Do carbon tariffs reduce carbon leakage? Evidence from trade tariffs

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Abstract

Pricing the carbon content of imports, or *carbon tariffs*, is being considered as a solution to policy-induced carbon leakage. However, the unilateral implementation of carbon tariffs could have unintended consequences, such as further emission reshuffling or costly trade retaliation. This paper estimates how carbon tariffs will affect carbon leakage by exploiting variation in export tariffs. Using a two-country model, I show that trade tariffs can be used to identify the effect of carbon tariffs on carbon leakage. Empirically, I estimate the foreign emission effect of export tariffs using plausibly exogenous increases in export tariffs during the 2018-2019 trade war for US facilities, while controlling for other tariff changes. While I find evidence that US greenhouse gas emitting facilities respond to export tariffs on their outputs by reducing their emissions, I also find evidence of increased emissions from downstream facilities through input-output linkages. In the case of the US industries that faced export tariff increases during the trade war, emission increases from input users offset the emission reductions from facilities in the upstream targeted industries. This result highlights the importance of input-output linkages for the net emission effect of incomplete carbon tariffs.

Keywords: climate policy, carbon leakage, carbon tariffs, trade policy

JEL Codes: F18, Q54, Q56, Q58

Code and data availability

The code and the underlying data to reproduce the figures, and tables are accessible here.

Disclosure statement

The author declares no competing interests.

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1 Introduction

After three decades of multilateral negotiations, countries have failed to deliver a binding and cooperative global solution for climate change mitigation. Global greenhouse gas (GHG) emissions continue to rise (NOAA, 2022), prompting some countries like those in the European Union to implement varying domestic policies to mitigate climate change, such as carbon trading markets. The UN Glasgow Climate Pact and the COP27 meeting are continuing to lay the foundations of an international carbon market to link domestic carbon markets, and to ensure cost-effective emission reductions (Simmons et al., 2021).

One problem with this patchwork of country-level climate policies is carbon leakage, where emission reductions from regulated countries are offset by emission increases in unregulated countries. Carbon leakage undermines the global benefits of country-level or unilateral climate policies by countering their GHG reductions. As a response to potential carbon leakage, countries with carbon prices are considering imposing carbon tariffs on trading partners without equivalent climate policies. Carbon tariffs price the carbon content of imports. Beyond reducing carbon leakage, Nordhaus (2015) demonstrates that targeted tariffs could also provide an incentive for unregulated countries to implement climate policies. This paper asks: Do carbon tariffs reduce carbon leakage? I follow the carbon leakage definition of Fowlie and Reguant (2018) which is the foreign emission response to unilateral domestic carbon pricing policy.

The implementation of country-level climate policies can lead to carbon leakage. Studies find that carbon emissions from unregulated countries can increase by 5 to 25% compared to the emissions reductions in the regulated country (Copeland, 2018). Aichele and Felbermayr (2015) empirically estimate that the Kyoto Protocol led to an 8% increase in imported carbon emissions. A proposed policy solution to reduce carbon leakage and incentivize climate policy adoption in unregulated countries is imposing carbon tariffs (Markusen, 1975; Drake, 2018; Nordhaus, 2015).

The European Union (EU) plans to implement carbon tariffs in 2026. In the US, carbon tariffs were part of the failed Waxman-Markey Bill, and are part of the proposed Clean Competition Act (Clausing and Wolfram, 2023). However, carbon tariffs could have important unintended consequences. For example, a country's imposition of carbon tariffs on trading partners could further reshuffle carbon emissions or lead to costly trade retaliations. Proposed carbon tariffs also target upstream manufactured goods, such as steel, aluminum, cement, and paper. Therefore, these tariffs might also have unintended effects on the emissions from downstream polluting industries. Since no carbon tariffs are currently in place but are being proposed, the goal of this paper is to empirically estimate the effect of carbon tariffs on carbon leakage by looking at the emission change of facilities in industries facing increased export tariffs.

I first develop a partial equilibrium two-country model to show that carbon tariffs can reduce carbon leakage. Since there are currently no carbon tariffs in place, I also use the conceptual model to show that trade tariffs can be used to proxy the effect of carbon tariffs on carbon leakage. Even if current trade policy has been shown to implicitly subsidize the carbon content of traded goods (Shapiro, 2021), it is not evident that trade tariff variation can inform the emission effects of carbon tariffs.

Assuming that foreign and domestic goods are substitutes, the stylized model shows that trade tariffs provide a lower bound of the emission effect from a carbon tariff. This is because the carbon tariff reduces emissions through both an emission intensity and scale effect, whereas the trade tariff only induces emission reduction through a scale effect. In the case where carbon tariffs are imposed according to an industry-level average carbon intensity instead of the foreign producer's specific emissions, the trade tariffs and carbon tariffs have the same emission reduction effect.

Empirically, I exploit increases in tariffs faced by US industrial facilities during the 2018-2019 trade war to proxy the effect of carbon tariffs on trading partner GHG emissions. I use difference-in-differences models to estimate the GHG emission response of US facilities to facing increases in export tariffs. Importantly, I account for the emission consequences of supply-chain linkages where emissions of downstream industrial facilities are affected by the use of the outputs from directly tariffed industries as inputs. In terms of expected effects, export tariffs on the output of a facility restrict their foreign market access and hence should lead to emission reductions. The use of those products facing export tariffs as inputs will have a counteracting emission effect by lowering the cost of domestic inputs for those producers. Since US facilities were also simultaneously protected by import tariff measures applied to foreign trading partners, I also control for the emission effects of these import tariff increases. By reducing import competition, import tariffs should increase emissions. The increased cost of the use of tariffed inputs should reduce emissions of downstream facilities.

I find evidence that export tariffs imposed on the output of US facilities reduced GHG emissions. I estimate that GHG emissions of US facilities facing export tariff increases on their output fall by about 3% for each 1 percentage point (pp) increase in export tariffs. However, I also find that emissions increase for downstream facilities that use as outputs from facilities targeted by the export tariffs as inputs. For each 1 pp increase in export tariffs, downstream facility emissions increase by 4%. Using these estimated semi-elasticities and the emission scale of upstream and downstream producers, I find that the emission reduction effect is offset by the emission increase from downstream users. Such results are consistent with other empirical studies on the 2018-2019 trade war and the North American Free Trade Agreement (NAFTA) finding evidence of larger effects of tariffs on downstream input users (Cherniwchan, 2017; Flaaen and Pierce, 2022).

Proposed carbon tariffs by the EU are incomplete as they are restricted to emissions from upstream products (Titievskaia, Simões and Dobreva, 2022). Results in this paper highlight the importance of considering the downstream emission effects of incomplete carbon tariffs. In the case of the set of industries covered by the 2018-2019 trade war, emission rebounds from downstream producers offset the emission reductions from producers directly targeted by the export tariffs. In this study, I estimate the impact of carbon tariffs on foreign emissions. In the case where the imposing country, such as the European Union, has a cap-and-trade policy, then domestic emissions should not rebound in the domestic country. In that case, the foreign emission effect should equal the global emission effect. If the country imposing carbon tariffs instead has a carbon tax, then domestic emissions can increase as a response to carbon tariffs. In this case, it still matters to study foreign emission responses to domestic climate policies, as national emissions are centerpieces of current climate negotiation processes under the United Nations Framework Convention on Climate Change.

I also estimate event-study models to test for differences in pre-trends, and conduct several robustness checks. To explore potential heterogeneity driving this main result, I interact the tariff changes with industry measures of trade and GHG intensity. I find some evidence that facilities in trade-intensive industries reduced their emissions more in response to export tariffs, and that less trade-intensive downstream users increased their emissions by more. This result is consistent with less trade-intensive downstream users benefiting more from the domestic reductions in the price of affected products used in their production. I also find some evidence of more important emission changes for upstream and downstream facilities in GHG-intensive industries.

I build on the empirical trade literature which uses tariff changes as quasi-experimental variation to study numerous outcomes. Researchers have estimated the effect of the 2018-2019 trade war tariff changes on US consumption, elections, employment, prices, and output (Amiti, Redding and Weinstein, 2019; Blanchard, Bown and Chor, 2019; Goswami, 2019; Waugh, 2019; Fajgelbaum et al., 2020; Flaaen and Pierce, 2022). More closely related to this study, studies have also leveraged tariff variation to empirically identify the effect of trade on local air pollution. Cherniwchan (2017) finds that trade liberalization under NAFTA leads to air pollution reduction in US manufacturing plants through access to cheaper inputs from Mexico. Bombardini and Li (2020) exploit changes in export tariffs faced by Chinese producers from 1982 to 2010 to study the effect of trade on pollution and mortality in China. I contribute to this literature by studying the effects of tariffs on global air pollution, namely greenhouse gas emissions.

There exists also a theoretical, numerical, and structural literature studying the effects of carbon tariffs. Studies have found that a large enough country or group of countries can reduce the foreign production of a polluting good through the use of an import tariff (Markusen, 1975; Fowlie, Reguant and Ryan, 2016; Böhringer, Carbone and Rutherford, 2018; Hsiao, 2020).[1] This study contributes to this literature chiefly by providing empirical evidence of the effect of carbon tariffs.

Recent studies have also developed and calibrated quantitative trade models to study global carbon emission reductions from optimal carbon tariff policies (Farrokhi and Lashkaripour, 2021; Kortum and Weisbach, 2021; Weisbach et al., 2023). These studies generally find that optimal carbon border taxes are ineffective at cutting global emissions relative to other policies such as climate clubs or optimal multilateral carbon taxes. This study aims to complement these models by highlighting the potential importance of input-output linkages in the manufacturing sector when considering proposed incomplete carbon tariffs.

While the impact of supply-chain linkage emission consequences of incomplete carbon tariffs has been discussed conceptually in Clausing and Wolfram (2023) and estimated with an empirically calibrated quantitative trade model in Campolmi et al. (2023), they have not been estimated using causal models. This study provides causal evidence of the importance of the downstream emission effect of upstream carbon tariffs.

The rest of the paper has the following structure. Section 2 provides background on the 2018-2019 trade war and the proposed European carbon tariffs. Section 3 presents a conceptual framework to think about the emission effects of carbon tariffs and trade tariffs. Section 4 discusses the data. Section 5 presents the empirical framework. Section 6 presents and discusses the results. Section 7 concludes the paper. Appendix A, and B offer additional figures and tables.

2 Background

2.1 The 2018-2019 trade war

Through 2018 and 2019, the US raised import tariffs on major trading partners, and trading partners retaliated with export tariffs. This trade war was characterized by new tariffs applied on thousands of traded goods, and most increases ranged from 10 to 25 percentage point increases in ad valorem tariff rates (Fajgelbaum et al., 2020). Important manufacturing industries affected by the trade war include the iron, steel, and aluminum manufacturing industries. Major retaliatory partners to the US import tariffs include China,

[1] In the case of a group of countries, Hsiao (2020) highlights the importance of coordination and commitment between the countries' policy stringency and timeline to effectively reduce leakage.

the EU, Canada, Mexico, India, Russia, and Turkey. Retaliatory or export tariffs on US GHG reporting manufacturing industries imposed by China, Canada, the EU, and Mexico affected respectively about 5%, 2%, and both 1% of the total value of US exports. Tariffs imposed by India, Russia, and Turkey account for less than 0.1% each. Tariffs between the US, and Canada and Mexico were lifted in 2019, and in 2021 with the EU. Import and export tariffs between the US and the other trading partners remain in place.

2.2 The European Union's Carbon Border Adjustment Mechanism

In 2026, the EU will require importers (or exporters to the EU) to pay a carbon tariff for the embedded GHG emission content of their goods (Titievskaia, Simões and Dobreva, 2022). The policy is called the Carbon Border Adjustment Mechanism (CBAM). In practice, the CBAM will require importers to purchase GHG permits priced at the prevailing EU ETS price. The CBAM will apply to a subset of upstream traded products: cement, electricity, fertilizers, iron, steel, and aluminum. The emissions of downstream products using these tariffed upstream products will not be covered. For example, the embedded GHG emissions in imported rolled steel would face a carbon tariff, but not the emissions embedded in the steel content of imported automobiles. To determine the carbon content of imports, the CBAM will have a hybrid structure. Importers can either report their verified emissions to pay the price of the actual embedded emissions in their products or pay based on a default emission intensity. Default values by exporting country and good will be set at an average emission intensity. I refer to the former type of carbon tariffs as facility-level carbon tariffs, and the latter as industry-level carbon tariffs.

Given that the 2018-2019 trade war covered most of the same industries targeted by the upcoming CBAM, namely the iron, steel, and aluminum manufacturing industries, learning the GHG emission effect of the trade war on these industries could inform the effect of proposed carbon tariffs. However, since trade tariffs do not incentivize emission abatement directly, trade tariffs should not have the same emission effect as carbon tariffs. As such, it is not obvious that one can use trade tariff variation as a proxy for carbon tariff variation. The next section develops a stylized model to show that trade tariffs can provide a lower bound for the facility-level carbon tariff foreign emission effect and the same emission effect for industry-level carbon tariffs.

3 Theory: Emission changes under different tariffs

I turn to a two-country, two-good, partial equilibrium model to decompose the foreign emission effect from trade tariffs versus carbon tariffs. While I am interested in the emission effect of carbon tariffs, empirically I only observe trade tariffs. I consider the simple comparison of the emission effects of trade and carbon tariffs for the direct effect on targeted foreign firms as opposed to including the indirect effect on downstream foreign input users which I consider empirically. As shown below, this simplifying case is reasonable for proposed industry-level carbon tariffs. The model draws inspiration from Fischer and Fox (2012) and Böhringer, Fischer and Rosendahl (2014), who develop partial equilibrium models to study unilateral climate policies in international settings.

3.1 Set-up

Consider two countries, home and foreign, each with a perfectly competitive industry with a representative firm $i \in (H, F)$ that is a price taker in the input and output markets. Each firm produces a good with constant returns to scale and a unit cost function $c_i(r_i)$ where r_i is the reduction in emission intensity from their baseline intensity e_i^0. Production costs are rising in reductions in emission intensity. Each country's emissions are $E_i = (e_i^0 - r_i)Q_i$, where Q_i is output.

A representative consumer in each country determines home and foreign consumption for the two goods. Consumption of the good Q_H is composed of the home domestic consumption h and exports to foreign x, and consumption of the good Q_F is foreign domestic consumption f and home imports m. The consumer demand for each good is represented by a function of prices of the competing goods in each country: $h(p_h, p_m)$, $m(p_h, p_m)$, $x(p_x, p_f)$, and $f(p_x, p_f)$. I assume symmetric and constant elasticity of demand functions, for example, $h = \alpha p_h^{\eta_0} p_m^{\eta_1}$, where α is a demand shifter, $\eta_0 < 0$ an own-price elasticity, and $\eta_1 > 0$ a cross-price elasticity, meaning the goods are substitutes.[2]

Market equilibrium is defined by $Q_H = h(p_h, p_m) + x(p_x, p_f)$ and $Q_F = f(p_x, p_f) + m(p_h, p_m)$. Also, let $r_i(\tau)$ reflect the cost-minimizing emission intensity at the carbon price τ. I assume that the home country's baseline emission rate e_H^0 includes the effect of a pre-existing domestic carbon price.

I am interested in assessing changes in foreign emissions E_F under different trade policy measures, namely a facility-specific carbon tariff, an industry-level carbon tariff, and a trade tariff. Specifically, I want to compare the effect of the various policy interventions on the following changes in foreign emissions:

$$dE_f = \underbrace{-dr_F Q_F}_{\text{Technique effect}} + \underbrace{(e_F^0 - r_F)dQ_F}_{\text{Scale effect}} \tag{1}$$

Changes in foreign emissions in equation (1) can be split into a technique effect from changes in the emission intensity and a scale effect from changes in the production of the good. There are no composition effects in this model since each country only has one industry.

3.2 Policy interventions

Below I compare changes in foreign emissions for different trade policy interventions. I compare foreign emission changes from carbon tariffs to the empirical context in my data, namely trade tariffs. I consider both the comparison of the effect of a trade tariff to a facility-level carbon tariff, and an industry-level carbon tariff.

3.2.1 Trade tariff

Here I model the trade tariff as a specific tariff that directly taxes the foreign good imports at a rate of τ_T per unit. Home consumers of the foreign good now face price $p_m = c_F(e_F^0) + \tau_T$. In the absence of a change in the home carbon price, home prices are equal to the marginal production cost without additional emission intensity reductions, such that $p_h = p_x = c_H(e_H^0)$. Since there are also no incentives to cut foreign emission intensity, foreign consumers of the foreign good face price $p_f = c_F(e_F^0)$. I identify the trade tariff

[2] Heterogeneity in preferences does not qualitatively change the results of the model for the comparison of production emission effects from different tariffs.

intervention with the superscript τ_T. The change in foreign emissions becomes:

$$
\begin{aligned}
dE_f^{\tau_T} &= e_F^0 dQ_F^{\tau_T} \\
&= e_F^0 \eta_0 \frac{dp_m}{p_m} < 0
\end{aligned} \tag{2}
$$

where the first line comes from observing that $dr_F = 0$. The second line comes from substituting for $dQ_F = df + dm$ using the first-order approximations of the change in demand, which for example is $dm = \eta_0 \frac{dp_m}{pm} + \eta_1 \frac{dp_h}{p_h}$ for m. Since $e_F^0 > 0$, $\eta_0 < 0$ and $\frac{dp_m}{p_m} > 0$, the trade tariff reduces as expected foreign emissions, but only through a scale effect.

3.2.2 Facility-level carbon tariff

A facility-level carbon tariff τ on imports will give a direct incentive for the foreign producer to abate emissions by adjusting their emission intensity. The CBAM carbon tariff proposed by the EU has a voluntary facility-level carbon tariff component (Cicala, Hémous and Olsen, 2022). In the absence of a change in the home carbon price, home prices are equal to the marginal production cost without additional reductions, such that $p_h = p_x = c_H(e_H^0)$. Home consumers of the foreign good now face price $p_m = c_F(r_F^\tau) + \tau(e_F^0 - r_F^\tau)$. Home consumers of the foreign good pay for the embodied emissions and rising production costs. Because of the emission reduction incentives, the foreign goods producer sees its cost of production increase, $p_f = c_F(r_F^\tau)$. In evaluating the effect of the full policy change, I follow Fischer and Fox (2012) and assume $dr_F = r_F^\tau$. I identify this intervention with the superscript τ. The change in foreign emissions is:

$$
\begin{aligned}
dE_f^\tau &= -r_F^\tau Q_F^\tau + (e_F^0 - r_F^\tau) dQ_F^\tau \\
&= -r_F^\tau Q_F^\tau + (e_F^0 - r_F^\tau)\eta_0 \frac{dp_m}{p_m} < 0
\end{aligned} \tag{3}
$$

where the change in foreign emissions is now driven by both a technique and a scale effect.

For the sake of comparison, if we assume the same unit cost of the trade and carbon tariff, such that $\tau_T = \tau(e_F^0 - r_F^\tau)$ such that the change in output is the same, $dQ_F^{\tau_T} = dQ_F^\tau$, then

$$
dE_f^\tau - dE_f^{\tau_T} = -r_F^\tau (Q_F^\tau - dQ_F^\tau) \tag{4}
$$

$$
= -r_F^\tau (Q_F^\tau - \eta_0 \frac{dp_m}{p_m}) < 0 \tag{5}
$$

where the change in emissions from a trade tariff of the same unit cost as a facility-level carbon tariff is a lower bound of the foreign emission reduction effect.

3.2.3 Industry-level carbon tariff

Industry-level carbon tariff taxes the emissions embodied in imports of the foreign good based on an industry average emission intensity denoted $\bar{e}_F$. The default carbon tariff rate for CBAM is an industry average emission intensity rate, and other carbon tariff rates are most likely going to be industry-level averages given the difficulty in attributing embodied emissions to individual importers (Clausing and Wolfram, 2023). In the absence of a change in the home carbon price, home prices are equal to the marginal production cost without additional reductions, such that $p_h = p_x = c_H(e_H^0)$. Home consumers of the foreign good face price $p_m = c_F(e_F^0) + \tau \bar{e}_F$. Since there are no incentives to cut foreign emission intensity, foreign consumers of the foreign good face price $p_f = c_F(e_F^0)$. This also means that $r_F = dr_F = 0$. I identify the industry-level carbon tariff intervention with the superscript τ_I. The change in foreign emissions becomes:

$$dE_f^{\tau_I} = e_F^0 dQ_F^{\tau_I} < 0 \tag{6}$$

where foreign emission reduction follows directly from the trade tariff case.

For the sake of comparison, if we assume the same unit cost of the tariffs, namely $\tau_T = \bar{a}_F \tau_I$ such that $dQ_F^{\tau_T} = dQ_F^{\tau_I}$, then

$$dE_f^{\tau_T} - dE_f^{\tau_I} = 0 \tag{7}$$

and the foreign emission effect of the trade tariff has the same effect as the industry-level carbon tariff since both interventions only operate through a scale effect.

This stylized model highlights that the foreign emission effect of a trade tariff is either a lower bound of a facility-level carbon tariff or the same as an industry-level tariff. The model provides support for using the trade tariff increases during the trade war to learn about the foreign emission effects of proposed carbon tariffs.

4 Data

4.1 Trade war tariff data

Commodity or product-level tariffs are used in the analysis to construct industry-level trade tariffs protecting or faced by US manufacturing plants. While the variable of interest is the export tariffs, I need to account for confounding increases in import tariffs. The yearly average ad valorem trade war tariff increases for 2018 and 2019 between the US and retaliatory trading partners are taken from Fajgelbaum et al. (2020) and Fajgelbaum et al. (2021).

These data include the US tariffs waves on iron and steel, aluminum, China varieties, washing machines, and solar panels, and the retaliatory tariffs from China, Europe, Canada, Mexico, India, Russia, and Turkey. To a lesser extent, some non-manufacturing sectors, such as mining and agricultural production, were also targeted by the trade war. While the preferred specifications focus on the manufacturing sector, some figures and tables in Appendix A and Appendix B consider all the affected sectors. Similarly to other empirical papers studying the 2018-2019 trade war, I only consider trade war tariff increases as opposed to increases in the trade war tariffs on top of the baseline tariffs. This approach is also akin to Cherniwchan and Najjar (2022) which assumes that baseline tariff rates remain unchanged. Furthermore, I follow Cherniwchan (2017) and Bombardini and Li (2020) by only considering changes in tariffs as opposed to also considering changes in non-tariff barriers.

4.2 Trade data

Trade data are used to trade-weight the construction of the industry-level tariffs. I collect 2010 to 2021 US Census trade data from Schott (2008) and Fajgelbaum et al. (2020). I use the 2010 to 2017 data to construct the industry-level tariffs to avoid the impact of the change in tariffs may have had on industry-level trade.

4.3 Greenhouse gas data

The outcome variable of interest is manufacturing plant-level greenhouse gas emissions. I use US plant data to estimate the emission effect of tariff changes. Yearly plant-level GHG data measured in CO_2 equivalent (CO_2e) are obtained from the US EPA mandatory greenhouse gas reporting program (GHGRP). Variables provided include yearly CO_2e emissions, the six-digit North American Industrial Classification System (NAICS-6) code, geographic information, and parent firm name from 2010 to 2021. The US EPA mandates all facilities that emit more than 25,000 tonnes of CO_2e per year to report their emissions. The sample considered in this analysis includes about 5,500 reporting facilities per year, about half of which are in the manufacturing sector.

4.4 Industry-level tariffs

I construct industry-level tariffs using the commodity tariff data, and the trade data. Export tariffs are my main variable of interest, and I control for import tariffs. Ad valorem tariffs and trade value between the US and its trading partners are first assigned to NAICS-6 codes using the concordance tables created by Pierce and Schott (2012). I then aggregate the tariff data to the NAICS-6 level by taking a trade-weighted average of the tariffs using the average 2010-2017 trade values as weights. This procedure yields an export or import tariff at the NAICS-6 level, τ_{it}, for NAICS-6 i and year t. I then assign these tariff measures to each US manufacturing plant, p, based on the plants' NAICS-6 code i. There are more than 225 unique manufacturing NAICS-6 industries in the GHGRP. More than half of them were directly targeted by the trade war.

4.5 Industry-level input tariffs

Since tariffs can affect plants not only through their output but their inputs, I follow several papers in the empirical trade literature and build input tariffs from the export and import tariffs (Cherniwchan, 2017; Goswami, 2019; Flaaen and Pierce, 2022). I construct industry-level input tariffs using the industry-level export and import tariffs calculated above in combination with the 2012 US input-output (IO) table from the US Bureau of Economic Analysis. The *use* table of IO tables provides a dollar value of output use from industry j as input in industry i at the NAICS-6 level. For each NAICS code, I calculate the cost share of output use from other NAICS-6 industries. I then multiply the industry-level export and import tariffs of the use industry by the cost share and aggregate the input tariff at the NAICS-6 level.

4.6 Summary statistics

Figure 1 shows the distribution of the number of manufacturing facilities facing increases in new industry-level export tariffs between 2018 and 2019. Most GHG emitting plants facing tariff increases faced increases of less than 1 pp. A few hundred plants faced increases in output export tariffs of 2 pp or more, whereas a smaller number of facilities faced larger export tariff increases on their inputs. I exploit this intensity of tariff increases in my empirical strategy.[3]

[3]Figure A1 in Appendix A shows the distribution of GHG emitting US manufacturing plants for the increases in output and input import tariffs.

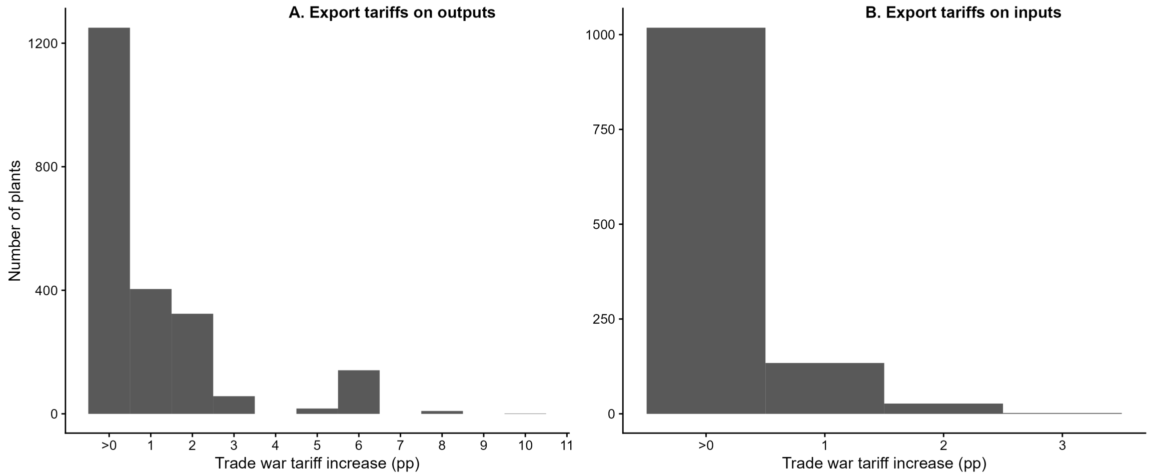

Figure 1: Distribution of NAICS-6 level export tariff increases facing U.S. GHG emitting facilities

Notes: Figure 1 shows the distribution of GHG emitting manufacturing facilities facing increases in export tariffs on their output or input during the 2018-2019 trade war.

Table 1 shows various summary statistics of NAICS-6 level export tariffs increase and manufacturing facility GHG emissions at the NAICS-3 level. The table highlights the downstream impacts of tariffs for industries not directly targeted by the trade war export tariffs. Tables A1 and A2 respectively show the export and import tariffs and further decomposed summary statistics of the NAICS-6 level industry tariffs at the NAICS-3 level for the manufacturing sector. They show that most facilities within the same industries often face both export and import tariff increases on their output or inputs, and hence the importance of accounting for all tariff changes.

Table 1: NAICS-3 manufacturing variation in trade war export tariffs increases and greenhouse gas emissions

		Export tariff increases (pp)						
		Output		Input		CO2e (kt)		
Manufacturing industry	NAICS-3	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	# plants
Food	311	0.69	1.1	0.11	0.29	114	348	330
Beverage and tobacco products	312	1.75	3.07	0.25	0.66	48	30	27
Textile mills	313	0.24	0.27	0.02	0.05	70	47	7
Textile product mills	314	0.32	0.48	0.03	0.03	46	22	6
Wood products	321	0.34	0.92	0.02	0.05	119	124	25
Paper	322	0.45	0.61	0.1	0.11	671	747	226
Printing and related activities	323	0.29	0.42	0.04	0.05	31	7	2
Petroleum and coal products	324	0.4	0.9	0.08	0.09	1,205	1,583	173
Chemical	325	0.66	0.8	0.07	0.12	306	725	650
Plastics and rubber products	326	0.24	0.45	0.13	0.18	39	19	34
Nonmetallic mineral products	327	0.6	1.4	0.06	0.08	304	412	344
Primary metal	331	1.11	1.73	0.26	0.58	304	1,041	274
Fabricated metal products	332	0.44	0.65	0.52	0.8	40	31	26
Machinery	333	0.44	0.47	0.29	0.31	38	21	18
Computer and electronic products	334	0.59	0.88	0.09	0.09	126	146	51
Electrical equipment and appliances	335	0.78	0.76	0.32	0.32	26	18	14
Transportation equipment	336	0.51	1.34	0.37	0.56	46	26	81
Furniture and related products	337	0.61	1.14	0.22	0.36	20	NA	1
Miscellaneous	339	0.39	0.39	0.13	0.13	62	25	3

Notes: pp = percentage point. kt = kiloton. Std. dev. = Standard deviation.

5 Empirical framework

To estimate the effect of export tariff increases on changes in US manufacturing plant emissions, I use difference-in-differences (DiD) models and event-study (ES) models. The unit of observation is at the facility-industry-year level, the outcome variable yearly greenhouse gas emissions, and the treatment variable NAICS-6 industry-level tariff increases from the 2018-2019 trade war. The main sample is restricted to facilities in the manufacturing sector.

To identify the causal impact of trade tariffs on facility-level greenhouse gas emissions, the DiD and ES research designs exploit both the temporal and industry variation in plausibly exogenous tariff increases brought by the 2018-2019 trade war. Since the tariff increases affected different industries, I compare changes in emissions for facilities facing high tariff exposures, to ones who face lower or no tariff changes, before and after the trade war. These two differences allow me to account for national trends and shocks in emission changes affecting the whole manufacturing sector, and time-invariant differences between facilities that affect their emissions. Also, the varying levels of export and import tariffs mean that I can simultaneously estimate the effects of the multiple different types of tariff increases.

Before studying the effect of export tariffs on facility-level GHG emissions, I first look into the effect of the constructed NAICS-6 industry-level tariffs on industry-level net export value. For example, industry-level export tariff increases should be correlated to decreases in the corresponding net export values through restricted foreign market access. In contrast, downstream exposure to export tariff increases should be related to increased net exports through lowered input costs.

I run the following DiD model:

$$y_{it} = \beta_1 \Delta\tau_i^O \times Post_t + \beta_2 \Delta\tau_i^I \times Post_t + X_{it}\theta + \mu_i + \eta_t + \epsilon_{it} \tag{8}$$

where y_{it} is net exports in millions of US dollars at the NAICS-6 industry i and year t level. $\Delta\tau_i^O$ is the averaged 2018-2019 export tariff increase faced by NAICS-6 industry i on its output, and $\Delta\tau_i^I$ is the exposure to the export tariff increase through its input use. $Post_t$ is equal to one after 2017 once the trade war began. β_1 and β_2 are respectively semi-elasticities that identify the percent change in net export value from a 1 pp increase in either the output or input export tariff. X_{it} are control variables for the industry exposure to output and input import tariff increases during the trade war. Not controlling for the output and input import tariff increases could introduce omitted variable bias, as they are correlated with the export tariff increases as evident from Table A1. NAICS-6 fixed effects are accounted for by μ_i, and η_t are year-fixed effects. Standard errors are clustered at the NAICS-6 digit level. There are over 500 different NAICS-6 treated industries in the industry-level trade value sample. I also consider a specification with two-digit NAICS-by-year fixed effects to account for industrial sector-specific shocks.

After estimating the effect of the industry-level tariff increases on industry-level trade, the main estimating strategy explores the effect of the export tariff increases on facility-level GHG emission changes. Specifically, I estimate the following DiD model:

$$\ln\left(\mathrm{CO_2e}_{pit}\right) = \delta_1 \Delta\tau_i^O \times Post_t + \delta_2 \Delta\tau_i^I \times Post_t + X_{it}\Theta + \psi_p + \omega_t + \varepsilon_{pit} \tag{9}$$

where $\mathrm{CO_2e}_{pit}$ are greenhouse gas emissions measured in $\mathrm{CO_2e}$ for a US industrial plant p, in NAICS-6 industry i and year t. $\Delta\tau_i^O$ is the averaged 2018-2019 export tariff increase faced by NAICS-6 industry i on its output, and $\Delta\tau_i^I$ is the exposure to the export tariff increase through its input use. $Post_t$ is equal to one after 2017 once the trade war began. δ_1 and δ_2 are semi-elasticities interpreted as the percentage change in GHG emissions from a 1 pp increase in output or input export tariff exposure. X_{it} are control variables for the industry exposure to output and input import tariff increases during the trade war. ψ_p, and ω_t are respectively plant and year fixed effects; and ε_{pit} an error term. Standard errors are clustered at the level of treatment variation, namely at the NAICS-6 level. There are over 225 different NAICS-6 treated industries in the facility-level GHG sample.

The plant-fixed effects account for time-invariant differences between industrial facilities, such as emission intensity, and size. The year-fixed effects account for changes in national policies and shocks that affect manufacturing emissions, such as economic growth and exchange rate fluctuations. I also consider specifications with state-by-year and two-digit NAICS-by-year fixed effects. The state-by-year fixed effects control for important changes in state-level environmental policy changes, such as California's cap-and-trade system, and differences in COVID-19 stay-at-home policies. The varying composition of NAICS-6 industry plants within each state allows me to use state-by-year fixed effects. The two-digit NAICS-by-year fixed effects capture differential yearly emission changes in the broad categories of industrial sectors, namely in the food and textile manufacturing sector (NAICS-2 31), the wood, chemical, and non-metallic manufacturing sector (NAICS-2 32), and the automotive, machinery, and metals manufacturing sector (NAICS-2 33).

More formally, to interpret δ_1 and δ_2 as causal, I test for differences in pre-trends by running an event-study version of equation (9). Specifically, I interact the tariff increases with year dummies. I omit the year 2017, to interpret the interacted coefficients as differences in emission changes between facilities facing high tariff increases to those facing low or no tariff increases relative to that change in the year before the trade war began.

5.1 Upstream and downstream effects of export tariffs

While the coefficients β_1, β_2, δ_1, and δ_2 give the increases in industry-level net exports or facility-level emissions from a 1 pp increase in output and input tariffs, these are not the exact coefficients I want to compare the upstream and downstream effects of incomplete carbon tariffs. Instead, I scale the input tariff semi-elasticities β_2 and δ_2 by the implied input tariff increase from a 1 pp increase in upstream tariffs. Indeed, through input-output linkages in the manufacturing sample considered, a 1 pp increase in export tariffs in output corresponds to a 0.4 pp increase in input tariff on average for downstream industries.[4] Therefore, in the result figures and tables below, I compare the net export effect of a 1 pp point increase in export tariff on the direct upstream effect using β_1 and δ_1 to the respectively indirect downstream effect using scaled β_2 and δ_2 by the implied downstream input tariff exposure from a 1 pp upstream output export tariff. Standard errors are adjusted using the delta method.

6 Results

This section presents estimates of the effect of export tariff increases on industry-level trade and US manufacturing plant GHG emissions using equations (8) and (9). For the main estimates for facility-level GHG emissions, I first test for common pre-trends. I then discuss the overall difference-and-differences estimates, conduct robustness checks, and finally interact the export tariff variable with measures of emission

[4] I calculate the implied indirect downstream tariff from a 1 pp increase in direct tariff by dividing the average indirect tariff faced by downstream facilities during the trade war by the average direct tariff increase faced by directly targeted facilities. Note that the implied indirect tariff increase is slightly different for the import tariffs.

and trade intensity to explore potential heterogeneity of response.

6.1 Export tariff effects on industry-level net exports

Table 2 presents the estimates of the effect of the output and input export tariffs exposure on industry-level net exports using equation (8). The first column only includes industry and year-fixed effects, and the second column further includes NAICS-2 by year fixed effects to account for sector-specific shocks. The estimates show that net exports decrease for industries for which their output was targeted by export tariff increases. This reduction in net exports is consistent with these industries facing restrictions in foreign market access. Specifically, a 1 pp increase in export tariff on output is related to a nearly 300 million USD reduction in net exports for the average manufacturing industry. These upstream estimates are statistically precise for coefficients in both columns.

Net exports increase for industries exposed to export tariff increases on their inputs. This effect is consistent with the notion that domestic reductions in prices of affected output by export tariffs can be beneficial for US buyers of these products. Estimates suggest that a 1 pp increase in export tariffs on domestic products used for inputs increases net export value for industrial sectors by about 1 billion USD, and the estimates are statistically different than zero. These estimates suggest that downstream industries are more responsive to upstream export tariff increases than the targeted upstream industries.

Table 2: Industry-level US net export effect from a 1pp increase in trade war export tariffs

	Net exports (mil $)	
	(1)	(2)
Direct effect from export tariffs	-274.231^{*}	-291.702^{**}
	(143.325)	(142.274)
Indirect downstream effect from export tariffs	$1{,}039.853^{**}$	841.812^{**}
	(418.756)	(387.221)
Adj. R2	0.94	0.94
NAICS-2 X Year	×	✓
Observations	4,168	4,168

Notes: Estimates of the semi-elasticity from a 1 pp increase in export tariffs on NAICS-6 level net exports in millions of USD. All models include year fixed effects and NAICS-6 fixed effects. Facilities are restricted to the manufacturing sector. Column 1 is the baseline model, whereas column 2 further includes NAICS-2 by year fixed effects. Robust standard errors clustered at NAICS-6 level in parentheses.

Table 2 provides evidence of the relevance of the NAICS-6 industry-level tariffs. These estimates also suggest that downstream industries are more responsive to upstream export tariff increases than the targeted upstream industries. Table A3 presents a consistent story for net export effects for industries exposed to the output or input import tariff increases.

6.2 Export tariff effects on facility-level GHG emissions

I now turn to my main estimating strategy, namely the effect of the export tariff increase on manufacturing facility-level GHG emission changes. I first estimate the event-study version of equation (9) to compare changes in GHG emissions for facilities in NAICS-6 industries that faced export tariff increases to other manufacturing facilities in NAICS-6 industries that were not targeted by the trade war tariff changes. This allows me to visually test for pre-trends and the effect of the export tariff increases.

We would expect manufacturing facilities facing increases in export tariffs on their output to reduce their emissions, and facilities that use these outputs for their production to increase their emissions. These effects are consistent with the economic intuition of reduction in output from reduced access to foreign markets, and reduced domestic prices for the use of those outputs as inputs.

Figure 2 shows the percentage change in emissions for facilities facing increases in export tariffs on their outputs or their inputs during the trade war. Relative to 2017, the coefficients for years before the trade war for both panels are not statistically distinguishable from zero. For facilities facing export tariffs increase on their output, there is a decrease in emissions after the export tariff increases. For facilities exposed to export tariffs on their inputs, their emission increased after the beginning of the trade war. The event-study graphs for facilities facing output and input import tariffs are shown in Figure A2.

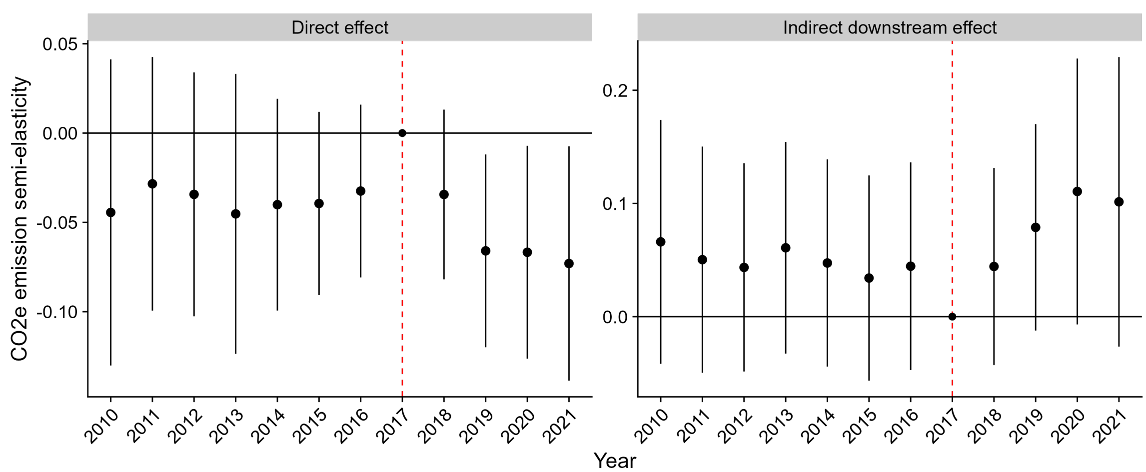

Figure 2: Event-study model of the effect of trade war export tariffs on CO2e emissions

Notes: Point estimates and 95% confidence intervals of the semi-elasticity effect of a 1 pp increase in export tariff on direct and indirect downstream log CO_2e emissions relative to 2017 using an event study version of equation (9). Estimates for the sample restricted to the manufacturing sector are shown. Standard errors are clustered at the NAICS-6 level.

Figure 2 provides evidence of a decrease in GHG emissions for facilities facing an increase in export tariffs, but offers a cautionary tale of a potential rebound of emissions from input users downstream. Table 3 presents the semi-elasticities of the export tariffs across different sets of fixed effects using equation (9). The first column only includes plant and year fixed effects, columns 2 and 3 respectively add state-by-year, and two-digit NAICS-by-year fixed effects to account for more unobserved shocks correlated with the trade war. Estimates from equation (9) in column 3 suggest that a 1 pp increase in export tariff on output reduces industrial facility emissions by 2%. In turn, a 1 pp increase in export tariffs leads to a 4% increase in downstream emissions. Coefficients for both the upstream and downstream emission effects are nearly all statistically different than zero.

This larger responsiveness of downstream producers is consistent with previous estimates shown above, and other studies that have found larger responses for tariff exposures on inputs (Cherniwchan, 2017; Flaaen and Pierce, 2022). Table A4 presents all the coefficients for both the upstream and downstream emission effects for both the export and import tariffs. The signs of the import coefficients are of the expected sign, and the estimates also show a greater responsiveness of downstream input exposure for import tariff increases relative to output import tariff exposure.

Table 3: Semi-elasticity of the trade war export tariffs on facility-level CO2e emissions

	ln(CO2e)		
	(1)	(2)	(3)
Direct effect from export tariffs	-0.019	-0.027^{**}	-0.027^{**}
	(0.017)	(0.013)	(0.013)
Indirect downstream effect from export tariffs	0.040^{*}	0.045^{*}	0.041^{*}
	(0.024)	(0.023)	(0.025)
Adj. R2	0.87	0.87	0.87
State X Year	×	✓	✓
NAICS-2 X Year	×	×	✓
Observations	27,514	27,514	27,514

Notes: Estimates of the emission semi-elasticity from a 1 pp increase in export tariffs. All models include year fixed effects and plant fixed effects. The control and treatment groups are restricted to facilities in the manufacturing sector. Column 1 is the baseline model. Column 2 further includes state by year fixed effects. Column 3 additional controls for NAICS-2 by year fixed effects. Robust standard errors clustered at NAICS-6 level in parentheses.

6.2.1 Net emission effect of export tariffs

The estimates from equation (9) in Table 3 show greater average responsiveness of downstream industries to upstream carbon tariffs. The estimates do not directly say whether the total downstream emission increases offset the upstream emission decrease of the targeted industries. To determine the net emission effect from a 1 pp export tariff increase, two other ingredients are needed besides the semi-elasticity estimates from Table 3, namely the size of GHG emissions in upstream and downstream emissions. In the context of the 2018-2019 trade war, the respective GHG emission size of upstream industries and downstream industries affected by the export tariffs on outputs is 808 and 584 Mt. Combining all these numbers and the semi-elasticities from the first column in Table 3, a 1 pp increase in export tariff-reduced upstream emissions by about 15 Mt, however, increased downstream emissions by 23 Mt. The net effect in this case is a foreign emission increase of 8 Mt.

This back-of-the-envelope calculation highlights a potential issue with incomplete carbon tariffs applied to upstream products, such as the proposed EU CBAM policy. If downstream emission rebound offsets the direct reductions in upstream emissions, then carbon tariffs could increase foreign GHG emissions. A limitation of this exercise is that the export tariffs facing US industrial facilities during the 2018-2019 trade war are not fully representative of the covered sectors under CBAM.

6.2.2 Robustness checks

I conduct several robustness checks of the effects of the export and import tariffs on upstream and downstream GHG emissions. I find that the estimates are qualitatively robust to transformations of the outcome variable and variations of the estimating sample. Table A5 presents qualitatively similar results if the dependent variable is in levels of facility GHG emissions instead of log emissions. The magnitude and precision of the semi-elasticities shown in Table 3 are also robust to considering all the broad affected industrial sectors as opposed to only manufacturing as shown in Table A6. Similarly, Figure A3 shows robust event-study estimates to the sample of all NAICS-3 treated industries. Finally, Table A7 presents estimates of the difference-in-differences specification for a balanced panel, single plant firms, multi-plant firms, and below and above median size emitters. While the coefficient estimates are statistically noisier for these smaller samples, the sign and magnitude of the estimated semi-elasticities are generally robust to these sample restrictions.

6.2.3 Heterogeneity

I now turn to heterogeneity analyses of the export tariff effects on two dimensions: industry-level trade intensity and GHG emission intensity. We expect trade and carbon tariffs to affect more tradable industries. While we also expect more carbon-intensive industries to respond more to carbon tariffs, it is unclear whether they should respond more or less to trade tariffs.

To measure trade intensity, I calculate for each NAICS-6 industry the ratio of total trade value (import + export) to total value of sales from the NBER-CES manufacturing database (Becker, Gray and Marvakov, 2021). I average the share of trade over the pre-trade war period of 2010-2017. Low values of the ratio imply low trade intensity, whereas trade-intensive industries have a higher value of the ratio. To explore the effect of trade intensity, I interact the export tariff variables in equation (9) with a dummy variable equal to 1 if the NAICS-6 treated industries have a higher share of trade than the median NAICS-6 treated industry. A value of 1 for the trade intensity dummy indicates a relatively trade-intensive industry.

Table 4 presents estimates of equation (9) by trade intensity. While noisy, the results show that emissions for facilities in more trade-intensive industries reduce more as a response to export tariffs affecting their output. The opposite is true for trade-intensive industries exposed to export tariffs on their inputs, they increase their emissions less. One explanation is that the trade-intensive downstream sectors benefit less from the reduction in the domestic price of the input than the less trade-intensive downstream industries more reliant on domestic inputs.

Table 4: Semi-elasticity of the trade war export tariffs on facility-level CO2e emissions by trade intensity

	ln(CO2e)		
	(1)	(2)	(3)
Direct effect from export tariffs	0.012	−0.008	−0.007
	(0.022)	(0.020)	(0.021)
Indirect downstream effect from export tariffs	0.033	0.053*	0.059*
	(0.032)	(0.031)	(0.032)
Direct effect from export tariffs X Trade intensity	−0.044*	−0.021	−0.020
	(0.026)	(0.023)	(0.024)
Indirect downstream effect from export tariffs X Trade intensity	−0.009	−0.036	−0.052
	(0.036)	(0.034)	(0.036)
Adj. R2	0.87	0.87	0.87
State X Year	×	✓	✓
NAICS-2 X Year	×	×	✓
Observations	27,514	27,514	27,514

Notes: Estimates of the emission semi-elasticity of the trade war export tariffs by trade intensity. trade intensity is a dummy variable equal to 1 if the NAICS-6 industries trade stock per employee is greater than the median value. All models include year fixed effects and plant fixed effects. Facilities are restricted to the manufacturing sector. Column 1 is the baseline model. Column 2 further includes state by year fixed effects. Column 3 additional controls for NAICS-2 by year fixed effects. Robust standard errors clustered at NAICS-6 level in parentheses.

The GHG emission intensity measure is the average 2010-2017 NAICS-6 industry total US emission from the GHGRP over the total value of sales for the same industry from the NBER-CES manufacturing database (Becker, Gray and Marvakov, 2021). Similar to the trade intensity estimates, I interact the export tariff variables in equation (9) with a GHG intensity dummy variable equal to 1 if the NAICS-6 treated industries' GHG emission per sales is greater than the median value for treated industries.

Table 5 shows the estimates by GHG emission intensity. The interacted results suggest that the emissions from plants in more emission-intensive industries generally respond more strongly to export tariff increases on their inputs or outputs. While mostly imprecise, the interacted coefficients on the preferred specification in column 3 show a greater increase for facilities in industries targeted by export tariffs on their output, and greater increases in emissions from downstream facilities in GHG-intensive industries.

Table 5: Semi-elasticity of the trade war export tariffs on facility-level CO2e emissions by GHG intensity

	ln(CO2e)		
	(1)	(2)	(3)
Direct effect from export tariffs	−0.016	−0.016	−0.007
	(0.021)	(0.017)	(0.018)
Indirect downstream effect from export tariffs	0.038	0.037	0.025
	(0.025)	(0.024)	(0.026)
Direct effect from export tariffs X GHG intensity	0.014	−0.013	−0.030
	(0.038)	(0.024)	(0.024)
Indirect downstream effect from export tariffs X GHG intensity	0.193	0.177	0.196*
	(0.135)	(0.120)	(0.104)
Adj. R2	0.87	0.87	0.87
State X Year	×	✓	✓
NAICS-2 X Year	×	×	✓
Observations	27,514	27,514	27,514

Notes: Estimates of the emission semi-elasticity of the trade war export tariffs by greenhouse gas (GHG) intensity. GHG intensity is a dummy variable equal to 1 if the NAICS-6 industries GHG emissions per sales is greater than the median value. All models include year fixed effects and plant fixed effects. Facilities are restricted to the manufacturing sector. Column 1 is the baseline model. Column 2 further includes state by year fixed effects. Column 3 additional controls for NAICS-2 by year fixed effects. Robust standard errors clustered at NAICS-6 level in parentheses.

Interacting the main DiD model with measures of trade and GHG intensity suggests that the emission response from the trade war export tariff increases have different effects. For trade intensity, the relative effect of emission changes for facilities in upstream and downstream industries goes in the opposite effect, whereas they move in the same direction for facilities in GHG-intensive industries. Since many important emitters were exempt from the trade war, such as products from pulp and paper mills and cement manufacturers, the importance of their trade and GHG intensity would affect the importance of the offsetting of emissions from downstream sectors.

7 Conclusion

In this paper, I attempt to predict the effect of proposed carbon tariffs on foreign emission changes for manufacturing GHG emitting facilities. Using a two-country partial equilibrium model, I first show that observable trade tariffs can be used to estimate the upstream effect of unobservable carbon tariffs on foreign GHGs. Assuming that foreign and domestic goods are substitutes, variation in trade tariffs provides a lower bound of the emission effect of carbon tariffs.

Empirically, I exploit changes in trade tariffs during the 2018-2019 trade war to estimate the net emission effect from export tariff increases for US manufacturing facilities. While controlling for other tariff changes, I find evidence that US emitting facilities respond to export tariff increases targeting their output by reducing their emissions. Importantly, results also highlight that downstream facilities that use the targeted outputs as inputs respond by increasing their emissions. This rebound effect from downstream emissions offsets the upstream emission reductions in the case of GHG-emitting manufacturing facilities affected by the 2018-2019 trade war.

The offsetting emission effect from downstream facilities highlights a potential issue with incomplete carbon tariffs applied to upstream products, such as the proposed EU CBAM policy. The EU CBAM will only cover five product categories: cement, iron and steel, aluminum, fertilizers, and electricity. This paper highlights the importance of considering input-output linkages for the net emission effect of incomplete carbon tariffs. Specifically, if uncovered downstream producers are large emitters, then their emission increases as a response to upstream carbon tariffs could offset the upstream emission reductions. As discussed in Titievskaia, Simões and Dobreva (2022), the EU Commission is aware of the potential emission reshuffling risks of downstream producers not currently considered under their CBAM, and is planning to re-evaluate in the coming years the inclusion of downstream products. Results in this paper suggest focusing on covering products of downstream producers that are large emitters.

A limitation of this paper is that the export tariffs facing US industrial facilities during the 2018-2019 trade war are not fully representative of the covered sectors under CBAM. The trade war tariff increases mostly affected the steel, iron, and aluminum sectors. Further research should study the net emission response to export tariffs of other covered sectors by the EU CBAM, namely the cement, fertilizers, and electricity sectors.

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A Figure appendix

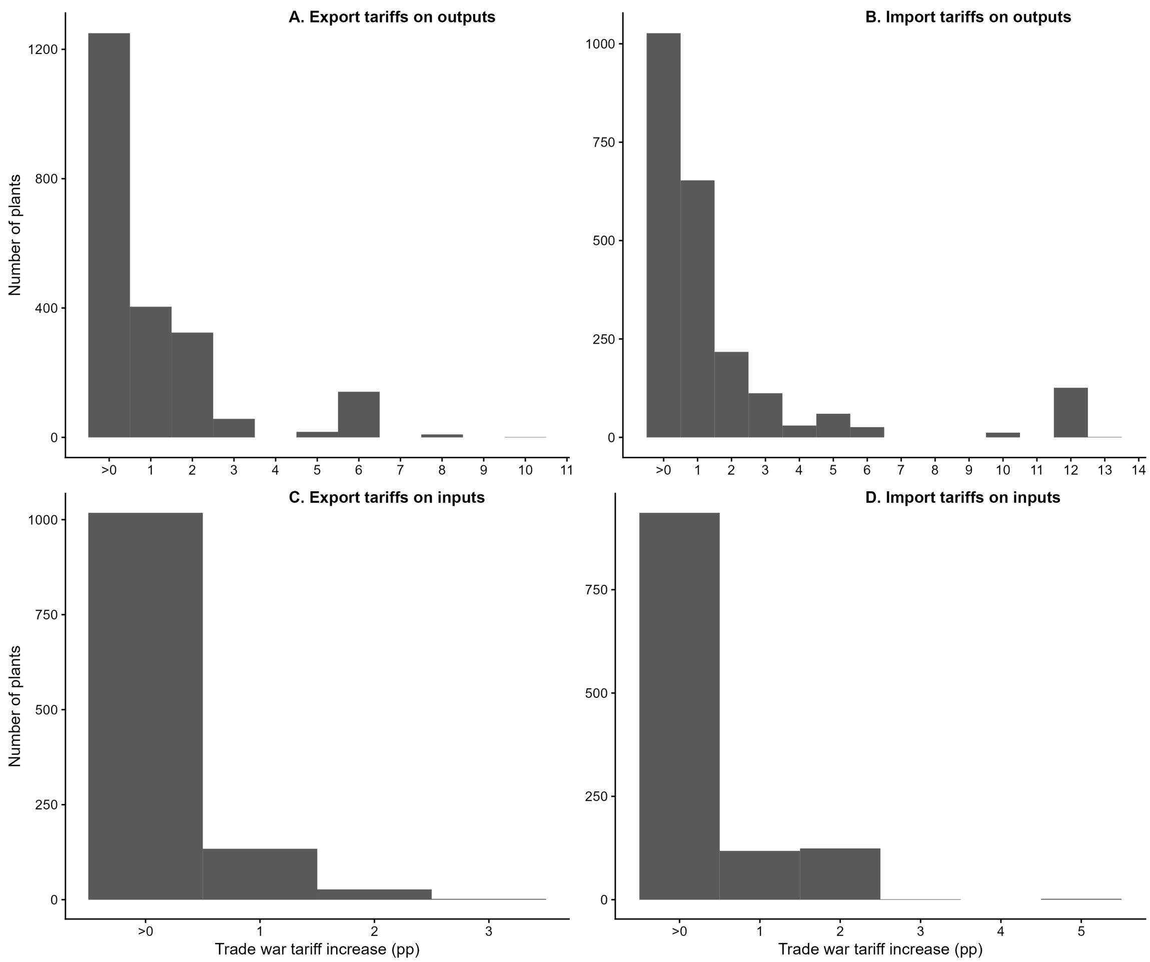

Figure A1: Distribution of NAICS-6 level trade-war tariff increases facing U.S. GHG emitting facilities

Notes: Figure A1 shows the distribution of GHG emitting manufacturing facilities facing increases in export or import tariffs on their output or input during the 2018-2019 trade war.

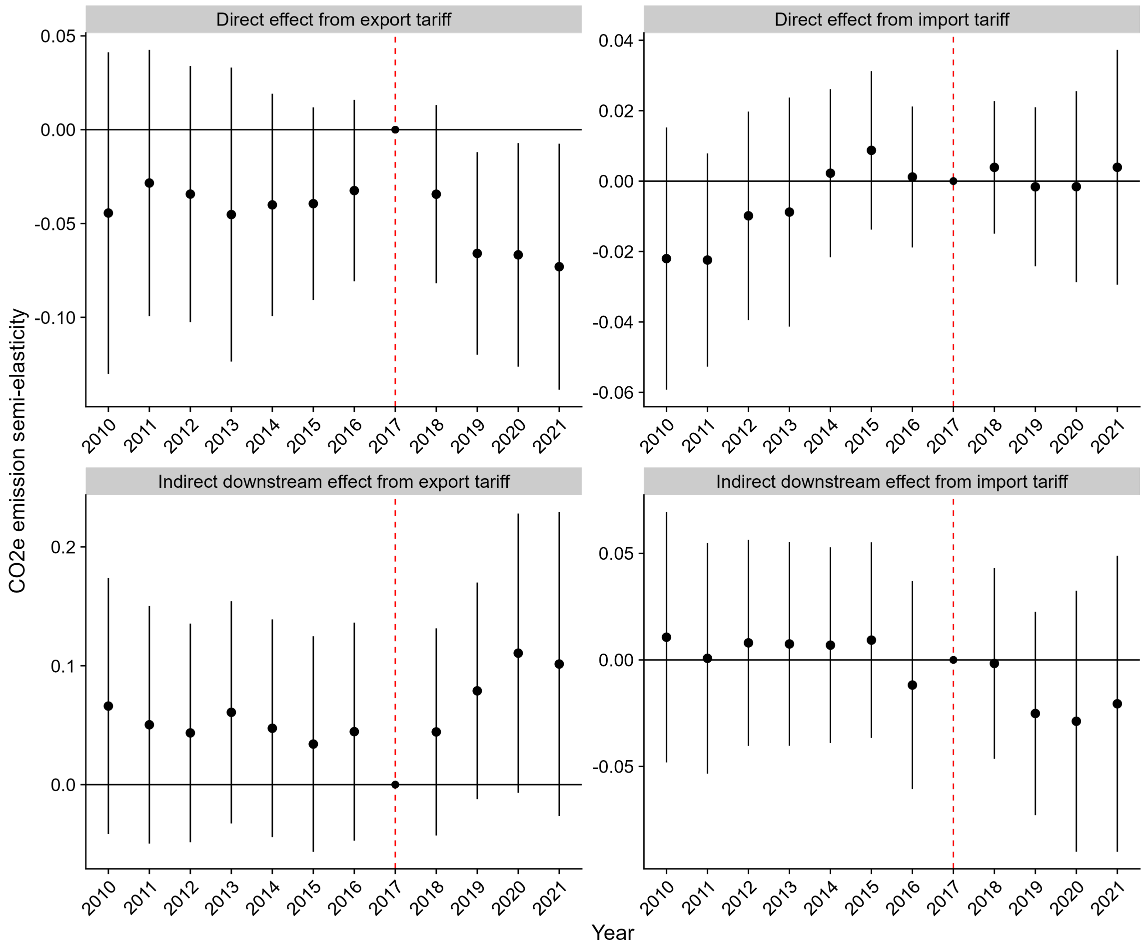

Figure A2: Event-study model of the effect of trade war tariffs on CO2e emissions

Notes: Point estimates and 95% confidence intervals of the semi-elasticity effect of output and input trade war tariffs on log CO_2e emissions relative to 2017 using an event study version of equation (9). Estimates for the sample restricted to the manufacturing sector are shown. Standard errors are clustered at the NAICS-6 level.

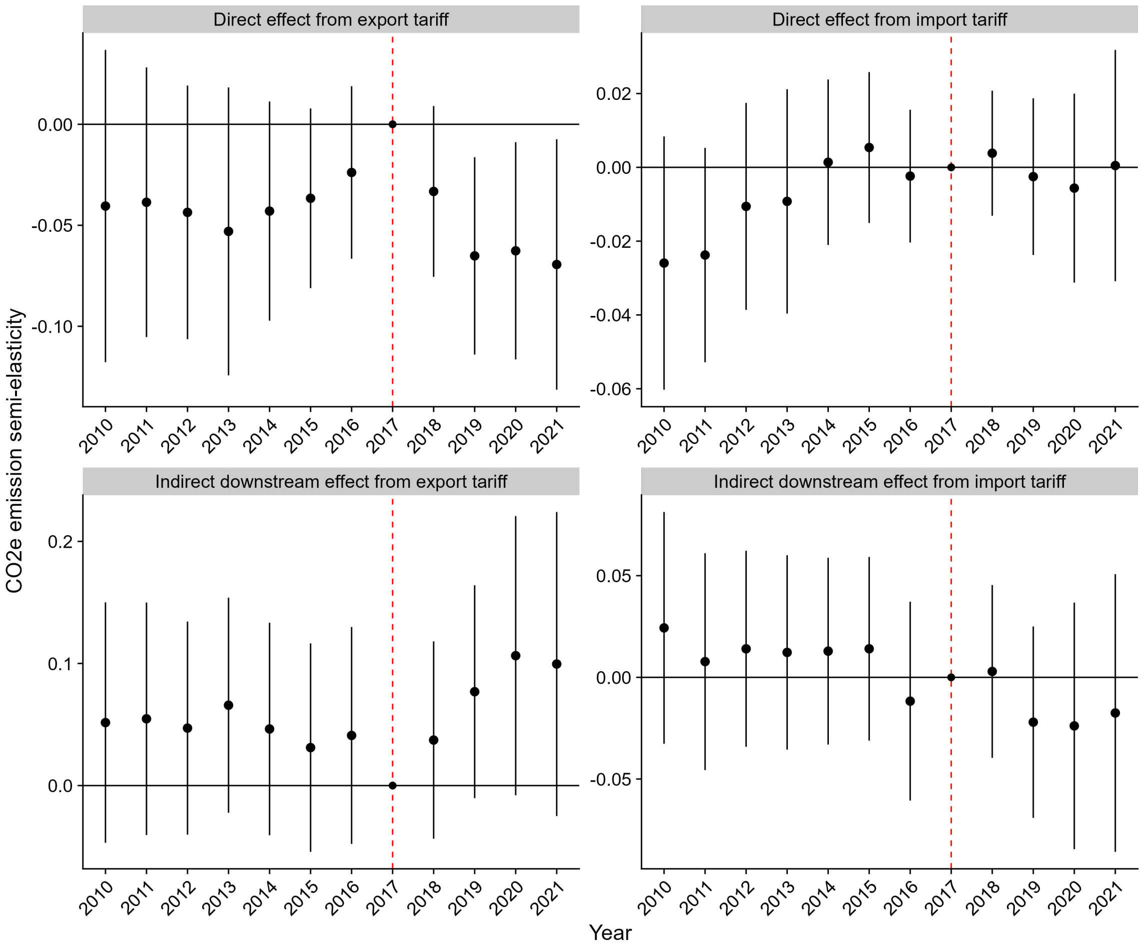

Figure A3: Event-study model of the effect of trade war tariffs on CO2e emissions

Notes: Point estimates and 95% confidence intervals of the semi-elasticity effect of output and input trade war tariffs on log CO_2e emissions relative to 2017 using an event study version of equation (9). Estimates for the sample restricted to NAICS-3 treated industries are shown. Standard errors are clustered at the NAICS-6 level.

B Table appendix

Table A1: NAICS-2 industry variation in trade war tariffs increases and greenhouse gas emissions

		Tariff increases (pp)										
		Export		Import		Export input		Import input		CO2e (kt)		
Sector	NAICS-2	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	# plants
Agriculture	11	1.4	3.08	0.2	0.57	0.03	0.08	0.05	0.16	48	17	7
Mining	21	0.7	1.56	0.45	1.59	0.03	0.05	0.05	0.1	175	331	1275
Water and sewage	22	0	0	0	0	0.01	0.01	0.02	0.02	114	337	260
Food and textile	31	0.7	1.36	0.96	1.78	0.09	0.31	0.07	0.17	107	330	370
Petroleum, chemical and wood	32	0.48	0.9	1.21	1.91	0.08	0.12	0.13	0.22	459	868	1454
Primary and secondary metal	33	0.58	0.96	2.22	3.07	0.3	0.5	0.67	0.98	205	806	468
Wholesale	42	0	0	0	0	0.01	0.01	0.04	0.03	22	24	4
Warehousing	49	0	0	0	0	0.02	0.02	0.04	0.04	52	65	8
Buidlings	53	0	0	0	0	0.02	0.02	0.05	0.07	66	31	5
Research and development	54	0	0	0	0	0.01	0.01	0.07	0.11	38	23	19

Notes: pp = percentage point. kt = kiloton. Std. dev. = Standard deviation.

Table A2: NAICS-3 manufacturing variation in trade war tariffs increases and greenhouse gas emissions

		Tariff increases (pp)										
		Export		Import		Export input		Import input		CO2e (kt)		
Sector	NAICS-3	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	# plants
Food	311	0.69	1.1	0.55	1.11	0.11	0.29	0.07	0.16	114	348	330
Beverage and tobacco products	312	1.75	3.07	0.3	0.79	0.25	0.66	0.18	0.32	48	30	27
Textile mills	313	0.24	0.27	1.73	2.07	0.02	0.05	0.04	0.08	70	47	7
Textile product mills	314	0.32	0.48	1.93	2.31	0.03	0.03	0.07	0.08	46	22	6
Wood products	321	0.34	0.92	1.31	1.65	0.02	0.05	0.05	0.16	119	124	25
Paper	322	0.45	0.61	2.18	3.12	0.1	0.11	0.14	0.18	671	747	226
Printing and related activities	323	0.29	0.42	0.64	1.22	0.04	0.05	0.14	0.18	31	7	2
Petroleum and coal products	324	0.4	0.9	0.09	0.13	0.08	0.09	0.09	0.12	1,205	1,583	173
Chemical	325	0.66	0.8	0.71	1	0.07	0.12	0.15	0.25	306	725	650
Plastics and rubber products	326	0.24	0.45	1.44	1.89	0.13	0.18	0.16	0.24	39	19	34
Nonmetallic mineral products	327	0.6	1.4	1.51	2.27	0.06	0.08	0.16	0.22	304	412	344
Primary metal	331	1.11	1.73	3.75	4.61	0.26	0.58	0.63	1.13	304	1,041	274
Fabricated metal products	332	0.44	0.65	1.65	2.5	0.52	0.8	1.01	1.5	40	31	26
Machinery	333	0.44	0.47	2	1.75	0.29	0.31	0.7	0.72	38	21	18
Computer and electronic products	334	0.59	0.88	2.29	2.45	0.09	0.09	0.27	0.28	126	146	51
Electrical equipment and appliances	335	0.78	0.76	3.41	4.2	0.32	0.32	0.74	0.79	26	18	14
Transportation equipment	336	0.51	1.34	1.11	2.06	0.37	0.56	0.85	1.02	46	26	81
Furniture and related products	337	0.61	1.14	3.93	4.61	0.22	0.36	0.51	0.74	20	NA	1
Miscellaneous	339	0.39	0.39	1.17	2.07	0.13	0.13	0.22	0.26	62	25	3

Notes: pp = percentage point. kt = kiloton. Std. dev. = Standard deviation.

Table A3: Industry-level US net export effect from a 1pp increase in trade war tariffs

	Net exports (mil $)	
	(1)	(2)
Direct effect from export tariffs	-274.231^{*}	-291.702^{**}
	(143.325)	(142.274)
Direct effect from import tariffs	159.131^{**}	204.924^{***}
	(69.195)	(72.922)
Indirect downstream effect from export tariffs	$1,039.853^{**}$	841.812^{**}
	(418.756)	(387.221)
Indirect downstream effect from import tariffs	-703.348^{***}	-523.849^{**}
	(243.127)	(215.693)
Adj. R2	0.94	0.94
NAICS-2 X Year	×	✓
Observations	4,168	4,168

Notes: Estimates of the emission semi-elasticity of the trade war tariffs on NAICS-6 level net exports in millions of USD. All models include year fixed effects and NAICS-6 fixed effects. Facilities are restricted to the manufacturing sector. Column 1 is the baseline model, whereas column 2 further includes NAICS-2 by year fixed effects. Robust standard errors clustered at NAICS-6 level in parentheses.

Table A4: Semi-elasticity of the trade war tariffs on facility-level CO2e emissions

	ln(CO2e)		
	(1)	(2)	(3)
Direct effect from export tariffs	-0.019	-0.027^{**}	-0.027^{**}
	(0.017)	(0.013)	(0.013)
Direct effect from import tariffs	-0.002	0.004	0.007
	(0.009)	(0.008)	(0.008)
Indirect downstream effect from export tariffs	0.040^{*}	0.045^{*}	0.041^{*}
	(0.024)	(0.023)	(0.025)
Indirect downstream effect from import tariffs	-0.026^{**}	-0.029^{**}	-0.023
	(0.013)	(0.014)	(0.016)
Adj. R2	0.87	0.87	0.87
State X Year	×	✓	✓
NAICS-2 X Year	×	×	✓
Observations	27,514	27,514	27,514

Notes: Estimates of the emission semi-elasticity of the trade war tariffs. All models include year fixed effects and plant fixed effects. The control and treatment groups are restricted to facilities in the manufacturing sector. Column 1 is the baseline model. Column 2 further includes state by year fixed effects. Column 3 additional controls for NAICS-2 by year fixed effects. Robust standard errors clustered at NAICS-6 level in parentheses.

Table A5: Facility-level CO2e emission effect of the trade war tariffs

	CO2e (kt)		
	(1)	(2)	(3)
Direct effect from export tariffs	-5.853	-6.753^{*}	-2.786
	(4.174)	(3.892)	(2.751)
Direct effect from import tariffs	-0.664	-0.636	-4.657^{*}
	(2.042)	(2.471)	(2.414)
Indirect downstream effect from export tariffs	9.127^{**}	12.002^{***}	7.714^{*}
	(4.270)	(4.338)	(4.252)
Indirect downstream effect from import tariffs	-8.001^{***}	-8.983^{***}	-6.007^{**}
	(2.291)	(2.636)	(2.379)
Adj. R2	0.96	0.97	0.97
State X Year	×	✓	✓
NAICS-2 X Year	×	×	✓
Observations	27,514	27,514	27,514

Notes: Estimates of the emission effect of the trade war tariffs. All models include year fixed effects and plant fixed effects. The control and treatment groups are restricted to facilities in the manufacturing sector. Column 1 is the baseline model. Column 2 further includes state by year fixed effects. Column 3 additional controls for NAICS-2 by year fixed effects. Robust standard errors clustered at NAICS-6 level in parentheses.

Table A6: Semi-elasticity of the trade war tariffs on facility-level CO2e emissions

	ln(CO2e)		
	(1)	(2)	(3)
Direct effect from export tariffs	−0.008	−0.019	−0.023*
	(0.018)	(0.012)	(0.012)
Direct effect from import tariffs	0.001	0.008	0.007
	(0.009)	(0.008)	(0.008)
Indirect downstream effect from export tariffs	0.036	0.045*	0.038
	(0.026)	(0.024)	(0.024)
Indirect downstream effect from import tariffs	−0.028**	−0.032**	−0.024
	(0.014)	(0.014)	(0.016)
Adj. R2	0.85	0.85	0.85
State X Year	×	✓	✓
NAICS-2 X Year	×	×	✓
Observations	46,875	46,875	46,875

Notes: Estimates of the emission semi-elasticity of the trade war tariffs. All models include year fixed effects and plant fixed effects. The control group is restricted to facilities in the same NAICS-3 industries as the treated facilities. Column 1 is the baseline model. Column 2 further includes state by year fixed effects. Column 3 additional controls for NAICS-2 by year fixed effects. Robust standard errors clustered at NAICS-6 level in parentheses.

Table A7: Robustness checks of semi-elasticities of the trade war tariffs on facility-level CO2e emissions

	ln(CO2e)				
	(1)	(2)	(3)	(4)	(5)
Direct effect from export tariffs	−0.014	0.028	−0.029*	−0.022	−0.012
	(0.019)	(0.032)	(0.017)	(0.016)	(0.039)
Direct effect from import tariffs	−0.009	0.001	−0.004	0.002	−0.005
	(0.010)	(0.013)	(0.009)	(0.008)	(0.016)
Indirect downstream effect from export tariffs	0.016	0.007	0.049	0.039	0.040
	(0.020)	(0.043)	(0.030)	(0.026)	(0.043)
Indirect downstream effect from import tariffs	−0.010	−0.005	−0.031*	−0.025*	−0.030
	(0.011)	(0.020)	(0.016)	(0.014)	(0.021)
Adj. R2	0.91	0.81	0.88	0.56	0.85
Sample	Balanced	Single	Multi	Small	Large
Observations	21,619	6,566	20,946	12,570	14,582

Notes: Estimates of the emission semi-elasticity of the trade war tariffs for different samples. The first column restricts the sample to a balanced panel of plants. The second and third columns respectively restrict the plants to single and multi plant firms. The fourth and fifth row restrict the samples to above and below median CO2e emitters for the years before the trade war. All models include year fixed effects and plant fixed effects. Facilities are restricted to the manufacturing sector. Robust standard errors clustered at NAICS-6 level in parentheses.