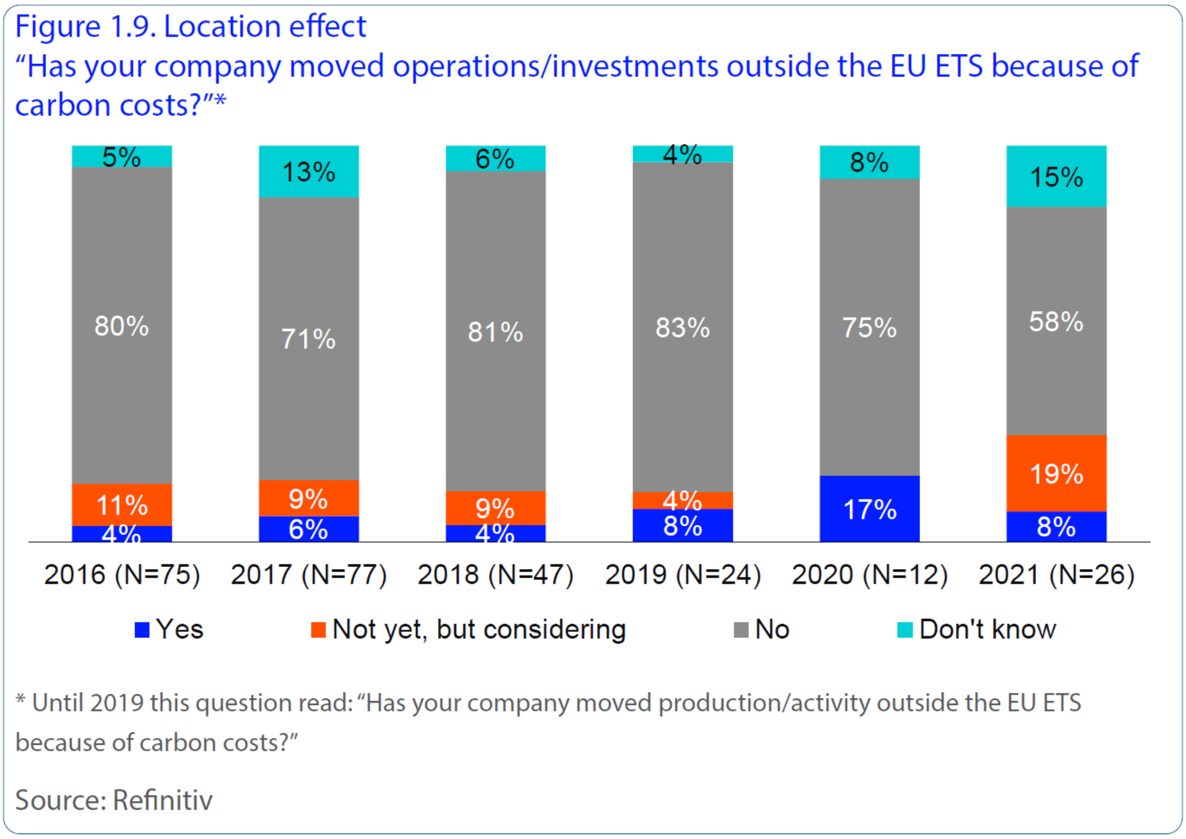


Notes: This figure shows effective European carbon prices in real 2018 euros for countries with relatively high average carbon prices. Carbon taxes and ETS prices are deflated with the GDP deflator as of 2018 and converted into euros using the 2018 exchange rate, where applicable. We weigh the carbon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

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



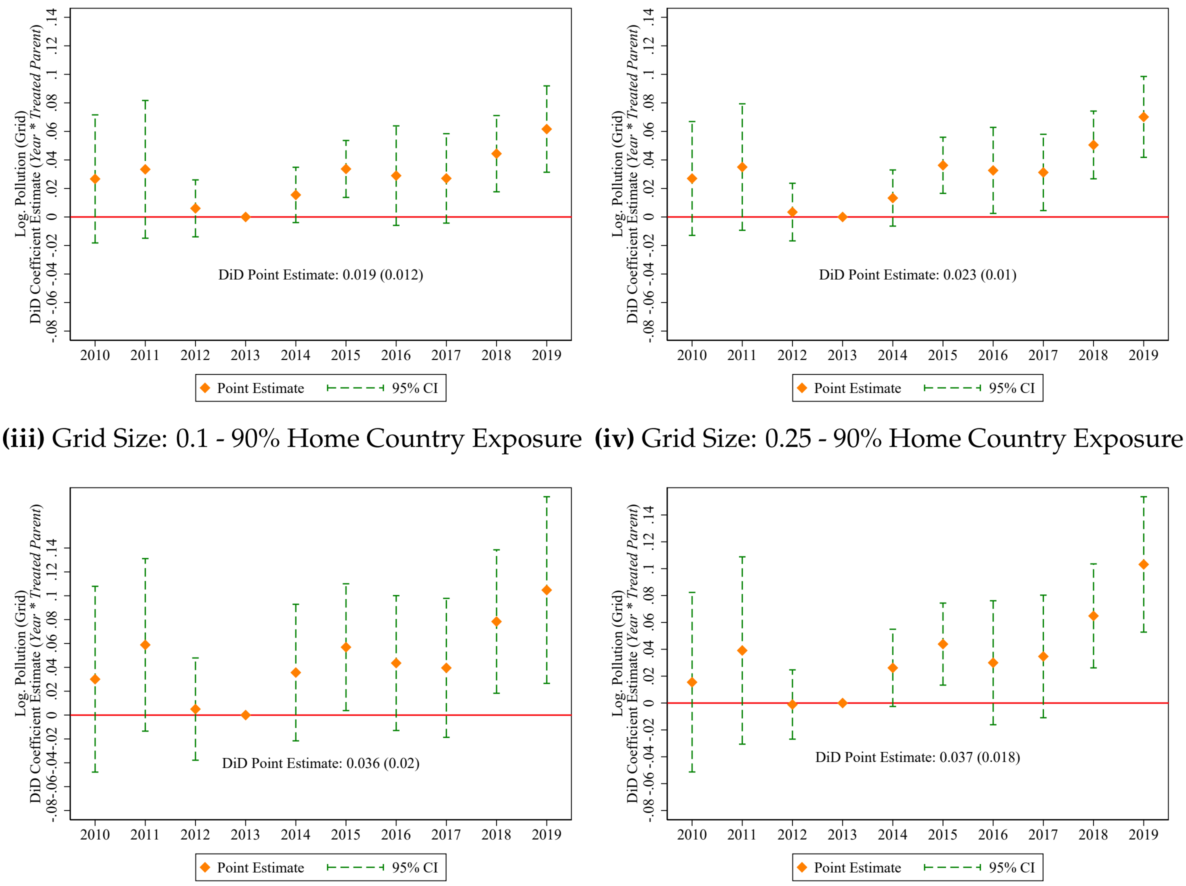
C Supplementary and Robustness Tests

C.1 Main Results - Alternative Specifications

Figure A-5: French Carbon Tax and Firms' Emissions in Africa - Alternative Specs

(i) Grid Size: 0.1 - All FR/DE Multinationals **(ii)** Grid Size: 0.25 - All FR/DE Multinationals

(iii) Grid Size: 0.1 - 90% Home Country Exposure **(iv)** Grid Size: 0.25 - 90% Home Country Exposure



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 at African subsidiaries of multinational firms with headquarters in France. The control group are African subsidiaries of multinational firms with headquarters in Germany. 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* $\times$ *Treated* indicator from the corresponding differences-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 (Panels i and iii) or 0.25×0.25 (Panels ii and iv) around the firm location based on data from EDGAR. In Panels i and ii, we use all multinational sample firms with headquarters in France or Germany, irrespective of their share of total assets located in their home country. In Panels iii and iv, we restrict the sample to firms which have an exposure of $> 90\%$ to the domestic market based on their total assets. Confidence intervals are reported based on Conley spatial HAC standard errors.

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

	(1)	(2)	(3)	(4)	(5)	(6)
Panel A			ln(CO2)			
Grid Size:	0.1 × 0.1	0.1 × 0.1	0.1 × 0.1	0.1 × 0.1	0.1 × 0.1	0.1 × 0.1
Treat × Post	0.019	-0.002	0.026*	0.013	0.036*	0.028
	(0.012)	(0.005)	(0.015)	(0.010)	(0.020)	(0.018)
Obs.	19,270	19,270	6,960	6,960	2,090	2,090
Adj. R2	0.001	-0.000	0.001	0.001	0.006	0.005
Sample Restriction	Full	Full	> 80%	> 80%	> 90%	> 90%
Subsidiary FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes		Yes		Yes	
Country × Year FE		Yes		Yes		Yes

Panel B			ln(CO2)			
Grid Size:	0.25 × 0.25	0.25 × 0.25	0.25 × 0.25	0.25 × 0.25	0.25 × 0.25	0.25 × 0.25
Treat × Post	0.023**	0.003	0.024*	0.012*	0.037**	0.028*
	(0.010)	(0.003)	(0.013)	(0.007)	(0.018)	(0.015)
Obs.	21,180	21,180	7,790	7,790	2,360	2,360
Adj. R2	0.003	0.000	0.002	0.002	0.005	0.004
Sample Restriction	Full	Full	> 80%	> 80%	> 90%	> 90%
Subsidiary FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes		Yes		Yes	
Country × Year FE	Yes	Yes		Yes		Yes

Notes: This table reports results from difference-in-differences models, estimating the effect of the introduction of a carbon tax in France on CO2 emissions at African subsidiaries of multinational firms with headquarters in France. The control group consists of multinational firms with headquarters in Germany. The models complement the results reported in Figure 4 based on equation (1) by varying the fixed effects structure and sample. Panel A shows the results based on a grid size of 0.1 × 0.1, Panel B reports the results for a grid size of 0.25 × 0.25.

Table A-5: Alternative Measures of European Carbon Policy Exposure

	(1)	(2)	(3)	(4)	(5)
			ln(CO2)		
Grid Size:	0.1 × 0.1	0.1 × 0.1	0.1 × 0.1	0.1 × 0.1	0.1 × 0.1
Carbon Policy Exp.	0.0310***	0.0275***	0.0261***	0.0223***	-0.0030
	(0.0076)	(0.0084)	(0.0062)	(0.0062)	(0.0103)
Exposure Definition:	All subsidiary industries in Europe	Empl.-weighted	CO2 taxes only	CO2 taxes only and no ETS firms	ETS prices only
Obs.	41,070	39,890	40,640	24,160	40,640
Adj. R2	0.004	0.002	0.004	0.003	-0.000
Subsidiary FE	Yes	Yes	Yes	Yes	Yes
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 (1) of Table 4 and vary by the definition of the carbon policy exposure measure and sample composition as indicated in the table. Standard errors account for spatial dependence in a linearly decreasing manner up to 500km (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 (2022). The ETS data are from euets.info.

Table A-6: ALTERNATIVE SPECIFICATION CHOICES

	(1)	(2)	(3)	(4)
	ln(CO2)			
Grid Size:	0.1×0.1	0.25×0.25	0.1×0.1	0.1×0.1
Carbon Policy Exp. (FTanA)	0.0296***	0.0260***	0.0210**	0.0122**
	(0.0079)	(0.0063)	(0.0101)	(0.0054)
Outcome or Sample Variation	Non-winsorized ln(CO2)	Non-winsorized ln(CO2)	No subs. in South Africa	No subs. in South Africa
Obs.	40,640	43,950	24,350	24,350
Adj. R2	0.003	0.004	0.001	0.001
Subsidiary FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	
Country × Year FE	No	No	No	Yes

Notes: This table reports results from estimating equation 4 using OLS. The specifications are based on the main model in Column (1) of Table 4. Columns 1 and 2 use non-winsorized CO2 proxies from the Edgar database. Columns 3 and 4 exclude subsidiaries located in South Africa from the sample.
Standard errors account for spatial dependence in a linearly decreasing manner up to 500km (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 (2022). The ETS data are from euets.info.

Table A-7: ACCOUNTING FOR COUNTRY-YEAR TRENDS IN FIRMS' ACTIVITY RESPONSES

	(1)	(2)	(3)
	All EU 28	CO2 Tax $\leq$10	CO2 Tax $>$10
Panel A			
Carbon Policy Exp. (FTanA)	-0.0312*	-0.0380	-0.0583
	(0.0177)	(0.0262)	(0.0449)
Obs.	53,099	38,139	13,473
Adj. R2	0.935	0.942	0.943
Panel B			
Carbon Policy Exp. (FTanA)	-0.0066	-0.0003	0.0260
	(0.0146)	(0.0176)	(0.0476)
Obs.	64,205	44,679	17,673
Adj. R2	0.925	0.928	0.949
Panel C			
Carbon Policy Exp. (FTanA)	-0.0172**	-0.0174*	-0.0469
	(0.0076)	(0.0100)	(0.0328)
Obs.	46,726	32,546	12,661
Adj. R2	0.947	0.950	0.962
Sub. FE	Yes	Yes	Yes
Sub. Country $\times$ Year FE	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 6 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 (2022). The ETS data are from euets.info.

Table A-8: CONSOLIDATED EFFECTS FOR FIRMS FROM SAME HQ COUNTRY AND YEAR

	(1)	(2)	(3)
Panel A	ln(Fixed Tan. Assets)	ln(Total Assets)	ln(Employees)
Carbon Policy Exp. (FTanA)	-0.0198	-0.0095	0.0280
	(0.0342)	(0.0248)	(0.0266)
Obs.	5,871	5,906	5,534
Adj. R2	0.960	0.979	0.955

Panel B	ln(Scope 1 Emissions)	ln(Scope 1+2 Emissions)	ln(Scope 1 Em. Intensity)
Carbon Policy Exp. (FTanA)	-0.0172	-0.0677	-0.0126
	(0.0897)	(0.0758)	(0.0919)
Obs.	1,906	1,906	1,906
Adj. R2	0.955	0.960	0.928
Firm FE	Yes	Yes	Yes
Parent Country $\times$ Year FE	Yes	Yes	Yes

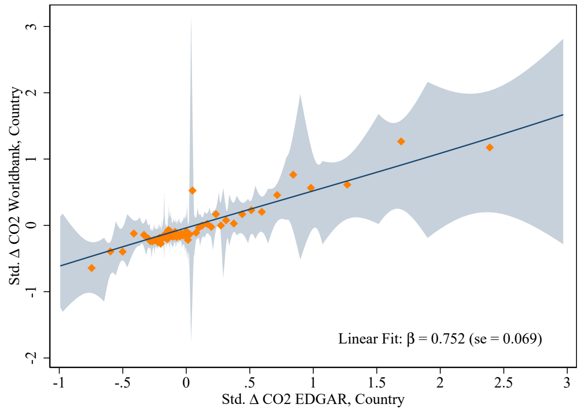
Notes: This table reports results from estimating a variant of equation 4 using OLS with multinational firms' at the consolidated level as the unit of observation. The specifications are based on the main model in Column (1) of Table 7 and include multinational firm parent country by year fixed effects. 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 (2022). The ETS data are from euets.info. Macroeconomic variables are based on data from the World Bank. Firm-wide emissions are from the S&P Trucost Environment Database as of May 2023. Scope 1 Emissions of public firms in the Trucost database are primarily from mandatory and voluntary company disclosures of public firms (annual reports and sustainability/CSR reports).

D Data Details and Validation

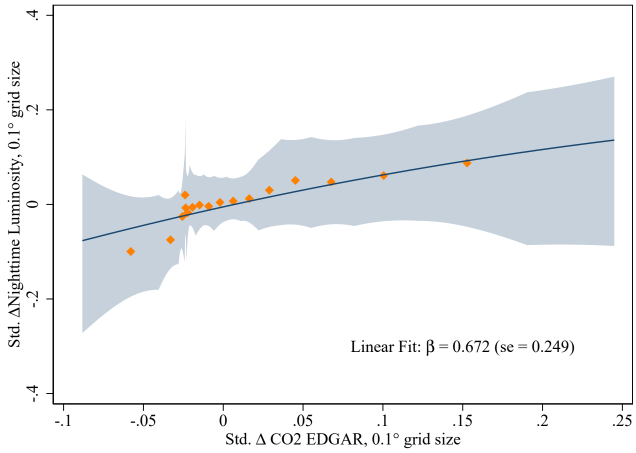
D.1 Validation of EDGAR CO2 Emissions Data

Figure A-6: 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 1991-2019. 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 2010-2019 as in our main tests.