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THE ENVIRONMENTAL BIAS OF TRADE POLICY

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ABSTRACT

This paper describes a new fact, then analyzes its causes and consequences: in most countries, import tariffs and non-tariff barriers are substantially lower on dirty than on clean industries, where an industry's "dirtiness" is defined as its carbon dioxide (CO₂) emissions per dollar of output. This difference in trade policy creates a global implicit subsidy to CO₂ emissions in internationally traded goods and so contributes to climate change. This global implicit subsidy to CO₂ emissions totals several hundred billion dollars annually. The greater protection of downstream industries, which are relatively clean, substantially accounts for this pattern. The downstream pattern can be explained by theories where industries lobby for low tariffs on their inputs but final consumers are poorly organized. A quantitative general equilibrium model suggests that if countries applied similar trade policies to clean and dirty goods, global CO₂ emissions would decrease and global real income would change little.

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An online appendix is available at <http://www.nber.org/data-appendix/w26845>

I Introduction

This paper describes a new fact, then analyzes its causes and consequences: in most countries, import tariffs and non-tariff barriers (NTBs) are lower on dirty than on clean industries, where an industry’s “dirtiness” is measured by its carbon dioxide (CO₂) emissions per dollar of output. This difference between dirty and clean industries creates an implicit subsidy to CO₂ emissions in internationally traded goods and so contributes to climate change. I describe this pattern as trade policy’s environmental bias.

This bias is widespread. I find it in most countries, in tariffs and NTBs, and in cooperative and non-cooperative tariffs. U.S. tariff data over the past 30 years suggest this bias has slowly diminished over time, though remains large. U.S. tariffs imposed in the 2018 trade war slightly attenuated but did not eliminate this bias. The global implicit subsidy in trade policy that I estimate, of \$85 to \$120 per ton of CO₂, is interesting because the global social cost of CO₂ emissions (and hence the optimal tax on CO₂ emissions) is usually estimated as around \$40 per ton of CO₂ (IWG 2016). The magnitude of the environmental bias of trade policy is therefore larger than what research suggests is an optimal tax on CO₂ emissions, and the sign is opposite—trade policy is imposing lower tax rates on dirtier goods, while an optimal carbon policy would impose higher tax rates on dirtier goods.

One way to interpret this fact is in terms of climate change policy. Optimal climate change policy would impose a uniform Pigouvian tax (or equivalent quantity mechanism like a cap-and-trade market) in all countries and industries, since CO₂ creates the same climate change externality regardless of where it is emitted. Researchers and policymakers often claim that imposing climate change policy in some countries but not others could harm domestic energy-intensive industries and lead to relocation or “leakage” of emissions, more than an absolute decrease in emissions. Climate change regulation is far from global and covers about 20 percent of global CO₂ emissions, including in the EU, California, and elsewhere (World Bank 2018). Carbon prices in these policies differ substantially across regulations and are generally below \$10/ton. Some countries have considered pairing such sub-global policy with an import tariff or border adjustment that is proportional to the CO₂ emitted from producing and transporting goods.¹

Of course, most countries already impose tariffs and NTBs on traded goods. This paper asks whether dirty industries already face higher tariffs and NTBs, which would mean that countries already implicitly have carbon tariffs in their existing trade policies. Given media emphasis on dirty industries’ political lobbying, one might expect dirtier industries to receive relatively greater trade protection. I show that this prediction is incorrect, and that dirtier industries face relatively low tariffs and NTBs.

I obtain these findings from regressions of tariff (or ad valorem NTB) rates on CO₂ intensity. I

¹Some versions of this proposal would include rebates for exports. Several proposed U.S. climate change regulations would implement carbon tariffs, including the Waxman-Markey Bill (the American Clean Energy and Security Act), which passed the House but not the Senate in 2009; the American Opportunity Carbon Fee Act of 2014; and a current “carbon dividends” proposal by the U.S. Climate Leadership Council led by James Baker, Martin Feldstein, Greg Mankiw, and publicly endorsed by 27 economics Nobel laureates and 3500 economists. One common perception is that a carbon tariff is politically necessary (though so far not politically sufficient) to ensure support for any U.S. climate change regulation. Legal analyses suggest that regulations of the World Trade Organization (WTO) could allow such carbon tariffs, though disagree on exactly which type of carbon tariff WTO rules would allow (Hillman 2013; Pauwelyn 2013; Cosbey et al. 2017).

measure CO₂ intensity by inverting a global multi-region input-output table, which accounts for emissions embodied in intermediate goods. For example, the CO₂ emissions rate for U.S. kitchenware accounts for the Australian coal used to produce the Chinese steel used to produce a U.S. frying pan, and the bunker and diesel fuels used to transport each. The global input-output data this paper uses, from Exiobase, describe 48 countries and 163 industries, and so generate measures of CO₂ intensity for each international and intra-national trade flow in the global economy. The tariff data are even more detailed, with 200 million tariff measures that uniquely describe each origin×destination×industry. I obtain qualitatively similar results from several other datasets and sensitivity analyses.

Why have countries imposed more protection on clean than dirty industries? Theory and evidence suggest that countries do not explicitly consider CO₂ or intend to subsidize it in choosing trade policy; indeed, I believe that countries are not even aware of the implicit subsidy in trade policy this paper highlights, since previous literature has not tested for or identified it. Instead, this paper proposes that some forces which determine trade policy are correlated with CO₂ intensity.

To determine which forces account for the association between trade policy and CO₂ intensity, the analysis considers explanations based on 20 variables suggested by theoretical and empirical research. These explanations include optimal tariffs (inverse export supply elasticities), lobbying expenditures, unionization, labor and capital shares, declining or “sunset” industries, worker wages and education, firm size, industry concentration rates, intra-industry trade, levels and trend in trade exposure, dispersion in firm sizes and in firm locations, shipping costs, unemployment, “local” pollutants like sulfur dioxide, production efficiency, and an industry’s upstream location. These variables are available for the U.S.; a subset is available for all countries. To address potential endogeneity, some specifications instrument a particular political economy explanation (e.g., mean wages in a specific industry) with its value from the ten other smallest countries in the data. I focus on the ten smallest other countries since they are more likely to take conditions in the rest of the world as given.

Among these potential explanations, linear regressions and a machine learning algorithm highlight an industry’s location or “upstreamness” in global value chains as accounting for a large share of the association between CO₂ intensity and trade policy. The analysis measures upstreamness as the economic distance of each industry from final consumers (Antràs et al. 2012). More upstream industries have both lower protection and greater emissions.

I investigate one political economy explanation for the covariance of upstreamness and trade policy involving lobbying competition. Firms may lobby for high tariffs and NTBs on their own outputs, but also lobby for low tariffs on the goods they use directly and indirectly as inputs, so as to decrease production costs.² Because final consumers are poorly organized (Olson 1965), politicians give the least protection to

²Firms publicly emphasize this rationale. When President Trump initially proposed tariffs on steel, the American Automotive Policy Council announced, “The auto industry and the U.S. workers that the industry employs would be adversely affected and that [*sic*] this unintended negative impact would exceed the benefit provided to the steel industry” (Gibson 2017). The Consuming Industries Trade Action Coalition (CITAC), a twenty-year old U.S. lobby group focused on decreasing tariffs on upstream industries, experienced a doubling of membership during a “Stand up to Steel” campaign, and supported a bill in the U.S. House of Representatives (HR 2770) to give steel consumers greater standing in trade cases. When President Obama imposed tariffs on Chinese tires, CITAC responded, “[W]e believe that this case will undermine the jobs of many more US

the upstream industries (which are also the dirtiest) and the greatest protection to the most downstream industries (which are also the cleanest).

Figure I shows nonparametric local linear regressions that illustrate several key ideas in the paper. Each graph in this figure shows two lines. The downward-sloping dashed blue line shows a nonparametric regression of total CO₂ intensity on upstreamness. This line shows that the most upstream industries are dirtier. The upward-sloping solid red line shows a local linear regression of tariffs plus NTBs on upstreamness, which shows that the most upstream industries have the least protection. The patterns are similar for global and U.S. data. Previous research has not documented this systematic nonparametric relationship between trade policy and upstreamness, or between pollution and upstreamness. In these graphs, the relationships between each of these outcomes (CO₂ intensity, trade policy) and upstreamness are somewhat linear.

Appendix Figure I finds similar patterns in essentially each of the roughly 50 countries with data. This figure plots nonparametric relationships between CO₂ intensity and upstreamness, and between trade policy (tariffs+NTBs) and upstreamness, separately for each country in Exiobase. While this figure provides almost 50 separate small graphs, casual inspection shows the “X”-shaped pattern that in most countries, CO₂ intensity increases somewhat steadily with upstreamness, while tariffs and NTBs decrease.

A partial equilibrium back-of-the-envelope calculation suggests that this global implicit subsidy in trade policy to CO₂ emissions totals \$550 to \$800 billion dollars per year. This can be interpreted as revenue that a carbon tariff would collect if it had the same pattern as trade policy’s environmental bias (i.e., -\$85/ton to -\$120/ton).

I then use a quantitative general equilibrium model to assess how counterfactual trade policies would affect CO₂ emissions and social welfare. This analysis uses strong assumptions that provide an imperfect approximation to reality.

The model incorporates several common features—input-output links, trade imbalances, CO₂ emissions from fossil fuel, tariffs that are lump-sum rebated, and NTBs (Costinot and Rodriguez-Clare 2014; Caliendo and Parro 2015; Eaton et al. 2016; Shapiro 2016). I study six sets of counterfactual policies. In the first, each country sets a single tariff per trading partner which applies to all industries, and which equals the country’s mean baseline bilateral tariff. Each country implements a similar reform for NTBs. This counterfactual decreases global CO₂ emissions while leaving global real income unchanged or slightly increased. It has similar magnitude effects on CO₂ as two of the world’s largest actual or proposed climate change policies, the EU Emissions Trading System and the U.S. Waxman-Markey Bill. In the second counterfactual, only the EU adopts this policy. One could think of this as a way for the EU to address leakage from its CO₂ cap-and-trade market, the EU Emissions Trading System. This decreases global CO₂ emissions by half the amount of the global policy, and again leaves global real income unchanged or slightly higher.

The third and fourth counterfactuals find that changing tariffs and NTBs to equal either the base-
workers in downstream industries...” (Business Wire 2009).

line level of the cleanest third or dirtiest third of industries decreases global CO₂ emissions by several percentage points. Fifth, I consider a counterfactual in which every country adds a tariff proportional to goods' CO₂ intensity, i.e., a carbon tariff. This has modest environmental benefits. Finally, if countries completely eliminated tariffs and NTBs, both global CO₂ emissions and real income would rise. Although turning off trade policy by definition eliminates trade policy's environmental bias, the resulting increase in income dwarfs this environmental effect.

This paper has potentially important policy implications. In a first-best setting where every country implemented uniform carbon prices on all CO₂ emissions, trade policy would have no role in efficient climate policy. In a second-best setting where political economy constraints make optimal climate change policy infeasible, considering environmental concerns in designing trade policy could potentially increase welfare. But in either setting, a trade policy which subsidizes CO₂ may be inefficient, and hence limiting the greater protection of clean relative to dirty goods could increase welfare. I believe that a reform which considers the CO₂ intensity of an industry in negotiating bilateral or multilateral trade policy across industries but without a formal carbon tariff has not been discussed in government or academia.³ Such reforms may appeal to groups that typically disagree – dirty industries and environmentalists – because they can maintain protection of dirty domestic industries (at least relative to clean industries) while decreasing global CO₂ emissions. More broadly, the World Trade Organization (WTO) has sought to decrease protection of downstream relative to upstream industries, since such trade policy reforms would let developing countries sell more advanced technologies to industrialized countries. This paper suggests that such WTO goals may also help address climate change.

Several caveats are worth noting. This paper refers to the higher tariff and NTB rates on clean relative to dirty goods as an implicit “subsidy” in trade policy to CO₂ emissions. This “subsidy” refers to a lower tax rate in a setting where most goods face positive taxes (tariffs and NTBs). This difference in trade policy may encourage countries to purchase more clean goods domestically and dirty goods from abroad; internationally traded goods within an industry are more CO₂-intensive both because they require long-distance transportation and because they tend to be outsourced to countries like China and India that rely heavily on coal for production and so are CO₂-intensive (Shapiro 2016). The difference in trade policy also encourages firms and final consumers to substitute from consuming cleaner to dirtier goods (e.g., substituting from aluminum to steel). For these reasons and since the quantitative analysis finds that the difference in trade policy between clean and dirty industries increases global CO₂ emissions, I refer to this difference in trade policy as an implicit “subsidy.” This is a global subsidy—for example, if France imposes low import tariffs on dirty goods, this may increase CO₂ emissions from French trading partners and from the globe overall, though could decrease these emissions from within France.⁴

³Such reforms are likely feasible within WTO regulations. The WTO does not primarily regulate NTBs, so most changes in NTBs are permissible. WTO members negotiate maximum (“binding”) tariffs on trading partners. The binding tariffs do constrain the maximum possible level, but WTO members have flexibility in choosing tariffs below those levels through bilateral or multilateral agreements.

⁴A carbon subsidy through trade policy can also produce a range of behavioral responses, not all modeled here. For example, increasing the price of energy-intensive goods might lead consumers to use existing goods for longer, which could make the net effect on carbon emissions ambiguous. An analogous pattern in vehicle fuel economy standards is sometimes called the

It is also worth discussing the implications of using a second-best tool like trade policy as an alternative or complement to traditional environmental taxes on production or consumption. Important debates have considered the merits of taxing pollution through trade policy (e.g., [Kortum and Weisbach 2016](#)). One point of this paper is that current trade policy is subsidizing pollution for political economy (not efficiency) reasons, which no theoretical or empirical arguments claim is efficient.

This paper builds on several literatures. I believe this paper is the first to report the association of tariffs or NTBs with the pollution emitted to produce different goods, and the first to quantify the environmental consequences of harmonizing trade policy between clean and dirty goods. Research on trade and the environment asks how hypothetical changes in aggregate trade flows affect pollution, studies hypothetical carbon tariffs, or investigates how environmental policies and attributes of industries affect trade flows though not trade policies ([Antweiler 1996](#); [Copeland and Taylor 2003](#); [Frankel and Rose 2005](#); [Fowlie et al. 2016](#); [Shapiro and Walker 2018](#)). A large literature studies the consequences of hypothetical carbon border tax adjustments, relying primarily on computable general equilibrium (CGE) models and largely or completely abstracting from existing patterns of tariffs or NTBs. An entire field of academia, industrial ecology, quantifies the pollution required to produce internationally traded goods. Research in industrial ecology and economics measures pollution embodied in traded goods (e.g., [Antweiler 1996](#); [Davis and Caldeira 2010](#); [Aichele and Felbermayr 2012](#)). None of this work compares its measures of pollution embodied in traded goods against actual current levels of tariffs or NTBs.

This paper also introduces tariffs and NTBs as a new setting to study political economy and the environment. Research on the political economy of environmental policy is limited. Some work does use [Grossman and Helpman \(1994\)](#)'s "Protection for Sale" model to study domestic environmental policy ([Fredriksson 1997](#); [Schleich and Orden 2000](#)). Trade policy provides an appealing setting to study political economy and the environment because it governs the more than 20 percent of CO₂ that crosses international borders embodied in traded goods, substantially affects pollution, creates easily-observed tax rates that vary across industries and countries, and depends on political economy forces like lobbying.

This paper also builds on an older trade policy literature by providing the first nonparametric evidence of "tariff escalation" – the phenomenon that more processed goods face higher tariffs – using continuous measures of upstreamness; the first evidence of NTB escalation, which is important since NTBs create a larger trade barrier than tariffs in industrialized countries; and the first empirical link between tariff escalation and the environment. [Corden \(1966, p. 228\)](#) in the *Journal of Political Economy* described tariff escalation as "so well known that detailed substantiation is hardly needed." Research on tariff escalation has since become uncommon, despite renewed interest in global value chains. While the existing literature generally identifies tariff escalation by reporting three mean tariff rates, for "primary," "intermediate," and "consumer goods" ([Balassa 1965](#); [Golub and Finger 1979](#); [Marvel and Ray 1983](#)), I propose that upstreamness provides a natural and continuous measure to use for studying escalation. Upstreamness is also related to the explanation for tariff escalation that downstream industries may lobby for low tariffs on their intermediate inputs ([Cadot et al. 2004](#); [Gawande et al. 2012](#)). I am not aware

"Gruenspecht effect" ([Jacobsen and van Benthem 2015](#)).

of prior work interpreting tariff escalation through the full measure of upstreamness, though [Gawande et al. \(2012\)](#) relate it to the simpler measure of the share of an industry’s output sold as intermediates. I show that upstreamness is more strongly associated with tariffs or NTBs than are many other standard explanations for trade policy. The most relevant recent other parts of the trade policy literature link trade policy to global value chains ([Antràs and Staiger 2012](#); [Blanchard et al. 2016](#)) and link trade policy to other domains like the environment ([Copeland 2000](#); [Maggi 2016](#)).

The paper proceeds as follows. Section 2 describes the data and Section 3 the econometrics. Section 4 discusses the relationship between pollution intensity and trade policy. Section 5 evaluates political economy explanations. Section 6 evaluates consequences of counterfactual reforms. Section 7 concludes.

II Data

I combine data on three types of variables: trade policy, pollution emissions, and political economy. Unless otherwise noted, all data represent a cross-section for the year 2007 (which is the year Exiobase covers) or the closest available year. I show some estimates with multiple years of U.S. data. Appendix A provides additional detail on each set of files, including concordances that link different industry classifications, and Appendix A.6 compares the use of industry classifications versus input-output tables for measuring tariffs on intermediate versus final goods.

II.A Trade Policy

Tariffs are the most easily-quantified trade policy instrument, but NTBs are increasing in importance. I obtain data on tariff rates from the Market Access Map (Macmap) database. A 2-digit Harmonized System (HS) code version of these data is freely available online. I purchased the 6-digit HS code version from the French *Centre d’Etudes Prospectives et d’Informations* (CEPII) ([Guimbard et al. 2012](#)). The data provide the most comprehensive tariff records available. The data distinguish 5,000 different goods (6-digit Harmonized System codes) for 190 countries and account for most-favored nation tariffs, regional trade agreements, free trade agreements, customs unions, and tariff-rate quotas. The data cover all bilateral trading partners.

For tariffs on U.S. imports, I use records from the Census Bureau’s Imports of Merchandise files. While Macmap lists statutory tariff rates (i.e., official policy), Census records list tariff duties actually paid, so permit calculation of effective tariff rates.

Non-tariff barriers (NTBs) include policy barriers to trade that are not tariffs, such as price regulations, product standards, quantity restrictions like quotas, or others.⁵ I use data from [Kee et al. \(2009\)](#) on the

⁵A global social planner might set tariff rates to zero, since tariffs largely exist for political economy or terms-of-trade reasons. A global planner might set some NTBs to non-zero rates, since some NTBs could address market failures in health, safety, or the environment. I abstract from efficiency rationales for NTBs in part since I am not aware of data distinguishing the extent to which each country and industry’s NTBs are efficient versus reflect rent-seeking and protectionism. It is generally believed that NTB rates have risen in recent decades partly in response to decreased tariff rates, which would suggest that NTBs primarily represent protection rather than correction of market failures.

dollar (i.e., ad valorem) equivalent of NTBs; they describe how they calculate these values from raw data in the World Bank’s World Integrated Trade Solutions (WITS) system. These NTB values are calculated for each 6-digit HS code, for a year around 2000-2003 (the exact year varies across countries), and for about 100 countries.

II.B CO₂ Emissions

I first explain my approach to measuring CO₂ emissions informally for one closed economy, then explain it formally, then discuss multiple open countries, and finally describe data sources.

Consider two types of CO₂ emissions. First, an industry burns fossil fuels to produce output. Second, an industry purchases intermediate goods as inputs that themselves require CO₂ emissions to produce. I describe the first channel as “direct” CO₂ emissions and the second as “indirect.” An input-output table for one country contains one row per industry and one column per industry. Each value in the table represents the dollars of output from an industry in a row required to produce a dollar of output of the industry indicated in a column. This permits calculation of direct CO₂ emissions, since it shows how many dollars of coal, oil, and natural gas are required to produce a dollar of output in each other industry. To calculate direct CO₂ emissions, I consider the rows for the coal extraction, oil extraction, and natural gas extraction industries. The analysis uses independent data on the national price per physical unit of each fossil fuel and on the physical emissions rate (i.e., the tons of CO₂ emitted per ton of coal, barrel of oil, or cubic foot of natural gas burned). Multiplying these coal, oil, and gas input expenditures by the tons of CO₂ emitted per dollar of fossil fuel burned gives the direct emissions rate. This approach to using an input-output matrix to account for pollution is standard (Miller and Blair 2009, p. 447) and resembles what the Intergovernmental Panel on Climate Change calls the “Tier 1” or “default” method of calculating CO₂ emissions. It is designed to measure emissions from producing goods, which is appropriate for an analysis of tariffs on internationally traded goods.⁶ It obtains industry-level measures of CO₂-intensity, though abstracts from intra-industry heterogeneity (Lyubich et al. 2018).

This approach can calculate direct but not indirect emissions. For example, the emissions rate for cookware in this approach reflects fossil fuels burned to shape steel into a pan (which are listed in the cookware industry column) but not fossil fuels used to make the steel in the first place (which are listed in the steel industry column or its input industries like electricity). As shown formally below, inverting the input-output matrix permits calculation of total emissions, which equal the sum of direct and indirect emissions. This inverse indicates the dollars of coal, oil, and natural gas required to produce a dollar of output in each industry, including the coal, oil, and natural gas embodied in intermediate goods, and inputs to intermediates, and inputs to these inputs, etc. Environmental researchers call this a “life cycle” or “footprint” measure of emissions; international economists call it a “value chain” measure.

⁶One could also wonder how domestic or “behind-the-border” policies affect the choice among energy-consuming durable goods like cars or air conditioners. While Section IV.B discusses sensitivity analyses designed to account for energy used in consuming these goods, a detailed analysis of energy consumption for these goods and associated policies is the topic of an active body of research that uses models specialized to these sectors (e.g., Bento et al. 2009; Jacobsen et al. 2019).

Continuing this explanation for a single closed economy, let S denote the number of industries in the economy and let A be an $S \times S$ input-output table where each row lists the industry supplying inputs and each column lists the industry demanding outputs. Each entry in the matrix A describes the dollars of input from the industry in a given row required to produce a dollar of output for the industry in a given column. Let x be an $S \times 1$ column vector describing each industry’s gross output and let d be an $S \times 1$ vector of final demand, including exports. An accounting identity states that each industry’s gross output equals the value of its output used for intermediate goods in all industries plus the value of its output used for final demand: $x = Ax + d$. Simple algebra then reveals the total amount of intermediate inputs (including both direct and indirect inputs) required to produce a dollar of final demand: $x = (I - A)^{-1}d$. The matrix $(I - A)^{-1}$ is called the Leontief inverse or the matrix of total requirements. It describes the dollars of each input, including those required to produce intermediate inputs, and inputs to inputs, etc. required to produce an additional dollar of final demand. This approach does not account for changes in CO₂ emissions from goods that are complementary with or substitutes for the good of interest, which may be most relevant for energy-consuming durable goods like vehicles or housing.

Extending this approach to multiple open countries and industries is straightforward. Let N denote the number of countries. In a multi-region input-output table, A is an $NS \times NS$ matrix, where each row is a specific country×industry and each column is a specific country×industry. For example, one table entry might show the dollars of Chinese steel (one row) required to produce a dollar of U.S. cookware (one column). Then x and d are $NS \times 1$ column vectors describing gross output and final demand, respectively. Using a multi-region input-output table, the rest of the analysis proceeds as above.

Several data sources help measure CO₂ emissions. The main dataset is Exiobase, which combines trade data, input-output tables, and national accounts to construct a global multi-region input-output table. Exiobase reports the direct CO₂ emissions per million Euros of output for every country×industry. To construct data on CO₂ emissions per country×industry, Exiobase primarily uses emissions data from the International Energy Agency (IEA 2007a,b,c). I use Exiobase’s calculated CO₂ emissions from fossil fuel combustion for each country×industry. Appendix A.2 provides additional details on Exiobase.

I then calculate total (direct+indirect) emissions rates from Exiobase as follows. Let L_{ijst} denote an entry of the Leontief inverse $L = (I - A)^{-1}$, i.e., the dollars of output from industry s in country i required to produce one dollar of output from industry t in country j , including the entire global value chain (inputs, inputs to inputs, etc.). Let E_{is}^{direct} be the direct emissions from producing a dollar of output from country i in industry s , i.e., the CO₂ emitted from the coal, oil, and natural gas used directly in this country×industry. Exiobase reports E_{is}^{direct} . Then the total emissions rate is $E_{jt} = \sum_{i,s} L_{ijst} E_{is}^{direct}$.

II.C Political Economy Explanations

Why do different industries face different trade policies? One explanation involves optimal tariffs and the terms of trade—a large country can privately benefit by imposing small import tariffs on its trading partners. In this classic explanation, a country’s privately optimal tariff equals the inverse of the foreign export supply elasticity it faces (Bickerdike 1907). Optimal tariffs could correlate with CO₂ intensity,

since optimal tariffs are higher on more differentiated industries, and clean industries may be more differentiated. The second set of theories involves political economy. The more influential of these theories focus on organized interest groups (Olson 1965; Grossman and Helpman 1994, 1995; Maggi and Rodríguez-Clare 1998, 2007). Organized industries can provide campaign contributions and use other means to obtain trade protection. Politicians may find it privately optimal to distort trade policy in response to this lobbying, but in most settings a social planner would not.

Some political economy variables are available separately for each country×industry in Exiobase; I extract these variables and use them for the global analysis. A larger set of political economy variables are available for each industry in U.S. data; I use these data to analyze the U.S. only. The introduction lists each variable; Appendix A.3 describes measurement of each variable and their data sources. I choose variables to include following existing empirical trade policy research (Pincus 1975; Caves 1976; Anderson 1980; Ray 1981; Marvel and Ray 1987; Treffer 1993; Freund and Çağlar Özden 2008), especially Rodrik (1995).

I add a measure of “local” air pollution emissions and damages not discussed in the trade literature. Firms’ emissions of air pollutants, in addition to emissions of pollution through water and land, create local external costs. These externalities could lead to policies like low tariffs and NTBs on dirty industries which seek to relocate polluting activity to other countries.⁷

I discuss the one variable here which turns out to be the most important. I measure each industry’s “upstreamness” as the average economic distance of an industry from final use. One can also interpret upstreamness as the mean position of an industry’s output in a vertical production chain (Antràs and Chor 2013) or as the share of an industry’s output sold to relatively upstream industries (Fally 2012). If industry i is measured to be more upstream than industry j , this does not imply that industry i actually supplies industry j . Rather, this simply implies that industry i on average is further in economic distance from final consumers than industry j is. Appendix A.3 presents the equation used to measure upstreamness and discusses its measurement. Upstreamness is measured for each industry in the U.S. data and each country×industry in the Exiobase global data.

III Econometrics

III.A Trade Policy and CO₂ Intensity

To measure differences in trade policy between clean and dirty industries, I estimate the following:

$$t_{js} = \alpha E_{js} + \mu_j + \epsilon_{js} \tag{1}$$

⁷Another interpretation is that many regions impose domestic local zoning restrictions that relocate dirty production from richer to poorer areas. Similarly, imposing low tariffs and NTBs on dirty goods could reflect wealthy countries’ efforts to relocate dirty production to poor countries.

The dependent variable t is the mean import tariff rate or ad valorem NTBs that destination country j imposes on goods in industry s . In the global data, s represents the foreign industry which produced the good, not the domestic industry which consumed it. For example, the emissions rate E for Mexican imports of steel reflects the mean emissions from steel production in all countries from which Mexico imports, while the tariffs t reflects Mexico’s import tariffs on steel. Equation (1) has a j rather than both i and j subscript because the analyses averages across origin countries (weighted by the value of each trade flow) for three reasons: this enhances comparability between tariffs and NTBs, since the latter are defined only by destination country and industry; this helps address the presence of zero trade flows between some origin×destination×industry tuples; and this increases comparability of these regressions with political economy variables, which are observed at the country×industry level. I show some results with separate observations for each exporter×importer×industry ($i \times j \times s$) tuple. Appendix B provides some additional details on equation (1).

The main explanatory variable, E , represents the tons of CO₂ emitted per dollar of imported good. As discussed earlier, E is calculated from inverting an input-output table, so includes both direct CO₂ emissions, which are those emitted from industry s , and indirect emissions, which are those emitted from industries used as inputs to industry s , and inputs to inputs, etc.⁸

Equation (1) allows a useful interpretation: the parameter α represents the carbon tariff implicit in existing trade policy. The regression has this interpretation because t is measured in dollars of tariff duties (or NTB equivalent) per dollar of imports and E is measured in tons of CO₂ per dollar of imports. Therefore α represents duties collected per ton of CO₂ emitted.⁹ For example, $\alpha = 40$ would imply that an additional \$40 of import duties (or NTB ad valorem equivalent) is collected for each additional ton of CO₂ embodied in a good. My finding of $\alpha \approx -85$ to -120 implies that current trade policy embodies a carbon subsidy in trade policy of 85 to 120 dollars per ton of CO₂. As mentioned in the introduction, I refer to this as a “subsidy” in part because it represents a lower tax rate for traded dirty goods, even though it occurs in a setting where most traded goods face positive taxes.

Standard errors in most regressions are clustered by industry. I also report some results with standard errors clustered by importer. As discussed in Appendix B, the main estimates in the paper, including those of equation (1), include only observations for manufacturing.

⁸Formally, $E_{js} = (\sum_{i \neq j,t} E_{ijst} X_{ijst}) / \sum_{i \neq j,t} X_{ijst}$, where E_{ijst} is the emissions rate from inverting the global input-output table, and X_{ijst} is the value of the trade flow from origin country i and origin industry s to destination country j and destination industry t . The summation excludes $i = j$ because the emissions rate relevant for carbon tariffs and international trade applies only to international imports, not to intra-national trade. The emissions rate E_{ijst} differs by importer×exporter×industry. For example, the emissions rate for U.S. steel imports from China differs from the emissions rate for U.S. steel imports from Canada. These emissions rates differ because China and Canada use different fossil fuel inputs, both directly and indirectly.

⁹Imports appear to be in the denominator of both the left- and right- hand sides of equation (1), which could produce spurious correlation. In practice in the global data, as Section II.A explains, t is measured as statutory tariffs (or NTB equivalents). Hence, t reflects published regulations about which tariff rate applies to different types of products, and t is not measured through dividing data on duties collected by data on imports. In the U.S. data, t equals duties collected divided by imports. But as Section II.B explains, in the U.S. data, E equals emissions from a U.S. industry’s production of CO₂ (including life cycle CO₂) divided by the industry’s gross output. Additionally, the U.S. value of E from the input-output table is instrumented with its value from the direct survey MECS. Hence, the measurement of these variables in data limits the scope for bias from spurious correlation.

Measuring CO₂ intensity from an input-output table may involve two types of measurement error. The first is potentially relevant to all analysis with input-output tables—the input-output table itself has errors-in-variables. Constructing an input-output table requires judgments of analysts from national statistical agencies and adjustment through linear programming (Horowitz and Planting 2006). Second, prices paid for each fossil fuel vary by industry, and input-output tables lack data on such industry-specific input prices. Both types of measurement error could attenuate OLS estimates of α .

To address potential measurement error in measures of CO₂ intensity, I use direct emissions as an instrumental variable for total emissions. The first-stage regression is

$$E_{js} = \beta E_{js}^{direct} + \mu_j + \eta_{js} \quad (2)$$

The second stage is equation (1). Here E_{js} measures total (direct+indirect) emissions from the input-output table and E_{js}^{direct} measures direct emissions. Direct emissions reflect fossil fuels used in industry s but not fossil fuels embodied in intermediate goods used in industry s . For example, the direct emissions for producing a car include the natural gas used to heat and weld the car parts together at the car factory but not the coal used to produce steel that is then shipped to the car factory.

For the U.S. data, the instrument is the direct emission rate, measured from the Manufacturing Energy Consumption Survey and the Census of Manufactures. For the global data, the instrument is the direct emissions rate in the 10 smallest other countries. The validity of such leave-out instruments can be less clear than the validity of some other types of instruments, in part due to concerns about the reflection problem (Manski 1993). Due to the possibility that measurement error persists in the global estimates, the true global subsidy in trade policy may be larger in absolute value than what I estimate.

III.B Political Economy Explanations

I then test the hypothesis that the association between trade policy and CO₂ intensity reflects variables that are omitted from equation (1) but that both determine trade policy and correlate with CO₂ intensity. I estimate linear regressions including potential variables F_{js} that are believed to explain trade policy, along with CO₂ intensity:

$$t_{js} = \beta E_{js} + \pi F_{js} + \mu_j + \epsilon_{js} \quad (3)$$

I estimate a separate regression for each political economy variable F_{js} then assess which of these political economy variables most attenuates the estimated covariance β between trade policy and carbon intensity.

In separate estimates, I control for all potential political economy explanations at once. I implement this regression using both linear regression and using the least absolute shrinkage and selection operator (Lasso), which is a common machine learning algorithm for automatic model selection (Tibshirani 1996). Identifying which variables Lasso includes in a model can be informative though also sensitive to specification (Mullainathan and Speiss 2017). These regressions test whether each variable, including CO₂ intensity, has additional explanatory power for trade policy beyond these other variables.

IV Results: Trade Policy and CO₂ Intensity

IV.A Summary Statistics

Table I describes the cleanest and dirtiest industries in the global data, ranked by total (direct+indirect) CO₂ emissions. Panel A shows the cleanest five industries while Panel B shows the dirtiest. Column (1) shows mean CO₂ rates across all countries, column (2) shows mean tariffs, and column (3) shows NTBs.

The cleanest five manufacturing industries primarily produce food products and have a mean global emissions rate of 0.37 tons CO₂ per thousand dollars of output. The dirtiest five manufacturing industries mostly produce heavy goods like bricks or steel and have a mean global emissions rate of 1.88 tons CO₂ per thousand dollars of output. Motor vehicles appear relatively clean in these data (also in U.S. input-output tables) because, as discussed earlier, most of the emissions due to vehicles come from a separate good that is complementary, refined petroleum, and later I explore estimates accounting for this complementarity.¹⁰

It may be informative to calculate the CO₂ externality these numbers imply. If each ton of CO₂ emitted creates a social cost of carbon of \$40 (IWG 2016), this comparison involves multiplying by 40/1000. This calculation implies that globally, pork products create a social cost from CO₂ emissions of about 1.5 percent of product value (=0.34*40/1000). Producing iron and steel creates a CO₂ externality equal to 7 percent of its product value (=1.74*40/1000).

In the ten industries of Table I, column (2) shows that the cleanest industries face over four times the mean tariff of the dirtiest industries, at 9 versus 2 percent. Column (3) shows a similar difference between the cleanest and dirtiest industries for NTBs (25 versus 5 percent). I now turn to regressions analyzing all industries.

IV.B Implicit Carbon Tariffs

Tariffs

Figure II, Panels A and B, plots hypothetical \$40/ton carbon tariffs. Each point in these graphs is a separate country×industry (Panel A, all countries) or industry (Panel B, U.S. only). The tariff rate is a constant multiple of the emissions rate, which makes both graphs linear. In this hypothetical policy, the mean carbon tariff for all countries in Panel B is three percent, which is slightly over half of current global mean tariff rates. The mean U.S. carbon tariff is about four percent, which is larger than prevailing mean U.S. tariffs (Table II).

Figure II, Panels C and D, shows actual tariff data. In these graphs, the pattern across industries is the opposite of hypothetical carbon tariffs. The hypothetical carbon tariffs in Panels A and B impose

¹⁰Some developing countries directly subsidize the consumption of raw fossil fuels; trade policy also to some extent reflects these patterns. For global trade in fossil fuel industries (coal, crude oil, natural gas, and refined petroleum), average global tariffs are 1.7 percent and NTBs are 3.6 percent; for all other industries, these averages are 3.9 percent and 9.6 percent, respectively. In developing countries, mean tariff and NTB rates for fossil fuels are 5.8 percent and 6.7 percent, and for all other industries they are 7.5 percent and 9.0 percent. These values are weighted and include all industries (not only manufacturing).

higher tariffs on dirtier industries (positively sloped line), but actual tariffs in Panels C and D impose lower tariffs on dirtier industries (negatively sloped line).

Table II reports regressions corresponding to these graphs. Panels A and B show estimates for the world and U.S., respectively. Odd-numbered columns are unweighted; even-numbered columns are weighted by the value of the trade flow. For the U.S., weighting provides an efficient response to heteroskedasticity, since U.S. effective tariff rates equal total duties divided by total trade value. Columns (1) and (2) show a first-stage regression of total CO₂ intensity on direct CO₂ intensity, corresponding to equation (2). Columns (3) and (4) show reduced-form regressions of tariffs on direct CO₂ intensity. Column (5) and (6) show OLS regressions of tariffs on total CO₂ intensity. Columns (7) and (8) report instrumental variables regressions of tariffs on total CO₂ intensity, instrumented by direct CO₂ intensity.

In Table II, Panel A, the negative signs in columns (3) through (8) imply that global tariffs have a subsidy in trade policy to CO₂ emissions, not a tax. Columns (7) and (8) show that the mean subsidy to CO₂ emissions in global tariffs is \$11 per ton of CO₂ weighted, or \$32/ton unweighted. The first-stage F-statistics show that most of the instruments are strong, though the unweighted U.S. estimates have marginally weak instruments (F-statistic of 9.8, versus a standard cutoff of 10), and hence are possibly biased towards OLS. The instrumental variables estimates are modestly larger than the corresponding OLS estimates, which is consistent with attenuation bias in OLS due to measurement error, though their qualitative results are similar.

Figure III shows the estimated association between CO₂ intensity and tariffs for the U.S., separately for each year of available data 1989-2017. The red circle shows the point estimate for each year and the vertical bar shows the 95 percent confidence interval. This graph shows statistically significant negative associations between U.S. tariffs and CO₂ intensity in every year. The estimated U.S. subsidy in trade policy was \$13/ton in 1989, then decreased gradually to \$6/ton around 1998, and remained near that value through 2017. One potential explanation is that the secular decline in mean tariffs overall decreased the difference between tariffs on clean and dirty goods.

Non-Tariff Barriers

Figure II, Panels E and F, plots NTBs against CO₂ emission rates. These graphs have similar structure to the tariff graphs. They show that dirtier industries face lower NTBs in both the global and U.S. data. Some of the cleanest industries have NTB ad valorem equivalent values close to 100 percent, while many of the dirtiest industries face little or no NTB protection.

Table III reports regressions corresponding to these graphs. The table structure is similar to the tariff regressions in Table II. Again the numbers in columns (3) through (8) are all negative, showing a carbon subsidy in trade policy rather than carbon tax. Columns (7) and (8) show that the implicit subsidy to CO₂ in global NTBs is \$76 in the unweighted regressions or \$90 in the weighted regressions. The instrumental variables estimates in columns (7) and (8) show a large subsidy to CO₂ emissions implicit in U.S. NTBs, of about \$37 to \$48/ton. Summing up subsidies in tariffs from Tables II and NTBs from Table III, columns (7) and (8), gives the global subsidy that I emphasize of about \$85 (weighted) to \$120

(unweighted).

These implicit subsidies appear in both tariffs and NTBs but have larger magnitude in absolute value in NTBs, perhaps in part since NTB mean values are greater. The mean U.S. ad valorem equivalent of NTBs is 8 to 11 percent, which is over four times the mean tariff rate (Tables II and III). This supports the common claim that U.S. NTBs are more restrictive than U.S. tariffs. Globally, NTBs create a larger barrier to trade than tariffs do, at 9 to 13 percent (NTBs) versus 3 to 5 percent (tariffs).

Implicit Subsidies in Trade Policy, by Country

To investigate how these patterns vary by country, I sum together tariffs and the ad valorem equivalent of NTBs as a more complete measure of protection. I then estimate equation (1) separately for each country (hence, these regressions exclude country fixed effects).

Figure IV plots the result. Each point in this graph describes an estimate of the implicit carbon subsidy in trade policy for one country. Each point represents the subsidy to global emissions implicit in the trade policy of one country. The point for each country is estimated separately.¹¹ Points on the graph are ordered by the estimated implicit subsidy, with names shown for several countries of interest.

Almost every country in Figure IV has a negative value, implying that most countries have a carbon subsidy rather than a carbon tariff implicit in trade policy. European countries like France, Germany, Norway, and the UK have among the largest such subsidies in trade policy, with subsidy values exceeding \$175/ton. Russia, India, and China have smaller subsidies in trade policy. The y-axis of Figure IV shows each country's implicit subsidy. A country like China which has high emissions due to its reliance on coal can still nonetheless have a small value in Figure IV since its trade policies are not strongly correlated with industries' CO₂ emissions. The two regions with positive values in Figure IV are Romania and the Rest of the Middle East. Figure V plots these data in a global map which classifies countries by their subsidies implicit in trade policy.

The cross-country comparisons in Figures III and IV do not follow predictable patterns. Large subsidies in trade policy appear in both rich regions like the EU and poor regions like Africa; small subsidies also appear in both rich countries like Canada and poorer countries like Vietnam. Oil-intensive countries like Saudi Arabia and Iran have small subsidies in trade policy, while countries with strict environmental policies like Norway have large subsidies. This lack of patterns is consistent with the interpretation of Section 5 that these subsidies in trade policy are due to political economy forces which are correlated with CO₂ intensity.¹²

¹¹Stacking the regression to account for the covariance structure across countries might increase efficiency in these estimates. Most of the estimates are significantly different from zero, though not significantly different from each other. I view the most striking feature of Figure IV as the fact that even with completely separate regressions for each country, most of the country-specific subsidies in trade policy are negative and large in absolute value; stacking the regression makes the estimates no longer independent across countries.

¹²In unreported results, I took the estimated country-level subsidy to CO₂ in trade policy plotted in Figures III and IV, and regressed it on several country characteristics. This regression finds that a country's GDP per capita, its mean tariff rate, and its quality of environmental management are all significantly associated with larger subsidies in trade policy (more negative regression coefficients). The regression also controlled for mean NTB rates, mean CO₂ emissions rates, an index of perceived

Sensitivity Analyses and Extensions

Appendix C discusses numerous alternative estimates of these implicit carbon tariffs that are shown in Appendix Table I, including from a tobit, alternative approaches to inference, nonlinear specifications of CO₂ intensity, winsorizing the data, including non-manufactured goods, including intra-national trade, separating direct and indirect emissions, including all greenhouse gases, separately accounting for CO₂ emissions from consumption and not merely production (e.g., the gasoline used to power a vehicle), the reverse regression, using the World Input-Output Database (WIOD), excluding manufactured agricultural and food products, and specifically analyzing the recent trade war by focusing on recent changes in U.S. import tariffs. Most of these results are qualitatively similar to the main estimates, though some vary in their magnitudes.

One interesting pattern in Appendix Table I, rows 26-28, is that the implicit subsidy persisted in U.S. tariff data through the year 2017. Tariffs imposed in the 2018 trade war (Fajgelbaum et al. 2020) slightly attenuated but did not eliminate this implicit subsidy. Even in these more recent U.S. data, controlling for upstreamness eliminates the estimated association between trade policy and CO₂ intensity.

Appendix C describes an additional analysis which suggests these implicit subsidies appear in both cooperative tariffs, such as those negotiated through the WTO, and non-cooperative tariffs, such as those the U.S. lists for trade with North Korea.

V Explanations for the Relationship Between Trade Policy and Pollution

Why do countries impose higher tariffs and NTBs on clean than on dirty goods? The existence of these subsidies in trade policy is surprising, so the question of why they exist is interesting. Additionally, because no prior research has tested for or demonstrated the existence of these subsidies in trade policy, explaining why they exist enhances their plausibility. Finally, understanding why these patterns of trade policy occur may provide insight into the political feasibility of changing them.

V.A Explanations: Omitted Variables

Which are the most important omitted variables in regressions of trade policy on CO₂ intensity? Appendix Table III shows that an industry's upstream location is likely to play an important role. The table shows the difference in each political economy variable between "dirty" and "clean" industries (i.e., those above and below the median CO₂ intensity), separately for global and U.S. data. All political economy variables are expressed in z-scores (i.e., I subtract the mean and divide by the standard deviation). Relative to

country corruption, and the country's mean upstreamness; these other variables had marginally significant (upstreamness) or no (other controls) association with the level of a country's implicit subsidy in trade policy. I do not show this cross-country, cross-sectional regression, which has 7 explanatory variables and less than 50 observations, since it may be hard to interpret economically; I mention it because it provides another way to summarize the data in Figures IV and V.

clean industries, dirty industries are significantly more upstream, have a lower labor share, lower wages, higher unionization rates, higher shipping costs, and higher local pollution emissions; the global data give conflicting patterns for intra-industry trade and the import penetration ratio. While dirty industries anecdotally have outsized political influence, dirty industries make marginally lower PAC contributions, though PAC contributions are believed to be a very imperfect measure of lobbying influence.

Appendix Table III shows that the association between emissions and upstreamness is stronger than the association between emissions and other political economy variables in U.S. and global data. All variables are in z-scores so have the same units. In the global data, some of the other variables are correlated with dirtiness, but the correlations are weaker than for upstreamness. The association between emissions and upstreamness in the global data is over four times stronger than the association between emissions and other political economy variables. Additionally, the regressions below imply that these other variables have less strong direct relationships to trade policy than upstreamness.

Table IV asks which political economy explanation is the most important omitted variable in regressions of trade policy on CO₂ intensity. It shows regressions of trade protection (tariffs+NTBs) on total CO₂ intensity while controlling for one political economy variable at a time, with specification corresponding to equation (3). Total CO₂ intensity is instrumented with direct CO₂ intensity. Panels A and B show estimates for all global trade; Panel C shows U.S. estimates. Column (1) includes no controls. Columns (2) through (6) each control for one political economy variable, observed at the level of a country×industry. Column (2) controls for upstreamness, column (3) for intra-industry trade, column (4) for the import penetration ratio, column (5) for the labor share, and column (6) for the mean wage.

Table IV, Panel B, uses data from the ten smallest other countries to construct instrumental variables for the focal country×industry. The regressions in Panel B have two instruments (direct CO₂ and political economy variables, both averaged across the ten smallest other countries) and two endogenous variables (CO₂ and a political economy variable, both for the focal country). These help address the possibility that some political economy explanations are endogenous. One example would be if trade policy affects wages in a given industry and country but not in the same industry in other countries. Analyses of agglomeration and import competition similarly use somewhat similar instruments (Ellison et al. 2010; Autor et al. 2013; Antràs et al. 2017).

Table IV, Panel A, column (1) restates the earlier result that the total subsidy to global CO₂ emissions implicit in global trade policy is around \$120/ton. Column (2) shows that controlling for upstreamness attenuates this estimate to \$33/ton. Columns (3) through (6) show that controlling for other political economy variables one at a time only slightly changes the estimated implicit subsidy in trade policy.

Table IV, Panel B, obtains similar estimates from instrumenting each political economy variable with its mean in the ten smallest other countries. In column (2), controlling for upstreamness eliminates the estimated implicit subsidy—the estimated association between CO₂ emissions and trade policy is -\$120 (34) with no political economy controls, but \$34 (39) when controlling for upstreamness. Columns (3) through (6) show that instrumenting does not substantially change the other estimates. These estimates have strong instruments.

Panel C finds similar patterns using U.S. data. The estimated U.S. subsidy from tariffs and NTBs is \$50 (10) per ton. Controlling for upstreamness attenuates this estimate, to \$3 (10) per ton. Other political economy controls do not substantially change the estimated subsidy in trade policy.

Figure VI graphs the U.S. estimates from Table IV, along with estimates controlling for other political economy variables that are available for the U.S. but not all countries. Each blue circle in these graphs is the coefficient from a regression of tariffs+NTBs on total CO₂ intensity (instrumented by direct CO₂ intensity), controlling for one political economy variable, and corresponding to equation (3). Each red horizontal line shows a 95% confidence interval. The “Main Estimates” restates results from Table IV, Panel C, column (1). Each of the other numbers controls for one additional variable. The “Firm size: mean” entry, for example, comes from a regression that controls for the mean firm size in each industry.

Figure VI shows that controlling for most political economy variables one-by-one produces little change in the association of trade policy with CO₂ intensity. Only one variable, upstreamness, eliminates the estimated implicit subsidy in trade policy, and renders it statistically indistinguishable from zero.¹³

Appendix C.1 discusses a wide range of sensitivity analyses, which collectively suggest that upstreamness accounts for an important share of the association between CO₂ intensity and trade policy.

Figure VI and Appendix Table V suggest that local pollution does not statistically account for the association between CO₂ emissions and trade policy, since controlling for local pollution emissions or damages does not substantially change the coefficient on CO₂ intensity, though does decrease its precision. A few additional reasons suggest why concern for local pollution emissions is unlikely to be the primary explanation for why dirty industries face lower tariffs and NTBs. First, many policymakers seek to maintain dirty industries’ domestic production and directly regulate local pollution emissions by requiring installation of scrubbers or other technology that abates local air pollution (though not CO₂). Many environmental policies contain explicit provisions to prevent relocation of dirty production. Hence, relocating dirty industries abroad may not be a primary policy goal. Additionally, I am not aware of evidence that concern for local pollution emissions has led dirty industries to have lower tariffs or NTBs. Many trade agreements like NAFTA and TPP have side agreements dealing with the environment, but these agreements typically describe domestic environmental regulations or monitoring investments, not patterns of tariffs and NTBs. Many actually seek to prevent the relocation of dirty industries, by barring the use of weak domestic environmental policies to lure dirty production across borders. Moreover, this implicit subsidy in trade policy appears in most countries. Efforts to outsource local pollution would thus to some extent neutralize each other.

¹³This section’s comparison of the carbon content of goods against their upstreamness and trade policy has similarities to [Blanchard et al. \(2016\)](#)’s value-added content logic that a country may choose trade policy for a good to reflect the domestic content which is embodied in the value chain for that good. One important difference is that each country may have preference over policy for its own domestic content embodied in traded goods. For CO₂ externalities, however, it does not matter whether the CO₂ embodied in a good was originally emitted from domestic or foreign fossil fuels, since CO₂ has the same effect on global climate regardless of the location of its emission.

V.B Explanations: Empirical Reasons why Upstreamness Substantially Accounts for Subsidies in Trade Policy

Why is an industry's upstreamness strongly correlated with its CO₂ intensity? Using U.S. data from the Bureau of Economic Analysis, Appendix Figure III graphs the share of each industry's revenue accounted for on the production side by intermediate goods, labor expenditures, profits and taxes, and fossil fuels. Appendix Figure III shows that upstream industries use a larger share of fossil fuels than downstream industries do. For the upstream industries, nearly five percent of production costs are devoted to fossil fuels; for the most downstream industries, less than one percent of costs are. Relative to upstream industries, downstream industries spend relatively more on labor and intermediate goods. Previous research has not shown these patterns but they make intuitive sense—upstream industries are taking raw materials extracted from the ground and transforming them, while downstream industries depend more on labor and other inputs.

Appendix Figure III also helps answer an important question. If downstream goods are just combinations of upstream goods, why would different import tariff rates on upstream versus downstream goods affect CO₂ emissions? Imagine an economy in which upstream goods were made exclusively from coal and downstream goods were made from upstream goods. In this hypothetical economy, upstream and downstream goods would have the same CO₂ intensity, and tariff escalation could not affect global CO₂ emissions. Appendix Figure III shows that this hypothetical economy is misleading because downstream industries use as inputs both upstream goods and relatively clean factors like labor. Hence, imposing high tariffs on downstream but not upstream goods can encourage consumers to substitute from demanding relatively clean factors like labor to demanding relatively dirty factors like energy.

Buyers can respond to changes in trade policy in many ways, including substituting between goods, changing total demand for an industry's products, and changing trading partners. To what extent can firms and consumers substitute between industries with different levels of upstreamness? Certainly in examples, goods that are substitutes have different levels of upstreamness and CO₂ intensity. For example, steel and aluminum are likely substitutes, and in the U.S. data which have greater industry detail, steel is both more upstream and more CO₂ intensive than aluminum.¹⁴

Appendix D informally discusses how theories of trade policy might rationalize these findings, and describes a few reasons why the [Diamond and Mirrlees \(1971\)](#) production efficiency theorem does not well account for these patterns of trade policy.

¹⁴The example compares iron and steel mills (NAICS industry 331111) against aluminum sheet, plate, and foil manufacturing (NAICS industry 331315).

VI Consequences of Implicit CO₂ Subsidies in Trade Policy

VI.A Partial Equilibrium Approximation

I use a few approaches to investigate the aggregate consequences of these patterns of trade policy. The first is a partial equilibrium calculation:

$$\hat{\alpha} \sum_{j,s} E_{js} \sum_{i \neq j} X_{ijs} \tag{4}$$

where $\sum_{i \neq j} X_{ijs}$ represents the value of international imports by country j in sector s . This represents the revenue that a carbon tariff would collect if it had the same pattern as trade policy’s environmental bias (i.e., -\$85 to -\$120/ton). The parameter $\hat{\alpha}$ is the implicit carbon subsidy in trade policy from equation (1).

My primary estimate of Equation (4) uses regression results from Tables II and III, columns (7) and (8). This implies that global trade policy provided an implicit subsidy of \$550 to \$800 billion in the year 2007 (measured in 2016 dollars). This can be calculated simply: 6.5 billion tons of CO₂ are embodied in international trade (including in intermediate goods), times \$85 to \$120 in subsidy per ton of CO₂ traded, gives $\$550 \approx 6.5 \times 85$ or $\$800 \approx 6.5 \times 125$.¹⁵ Appendix Table I provides other estimates of the implicit subsidy α . These other regression estimates in turn lead to other estimates of the total global subsidy in trade policy. While the exact subsidy can vary with the regression specification, these magnitudes suggest this subsidy may have quantitatively important effects on trade and CO₂ emissions.

To put these estimates in perspective, global direct subsidies to fossil fuels were about \$530 billion in 2007 (IMF 2013). These direct subsidies are a focus of political debate. The CO₂ subsidies in trade policy, which have not been previously highlighted, have a similar magnitude. Of course, a direct subsidy to fossil fuel could have larger effects on CO₂ than an indirect subsidy through trade policy.

VI.B Analytical Model

The calculation of the previous subsection is simple but has limitations. I now turn to a model including several potentially important features—pollution can directly affect utility; pollution creates transboundary damages; countries may have pre-existing and sub-optimal trade policy on any goods; tariffs generate revenue which is lump-sum redistributed; and industries are connected through input-output links, so dirty industries can be upstream. This subsection describes a setting with two symmetric countries and two industries (one clean, one dirty). The next subsection describes a fuller quantitative model that

¹⁵In many regression settings, difference-in-difference analyses cannot measure the total effect of a policy, since such regressions are normalized against a comparison group and have fixed effects that remove any economy-wide effects. My summary calculations reflect a descriptive regression that is not differences-in-differences—the regression has no comparison group, and is not estimating a causal effect. Hence, this partial equilibrium calculation assumes that goods with zero tariff have zero subsidy.

impose fewer restrictive assumptions, but which thereby obtains numerical but not analytical results. These models make strong assumptions that are not literal descriptions of reality, like constant elasticity of substitution utility, but the benefit of these stylized descriptions is that they permit analysis of how specific counterfactual trade policy reforms affect CO₂ emissions and social welfare.

Preferences. The representative agent in country j maximizes national utility U_j .

$$U_j = \prod_s Q_{js}^{\beta_{js}} f(Z) \quad (5)$$

Here Q_{js} is a consumption aggregate given by $Q_{js} \equiv (\sum_i q_{ijs}^{(\sigma-1)/\sigma})^{\sigma/(\sigma-1)}$. The elasticity of substitution is $\sigma > 1$, which for simplicity here does not vary by sector. Utility depends on international trade (q_{ijs} , $i \neq j$) and intra-national trade (q_{jjs}) in each sector $s \in (1, 2)$. Global pollution emissions $Z = \sum_j Z_j$ create multiplicative damages $f(Z)$. The representative agent treats emissions as a pure externality, so ignores them in choosing expenditure. This analytical model does not need to specify the functional form of $f(Z)$, as I discuss below. Sector 1 represents dirty goods that emit pollution; sector 2 represents clean goods that do not. Preferences are Cobb-Douglas across sectors, with expenditure shares β_{js} . I describe an Armington model, in which countries have a taste for variety, and each country produces one variety per sector. Standard versions of Ricardian models with richer microfoundations, like [Eaton and Kortum \(2002\)](#) or [Dornbusch et al. \(1977\)](#), would produce the same aggregate equilibrium equations describing production, consumption, and trade ([Arkolakis et al. 2012](#)), and thus the same conclusions for emissions and social welfare.

The associated price index is

$$P_{js} = \left[\sum_i (c_{is} \phi_{ijs})^{-\epsilon} \right]^{-1/\epsilon} \quad (6)$$

Equivalently, one can write the trade elasticity $\epsilon > 0$ as $\epsilon = \sigma - 1$, where σ is the elasticity of substitution between goods from each country. The variable ϵ can be interpreted as the elasticity of trade flows with respect to trade costs. Goods face multiplicative trade costs $\phi_{ijs} \geq 1$. Trade costs may include a general iceberg friction, tariffs, and non-tariff barriers: $\phi_{ijs} = \tau_{ijs}(1 + t_{ijs})(1 + n_{ijs})$. Here $\tau_{ijs} \geq 1$ are iceberg trade costs, so τ goods must be shipped for one to arrive. Buyers pay bilateral import tariffs $t_{ijs} \geq 0$. Tariff revenues are lump-sum rebated to domestic consumers. I treat NTBs $n_{ijs} \geq 0$ as comparable to an iceberg trade cost. Intra-national trade costs equal one: $\phi_{jjs} = 1$.

Technology. The unit cost of producing goods is Cobb-Douglas in labor, which is sold at price w_i , and in intermediate goods from other sectors:

$$c_{is} = w_i^{1-\alpha_{is}} \prod_k P_{ik}^{\alpha_{iks}} \quad (7)$$

Here α_{is} is the labor share and α_{iks} is the cost share of industry k to produce output in country i and industry s .

Pollution. The pollution emitted to sell goods to a particular destination j is:¹⁶

$$Z_{ij1} = \frac{X_{ij1}}{c_{i1}(1 + t_{ij,1})} \quad (8)$$

One could think of c_{is} as the factory-gate price. One country's pollution emissions are $Z_i = \sum_j Z_{ij1}$, and global pollution emissions are $Z = Z_1 + Z_2$. Here X_{ijs} is total expenditure on goods produced in origin country i , shipped to destination country j , in sector s .¹⁷ Sales are deflated by the unit production cost c_{is} .

Trade flows. Consumer utility maximization implies the following international trade flows:

$$\begin{aligned} X_{ijs} &= \left(\frac{c_{is}\phi_{ijs}}{P_{js}} \right)^{-\epsilon} X_{js} \\ &= \lambda_{ijs} X_{js} \end{aligned} \quad (9)$$

where $\lambda_{ijs} \equiv X_{ijs}/X_{js} = (c_{is}\phi_{ijs}/P_{js})^{-\epsilon}$ denotes the share of country j 's expenditure on sector s varieties which is sourced from country i , and $X_{js} = \sum_i X_{ijs}$ is total expenditure on sector s goods in country j .

Equilibrium. In baseline data and counterfactuals, consumers maximize utility, firms maximize profits, and markets clear. Trade is balanced, so each country's revenues equal its expenditures. Global GDP is the numeraire, so $\sum_i Y_i' = 1$, where Y_i is a country's factor payments. Market clearing for labor is $L_i = \sum_s L_{is}$, where L_{is} is labor supply, which I assume is inelastic. Total expenditure on goods in a country \times sector equals the sum of expenditure on final and intermediate goods:

$$X_{js} = \beta_{js}(Y_j + T_j) + \sum_k \alpha_{jsk} R_{jk} \quad (10)$$

Here $X_j = Y_j + T_j$ is total expenditure, which comes from factor payments and from tariff revenues $T_j = \sum_{i,s} X_{ijs}t_{ijs}/(1 + t_{ijs})$. Tariff revenues are lump-sum redistributed to the representative agent. The term R_{is} represents country \times sector revenues, given by $R_{is} = \sum_j X_{ijs}/(1 + t_{ijs})$.

Counterfactual Methodology To study counterfactuals, I express each variable in changes from baseline levels, sometimes called "exact hat algebra" (Dekle et al. 2008; Costinot and Rodriguez-Clare 2014). Let a denote a variable from the model in the baseline data and a' the value in a counterfactual. Define the proportional change in this variable due to counterfactual policy as

$$\hat{a} \equiv \frac{a'}{a} \quad (11)$$

Counterfactual Results and Interpretation: Pollution. Equation (9) implies that the change

¹⁶Pollution here is isomorphic to the consumption of fossil fuels. While analyzing air and water pollution is more complex and involves a range of abatement technologies firms can install, because end-of-pipe abatement technologies like carbon control and sequestration for fossil fuels are not economically viable, knowing the fossil fuels consumed is sufficient to measure the CO₂ emitted (Shapiro and Walker 2020).

¹⁷The right-hand side of equation (8) has 1 rather than s subscripts because only dirty goods (sector 1) emit pollution.

in expenditure shares due to a counterfactual trade policy is

$$\hat{\lambda}_{ijs} = \left(\frac{\hat{c}_{is}\hat{\phi}_{ijs}}{\hat{P}_{js}} \right)^{-\epsilon} \quad (12)$$

Similarly, equation (6) implies that the change in country \times sector price index is

$$\hat{P}_{js} = \left[\sum_i \lambda_{ijs} (\hat{c}_{is}\hat{\phi}_{ijs})^{-\epsilon} \right]^{-1/\epsilon} \quad (13)$$

To derive the change in pollution emissions, I start from $\hat{Z} = Z'/Z$, then substitute in the definitions of pollution, trade flows, and counterfactual changes, from equations (8), (9), and (11):

$$\hat{Z}_i = \frac{\hat{X}_{i1}}{\hat{c}_{i1}} \left[\frac{\hat{\lambda}_{ii1} Z_{ii1} + (1 + \widehat{t_{ij1}})^{-1} \hat{\lambda}_{ij1} Z_{ij1}}{Z_i} \right] \quad (14)$$

To obtain another useful version of this result, I substitute in the equations for the changes in expenditure shares and the price index from equations (12) and (13):

$$\hat{Z}_i = \frac{\hat{X}_{i1}}{\hat{c}_{i1}} \left(\frac{\lambda_{ii1} + (\hat{\phi}_{ij1})^{-\epsilon} \frac{\lambda_{ij1}}{1+t_{ij1}}}{\lambda_{ii1} + (\hat{\phi}_{ij1})^{-\epsilon} \lambda_{ij1}} \right) \frac{1}{\lambda_{ii1} + \frac{\lambda_{ij1}}{1+t_{ij1}}} \quad (15)$$

The change in emissions due to a counterfactual policy equals the product of two terms: the change in real expenditure on dirty goods ($\hat{X}_{i,1}/\hat{c}_{i,1}$) and change in the pollution intensity of expenditure.

This interpretation is analogous to decomposing pollution into composition and technique effects. Scale is often part of such decompositions, but here is fixed by choice of the numeraire, at least in terms of nominal GDP. Equation (8) shows that pollution intensity in revenue terms is normalized to one, so that one dollar of dirty goods revenues always produces one unit of pollution. Because tariffs create a wedge between expenditures and revenues, pollution intensity in expenditure terms is less than one.

In equations (14) and (15), one can separate the change in pollution intensity into two channels that represent domestic and foreign spending. In equation (14), both appear in the numerator of the term in brackets—the first term reflects the counterfactual emissions from domestic sales and the second term reflects the counterfactual emissions from exports. In equation (15), the denominator of the term in parentheses equals the inverse of the change in the domestic expenditure share for dirty goods ($\hat{\lambda}_{111}^{-1}$). This denominator is less than one, so represents a channel by which a counterfactual policy increases emissions intensity. This reflects the idea that increasing tariffs on dirty goods increases pollution emitted to produce dirty goods sold domestically, which tends to increase the emissions intensity of expenditure. The magnitude of this effect grows as the trade elasticity (ϵ) increases, because this elasticity reflects how trade flows respond to trade costs, including tariffs.

In the numerator of the term in parentheses equation (15), the second term reflects emissions for

exports. This term shows that increasing tariffs on dirty goods discourages trade in dirty goods. This result is intuitive and tends to decrease the emissions intensity of expenditure. This channel also becomes more important as the trade elasticity becomes larger.

The change in real spending on dirty goods appears in the first ratio of equations (14) and (15). In that ratio, the change in expenditure follows directly from the country \times sector expenditure equation (10):

$$\hat{X}_{js} = \frac{\beta_{js}(Y_j + T'_j) + \sum_k \alpha_{j sk} R'_{jk}}{\beta_{js}(Y_j + T_j) + \sum_k \alpha_{j sk} R_{jk}} \quad (16)$$

The change in unit costs follows from substituting the price index into the unit cost equations in changes for each industry, then solving this system of equations:

$$\hat{c}_{11} = [\lambda_{111} + \lambda_{211}(\hat{\phi}_{211})^{-\epsilon}]^{-\frac{1}{\epsilon} \frac{\alpha_{121}\alpha_{112} + (1-\alpha_{122})\alpha_{111}}{(1-\alpha_{111})(1-\alpha_{122}) - \alpha_{112}\alpha_{121}}} [\lambda_{112} + \lambda_{212}(\hat{\phi}_{212})^{-\epsilon}]^{-\frac{1}{\epsilon} \frac{\alpha_{121}\alpha_{122} + (1-\alpha_{122})\alpha_{121}}{(1-\alpha_{111})(1-\alpha_{122}) - \alpha_{112}\alpha_{121}}} \quad (17)$$

The exponents reflect the interdependence of the unit cost and price index in (6) and (7) due to input-output links.

Equations (16) and (17) show that the change in real expenditure on dirty goods reflects changes in spending on dirty final goods, dirty intermediate goods, and the production cost. The first term in the numerator and denominator of equation (16), $\beta_{js}(Y_j + T'_j)$, represents expenditure on dirty final goods. The change in this expenditure occurs only due to changing tariff revenues. The assumption that expenditure on final goods is Cobb-Douglas implies that expenditure shares for final goods are fixed. Tariff revenues are typically a small percent of national income, so quantitatively, this channel may have small effects on emissions relative to the other channels. The second term in the numerator and denominator of equation (16), $\sum_k \alpha_{j sk} R_{jk}$, represents expenditure on dirty intermediate goods. Input-output links drive this channel. If all goods are final, this term equals zero.

Equation (17) represents the change in unit costs. If all goods are final in this model with symmetric countries, unit costs do not change ($\hat{c}_{11} = 1$). The first bracketed term represents the effects of changing trade policy for dirty goods, and the second bracketed term represents the effects of changing trade policy for clean goods. If trade policy for clean goods does not change, the second bracketed term in equation (17) equals one.

This model allows for pre-existing tariffs and for changes in tariffs on clean and dirty goods. Neither baseline nor counterfactual tariffs on clean goods change the pollution intensity of expenditure, because clean good tariffs (t_{212}) do not appear directly in equation (15). Baseline and counterfactual tariffs on clean goods do affect real expenditure on dirty goods by changing tariff revenues and intermediate good flows in equation (16), and also through changing the prices of clean goods and thus the second bracketed term in equation (17).

This model assumes both sectors are traded. Adding a third, non-tradable sector provides similar results. If the non-traded sector is clean, the main change is in the cost of production (17), which then accounts for the contribution of non-traded prices to the production cost of dirty goods. If the non-traded sector is also dirty, then expression for emissions include an extra term reflecting emissions from

non-tradables.

Counterfactual Results and Interpretation: Social Welfare. The change in social welfare due to a counterfactual equals the product of the change in real income and pollution damages: $\hat{W}_j = (\hat{X}_j/\hat{P}_j)\widehat{f(Z)}$. Substituting in the definition of expenditure and the price index from (13) gives

$$\hat{W}_j = \frac{Y_j + T'_j}{Y_j + T_j} \prod_s \left[\sum_o \lambda_{ojs} (\hat{c}_{os} \hat{\phi}_{ojs})^{-\epsilon} \right]^{\frac{\beta_{js}}{\epsilon}} \widehat{f(Z)} \quad (18)$$

If all goods are final, given symmetry and choice of the numeraire, this simplifies to¹⁸

$$\hat{W}_j = \frac{Y_j + T'_j}{Y_j + T_j} \left[\prod_s \left(\lambda_{11s} + \lambda_{21s} (\hat{\phi}_{21s})^{-\epsilon_s} \right)^{\frac{\beta_{js}}{\epsilon_s}} \right] \widehat{f(Z)} \quad (19)$$

Equations (18) and (19) show that the change in welfare equals the product of three terms. The first ratio represents the increase in nominal expenditure, which comes from tariff revenues (T'_j). The second term represents the (inverse of the) price index. Increasing tariffs on dirty goods increases the price index, decreases this term, and therefore decreases real income, though decreasing tariffs on clean goods increases real income.

The third term represents the change in pollution damages, which can be written independently of the functional form of the damages $f(\cdot)$. Knowing the change in global emissions and the functional form of pollution damages would be sufficient to calculate the change in pollution damages. One general finding is that the magnitude of the damages from climate change tends to be much smaller than the change in real income (Shapiro 2016). Hence, for calculating social welfare changes, the first two channels (nominal income and the price index) may matter more than the change in emissions.

I consider counterfactual policies which increase protection for dirty goods but decrease protection for clean goods. How do these counterfactuals affect social welfare? Equations (18) and (19) show that the sign of how these policy changes affect social welfare is theoretically ambiguous. Even if they decrease CO₂ emissions, they involve both increases and decreases in protection, so the net effect of these changes on the price index and on tariff revenues depends on specific parameters and data.

VI.C Quantitative Model

I now turn to quantify effects of these counterfactuals in a richer model. The quantitative model is stylized but incorporates some additional features—many asymmetric countries; many industries; input-output links; trade imbalances; multiple dirty (fossil fuel) industries; distinctions between iceberg trade costs, non-tariff barriers, and tariffs; and others. Because the model resembles the “structural gravity” literature in trade (Costinot and Rodriguez-Clare 2014) and the simpler model of the previous subsection,

¹⁸The price index term in brackets from this equation can be rewritten in terms of the change in the share of a country’s expenditure purchased from domestic producers (Costinot and Rodriguez-Clare 2014). I show the formulation in equation (18) since it is more similar to versions of the price index from the rest of this paper and allows simple interpretation.

I describe the model’s formal assumptions and counterfactual methodology in Appendix E.¹⁹

I apply the model using data from Exiobase. For computation, I aggregate the data to 10 regions and 21 industries, shown in Appendix Tables VI and VII. I assume intra-regional tariffs are zero. Three regions comprise the EU: Western, Southern, and Northern Europe.

I use sector-specific trade elasticities from aggregating studies that estimate these parameters: [Caliendo and Parro \(2015\)](#), [Shapiro \(2016\)](#), [Bagwell et al. \(2018\)](#), and [Giri et al. \(2018\)](#). Within a study, I aggregate multiple estimates for a sector using inverse variance weighting, which minimizes variance ([Hartung et al. 2008](#)).²⁰ I calibrate the damages from CO₂ emissions so that a one-ton increase in CO₂ emissions decreases global welfare by \$40, which corresponds with prevailing estimates of the social costs of CO₂ emissions in 2007 ([IWG 2016](#)).

Choice of Counterfactuals

I use this model to analyze several counterfactual policies. The main counterfactual changes each country’s bilateral import tariffs to the country’s weighted mean baseline bilateral tariff, and similarly for NTBs, with weights equal to baseline trade: $t'_{ijs} = [\sum_s t_{ijs} X_{ijs} / (1 + t_{ijs})] / [\sum_s X_{ijs} / (1 + t_{ijs})] \forall i \neq j$. Here t_{ijs} denotes the baseline tariff rate on goods from origin country i to destination country j and sector s , X_{ijs} denotes the tariff-inclusive baseline value of bilateral trade, and t'_{ijs} denotes the counterfactual tariff. The counterfactual makes a similar change for NTBs. Policies resembling this counterfactual could result from WTO multilateral negotiations focused on eliminating tariff escalation or from environmentalists lobbying for tariff harmonization between clean and dirty industries. In regions like the EU which already have a climate change policy, politicians could argue that this kind of reform decreases leakage. Such policies might even attract support from dirty industries.

Appendix E.4 describes several other counterfactuals, including one where only the EU imposes this policy change, where protection changes to the level of clean goods, where protection changes to the level of dirty goods, where I add a carbon tariff, and where I turn off all trade policy.

One important question is what channels account for any change in CO₂ emissions. I follow the

¹⁹One choice not standard in the “structural gravity” literature is the functional form of pollution damages. This does not matter in the analytical model, as discussed above, but does matter for exact numbers in the quantitative model. I specify pollution damages as multiplicative with utility from consuming goods:

$$U_j = \prod_s \left(\sum_i q_{ijs} \frac{\sigma_s - 1}{\sigma_s} \right)^{\frac{\sigma_s}{\sigma_s - 1} \beta_{js}} [1 + \delta(Z - Z_0)]^{-1}$$

Here Z are global CO₂ emissions, Z_0 is a reference or baseline level of emissions, and δ is a damage parameter chosen so a one-ton increase in emissions from baseline levels creates a global social welfare cost equal to the social cost of carbon, or \$40. The other terms here are more standard: U_j is the utility of the representative agent in country j , s indexes sectors, q_{ijs} is the quantity of goods produced in country i and consumed in country j from sector s , σ_s is the elasticity of substitution, and β_{js} are Cobb-Douglas expenditure shares. I choose this functional form since it makes it so that a one-ton increase in emissions decreases global social welfare by \$40, which is a central estimate from the climate change literature.

²⁰I take the median estimate across studies since confidence intervals for [Giri et al. \(2018\)](#) are small enough relative to the other papers that inverse variance weighting across studies implicitly puts disproportionately high weight on that study. [Bartelme et al. \(2018\)](#) take the median estimates across these studies to estimate trade elasticities.

environmental economics literature in decomposing the change in CO₂ emissions due to a counterfactual into three terms: the change in real output (“scale”), the change in the share of global output from each industry (“composition”), and the emissions intensity of each industry (“technique”) (Grossman and Krueger 1993; Copeland and Taylor 2003; Levinson 2009; Shapiro and Walker 2018). Appendix E.3 describes this methodology.

It is not straightforward to assess the extent to which certain endogenous changes in the model, such as reallocation of production and transportation, account for the full effect of any counterfactual. I can, however, provide indirect evidence on the importance of transportation. Most energy used in transportation comes from petroleum, and most petroleum is used for transportation. Coal is disproportionately used for the heaviest industries, like electricity generation, cement manufacturing, and steel blast furnaces, while natural gas is used for other purposes. Hence, examining the change in emissions from each fossil fuel provides some insight as to the importance of these channels.

Counterfactuals: Results for Main Counterfactual

Table V, Panel A, analyzes the first counterfactual, in which each country sets the same tariffs and NTBs on clean and dirty industries. Column (1) shows the percentage change in global CO₂ emissions. Column (2) shows the percentage change in global real income, defined as the weighted sum of country-specific changes in real income, where the weights are each country’s baseline real income. Column (3) shows the change in CO₂ intensity, which equals the change in CO₂ minus the change in real income (equal to column (1) minus column (2)). Column (4) shows the change in social welfare due to climate damages. Column (5) shows the change in social welfare due to both the gains from trade and climate damages. Differences in trade elasticities and values mean these counterfactuals can change trade’s volume and benefits even if they don’t change mean tariffs or NTBs.

I find that this counterfactual of harmonizing trade policy between clean and dirty industries would decrease global CO₂ emissions by about 3.6 percentage points but increase global real income by 0.7 percentage points (Table V, row 1). This counterfactual decreases CO₂ intensity by 4.2 percentage points.

Table V shows that the increase in social welfare due to the decreased CO₂ emissions is much smaller than the increase in social welfare due to the increased real income. The social welfare impact of changing CO₂ emissions in a counterfactual here scales roughly proportionally with the assumed social cost of CO₂. While I have assumed a social cost of \$40 per ton, in line with central values from the prevailing literature, some studies provide estimates have ranged up to \$100 per ton or greater (e.g., from an expert elicitation in Pindyck (2019), or from Stern (2006)). In general, the gains from trade are orders of magnitude larger than trade’s climate change externality, whether the damages per ton are \$40 or \$100 (Shapiro 2016). In part, this finding may reflect the fact that prevailing estimates of climate damages assume a quadratic damage function that is parameterized from the historical experience of modest changes in climate, and may poorly reflect the costs of large future climate change. A large potential cost is the uncertain possibility that the climate could increase by more than 5 or even more than 10 degrees Celsius,

which could create catastrophic damages not well measured in prevailing estimates (Weitzman 2009). In part for these reasons, I emphasize the physical decrease in CO₂ emissions more than the monetization of that decrease, though I show both.

Table V, Panel B, separates these changes by region, though interpreting it requires care. Because CO₂ mixes uniformly in the atmosphere, climate damages are the same regardless of where CO₂ emissions originate. Additionally, this regional allocation identifies where fossil fuels are extracted. Low protection on dirty industries in baseline data, as the EU has (Figure V), accelerates fossil fuel production and consumption in other regions like China and India but decreases it in the EU. Thus, changing prevailing patterns of trade policy tends to increase emissions in Europe and decrease them elsewhere. The largest driver of the differences in results across regions in Table V Panel B is the rate of baseline protection on dirty goods, shown in Figure V.

Accordingly, the regional allocation in Table V, Panel B, shows that this counterfactual causes the largest increases in emissions from Europe. The counterfactual causes the largest decreases in emissions from the Americas and Rest of the World. This counterfactual modestly increases real income in all regions; that is not predetermined but is driven by differences in trade elasticities and flows across regions. Some of the region-specific change are large, though within the range of historical experience.

Panel C separates these effects into scale, composition, and technique, using the methodology described in Appendix E.3. The scale effect shows that this counterfactual increases real output by 0.8 percentage points. The composition effect shows that this counterfactual reallocates production across industries to decrease emissions by about 1.3 percentage points. The technique effect shows that even holding composition and scale fixed, the (weighted) mean industry carbon intensity falls by about 2.5 percentage points.

Panel D reports the change by fossil fuel, which helps interpret the composition effect (since only fossil fuel directly emits CO₂ in this analysis). Coal production, which is primarily used for heavy industry, slightly increases. Oil and gas production each decrease by slightly more. A majority (though not all) of oil is used for transportation; this suggests that an important channel here for decreasing emissions is that dirtier goods are produced domestically and require less shipping. The decrease in gas suggests that decreased production of goods that rely heavily on gas is another important channel.

The introduction highlighted that using trade policy for environmental goals can produce a range of responses through changing sourcing countries, transportation, and input choices. This quantitative analysis suggests that each of these changes accounts for some of the results in this model. Panel B of Table V shows that this policy increases fossil fuel production from regions that are currently encouraging trade in dirty goods but decreases it in other regions; Panel D shows that this policy decreases in emissions from oil (one proxy for the change in emissions from transportation), which accounts for about half the policy's environmental benefits; and the policy reallocates expenditure across sectors (the composition effect), which also accounts for an important share of the decrease in emissions.

One way to benchmark these numbers is to compare against other climate change policies. The Waxman-Markey bill, which passed the House but not the Senate in 2009, would have created a U.S. cap-

and-trade market for CO₂. The European Union Emissions Trading System (ETS), a large cap-and-trade market for CO₂, is the world's largest climate change policy (excluding China's incipient cap-and-trade market). These policies decrease global CO₂ emissions by 2.6 percent and 1.1 percent, respectively.²¹ By comparison, I calculate that this trade policy counterfactual would decrease global greenhouse gas emissions by 3.6 percent, which is moderately more than the ETS. These calculations do compare a global trade policy reform against actual unilateral climate change policies, though most climate change policy to date has involved individual countries.

Counterfactuals: Decomposition

This subsection distinguishes several components of how changing trade policy affects emissions, and thereby seeks to provide some insight on why the model generates these results.

Appendix E.2 describes a decomposition of a counterfactual's effects on emissions through several channels—changes in the price of fossil fuels, changes in spending on domestic versus foreign fossil fuels, expenditure on fossil fuels as final versus intermediate goods, and other channels. Appendix Figure IV shows this decomposition visually, Appendix E.2 shows it mathematically, and Appendix Table IX shows it numerically.

Here I summarize the general patterns. The main counterfactual requires each country to impose the same trade policies on different goods, and thus it turns off differences in trade policy between clean and dirty goods. While this policy increases relative rates of protection for all energy-intensive goods, it also directly decreases international trade in fossil fuels. Domestic supply of fossil fuels does increase, but the domestic supply is not enough to offset the decrease in imported fuels.

As to more detailed channels, increasing protection for energy-intensive goods increases the price of fossil fuels, in part because fossil fuel extraction itself uses other energy-intensive goods as an input, and the price of other energy-intensive goods rises as well. In addition, this counterfactual policy leads to decreases in the share of fossil fuels purchased from international sources. While it also increases the share purchased from domestic sources, the value of the fall in international purchasing exceeds the value of the rise in domestic production.²² International trade is a small share of natural gas and coal, though is more common for oil. This counterfactual also tends to decrease spending on fossil fuels as an intermediate good, as it decreases demand for fossil fuels from other energy-intensive goods sectors. The change in spending on fossil fuels as a final good has mixed patterns—tariff revenue and factor incomes

²¹The Waxman-Markey bill would have decreased U.S. greenhouse gas emissions by 17 percent in the year 2020 relative to 2005 levels. The U.S. accounted for 15 percent of global CO₂ emissions in 2005. Although the Waxman-Markey bill did not pass, U.S. emissions were similar in 2014 as in 2005 ([Climate Watch 2019](#)). Assuming the Waxman-Markey bill would have decreased U.S. emissions by 17 percent, it would have decreased global emissions by 2.6 percent ($=0.15 \times 0.16$). In 2005, the EU emitted 11 percent of global CO₂-equivalent ([Climate Watch 2019](#)). Some research estimates that the EU ETS decreased EU emissions relative to a counterfactual by about 10 percent ([Dechezlepretre et al. 2018](#)), which implies that the EU ETS decreased global emissions by about 1.1 percent.

²²The main interesting exception discussed in Appendix E.2 is that India had exorbitant import tariffs on coal in the year 2007 (50 percent), and so this counterfactual actually decreases those tariffs and thus increases trade in coal, and emissions from coal trade.

both increase total spending (and thus spending on fossil fuels as a final good) in some cases but decrease it in others, and the net effect is small.

It may be useful to highlight similarities and differences between the full quantitative model, illustrated through this decomposition, and the analytical model of Section VI.B. Both models allow a natural separation of the change in emissions into a change in real expenditure on dirty goods, and a change in the pollution intensity of that expenditure. In both models, emissions reflect a tradeoff between emissions for domestic production and exports, where the trade elasticity magnifies that tradeoff. In addition, in both models, changes in tariff revenues drive changes in nominal expenditure on dirty goods, while input-output links play an important role in changing the price of dirty goods. One important difference is that even though the analytical model has input-output links, because it has only two sectors, one clean and one dirty, there is no distinction between energy-intensive goods like steel which are not fossil fuels versus relatively cleaner industries like food manufacturing; that distinction is more relevant in the full quantitative model. In addition, assumptions like symmetry and having two countries allow the analytical model to provide simpler and more intuitive equations for changes in pollution and other terms; the key ideas of those equations are still present in the fuller model, but is less direct.

Appendix E.4 discusses sensitivity analyses, which are shown in Appendix Table VIII, and give qualitatively similar results. Appendix E.4 and Appendix Table VIII also show results for the other counterfactuals, which are generally in line with the results of the main counterfactual.

The counterfactuals analyzed in the main text and Appendix suggest a few broader conclusions. Trade policy reforms can have quantitatively meaningful effects on CO₂ emissions; it is valuable to assess both the environmental and traditional costs and benefits of such trade policies; and policymakers concerned about the environment should consider decreasing protection on clean industries, not merely increasing protection on dirty industries.

VII Conclusions

This paper asks a simple but new question: how and why do tariffs and non-tariff barriers (NTBs) differ between clean and dirty industries? I define an industry’s “dirtiness” by the total CO₂ emitted to produce a dollar of output. I find a simple answer: tariff and NTB rates are substantially higher on clean than on dirty goods. This relationship appears in most countries, in cooperative and non-cooperative trade policy, and in many years and ways of analyzing the data.

At a broad level, this paper suggests that trade policy can have important impacts on environmental outcomes. The implicit subsidy to CO₂ in trade policy this paper analyzes, which has not been previously identified, totals \$550 to \$800 billion per year. For comparison, all direct global subsidies to fossil fuel consumption, which are a major focus of political debates involving the U.S., EU, World Bank, and IMF, together total about \$530 billion per year. General equilibrium model-based analyses require strong assumptions but suggest that if countries imposed similar tariffs and NTBs on clean and dirty industries, global CO₂ emissions would fall, while global real income would largely not change or slightly increase.

The resulting change in global CO₂ emissions has similar magnitude to the estimated effects of some of the world's largest actual or proposed climate change policies.

I find that trade policy has this subsidy because political economy variables that determine trade policy are correlated with CO₂ emissions. The data show an important role for an industry's upstream location—the extent to which it sells to other firms versus final consumers. I describe theory and evidence consistent with the idea that firms lobby for high protection on their own outputs but low protection on their intermediate inputs. Because industries can be well organized but final consumers generally are not, countries end up with greater protection on downstream (and clean) goods, and less protection on upstream (and dirty) goods.

These conclusions are relevant to policy. Climate change is a classic externality that would be addressed efficiently with a Pigouvian tax on CO₂ emissions. Today, however, a fifth of global output faces carbon prices, and existing carbon prices are heterogeneous and below typical estimates of the social cost of carbon emissions. Countries that do implement carbon prices face concerns that they will decrease the competitiveness of domestic energy-intensive industries and cause “leakage” of dirty production from regulated to unregulated regions. A common proposal to address these concerns is a tariff that is proportional to the carbon embodied in imported goods, usually called a carbon tariff or carbon border adjustment. I show that countries are imposing greater protection on clean than on dirty goods, so instead of internationally adopting a carbon tariff, most countries have implicitly created a carbon subsidy in trade policy. Using trade policy negotiations to decrease this environmental bias of trade policy could help address climate change. This proposal is particularly relevant in regions like the EU which already have a domestic carbon price, but which currently have trade policies that may be encouraging leakage of dirty production to other regions rather than preventing it.

What is the political feasibility of harmonizing tariffs and NTBs between clean and dirty industries? The exact reform, of course, influences its political feasibility. For example, if one region implemented this reform and other regions did not respond with similar reforms, this could increase domestic emissions of “local” pollutants like particulate matter, even while decreasing global CO₂ emissions. Additionally, increasing tariffs and NTBs on upstream goods could disadvantage developing countries, which may have a comparative advantage in producing upstream goods, though environmental interest groups and dirty industries might support such reforms. Because dirty industries are disproportionately upstream, downstream industries lobbying for low tariffs on their inputs might oppose such reforms. Lobbying from energy-intensive industries is usually a problem for climate change policy, but for these reforms would actually increase their feasibility. More generally, climate change and the environment have never been part of the argument against tariff escalation, and are rarely part of the debate in choosing relative levels of tariffs and NTBs across industries. This paper suggests that making the environment part of these policy conversations could produce important benefits.

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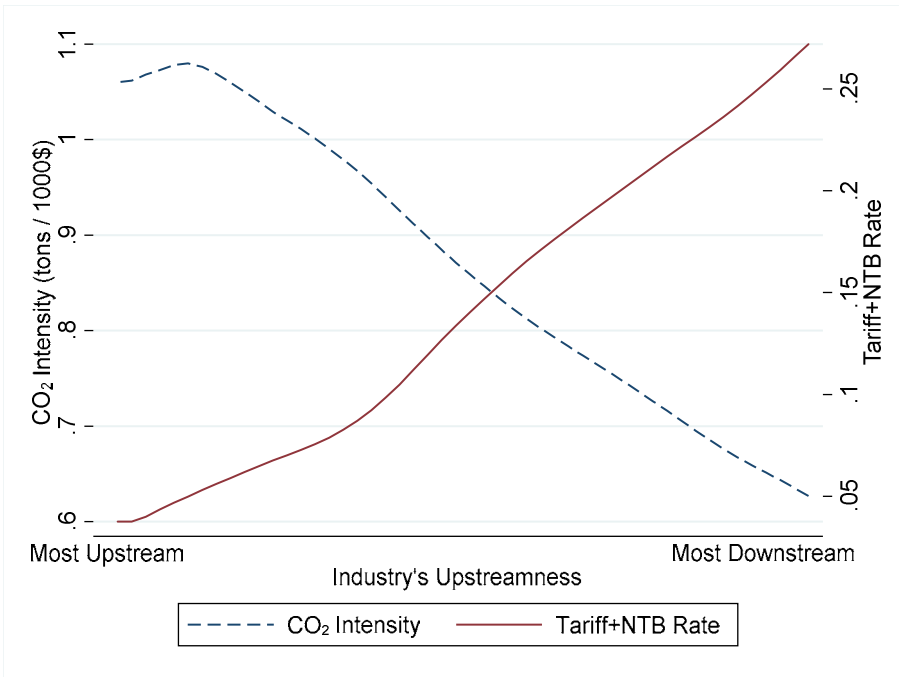
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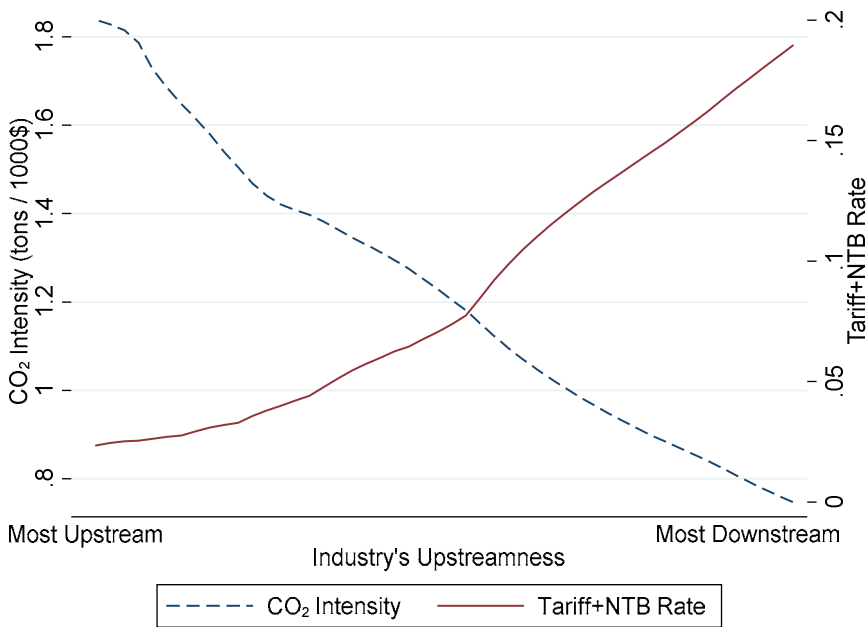
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FIGURE I
Upstreamness, CO₂ Intensity, and Trade Policy

Panel A: All Global Trade



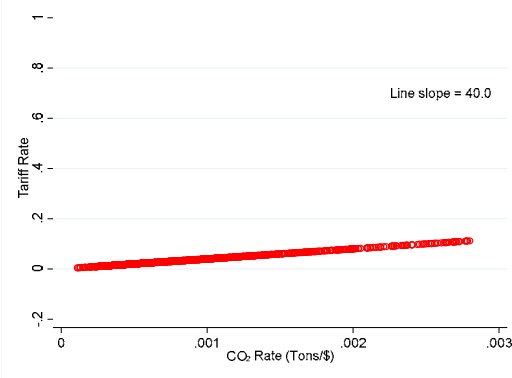
Panel B: U.S. Only



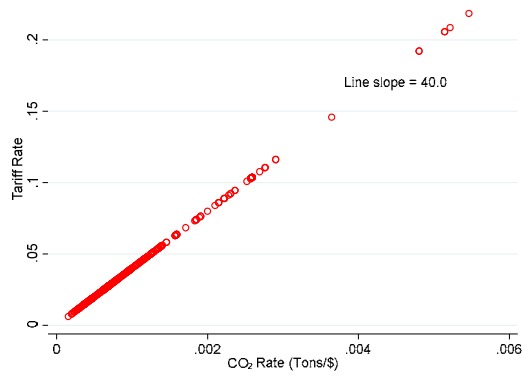
Notes: Solid line is local linear regression of tariffs plus NTBs on upstreamness. Dashed line is local linear regression of CO₂ intensity on upstreamness. Each observation is an importer×industry (Panel A) or an industry (Panel B). All lines use Epanechnikov kernel with bandwidth of 0.75.

FIGURE II
Trade Protection Versus CO₂ Emission Rates

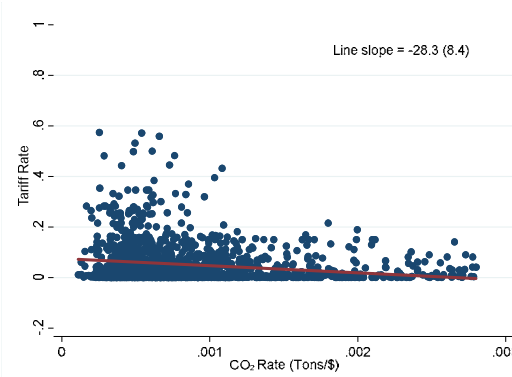
Panel A. Global hypothetical \$40/ton carbon tariff



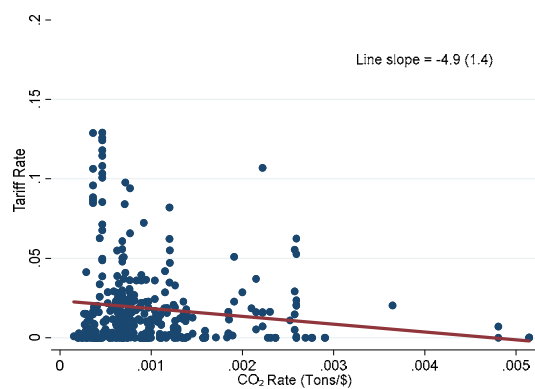
Panel B. U.S. hypothetical \$40/ton carbon tariff



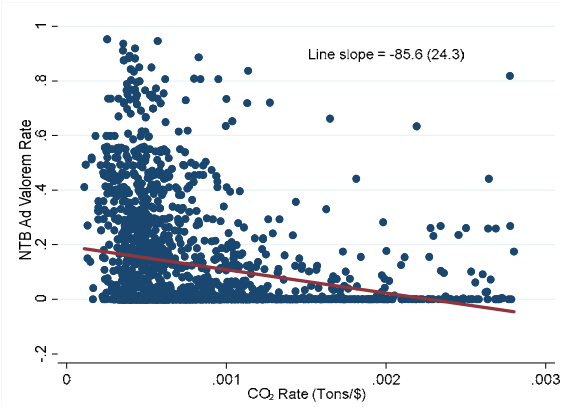
Panel C. Actual global tariffs



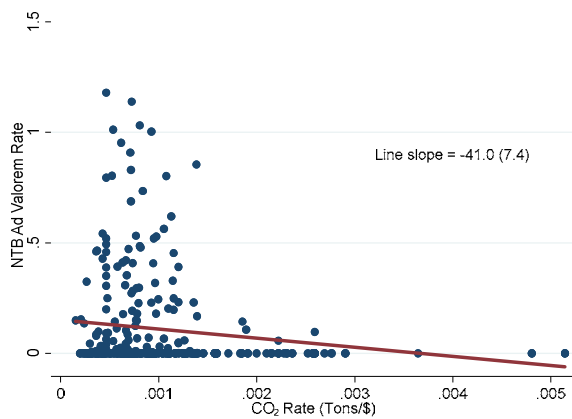
Panel D. Actual U.S. tariffs



Panel E. Actual global non-tariff barriers

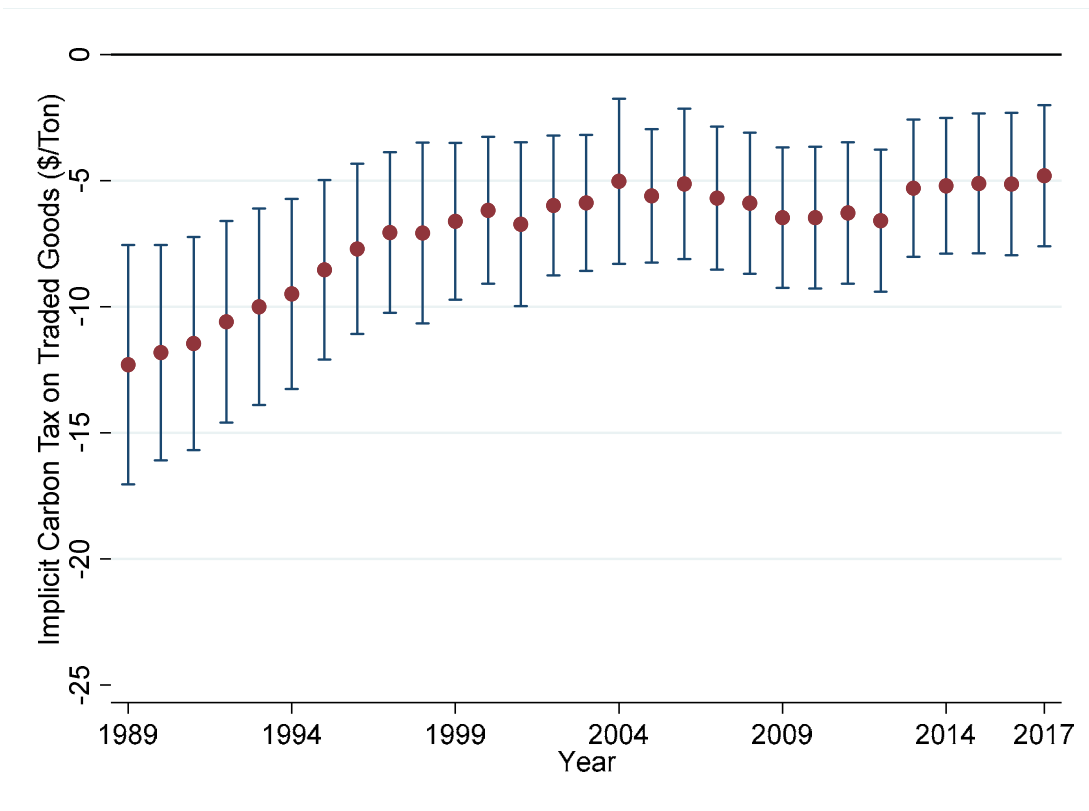


Panel F. Actual U.S. non-tariff barriers



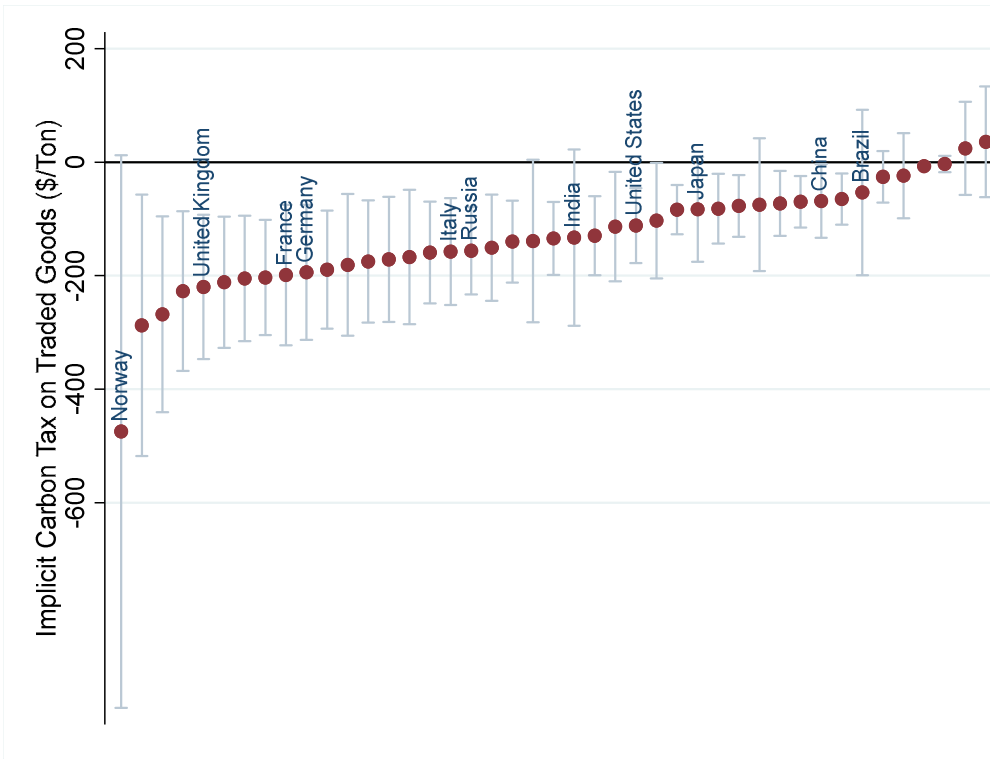
Notes: Panels A and B plot a hypothetical carbon tariff of \$40/ton. Each point in global data is an importer×industry pair; each point in U.S. data is an industry. CO₂ rate is total (direct+indirect) emissions measured from inverting an input-output table. Line is linear trend; in Panels C and E, line is fitted from regressions including importer fixed effects. Each graph excludes the top 1% of CO₂ rates, tariffs, and NTB rate. Numbers for line slopes correspond to the specifications and values of Tables II and III, column 5. Standard errors are clustered by industry.

FIGURE III
Correlation Between U.S. Import Tariffs and CO₂ Emission Rates



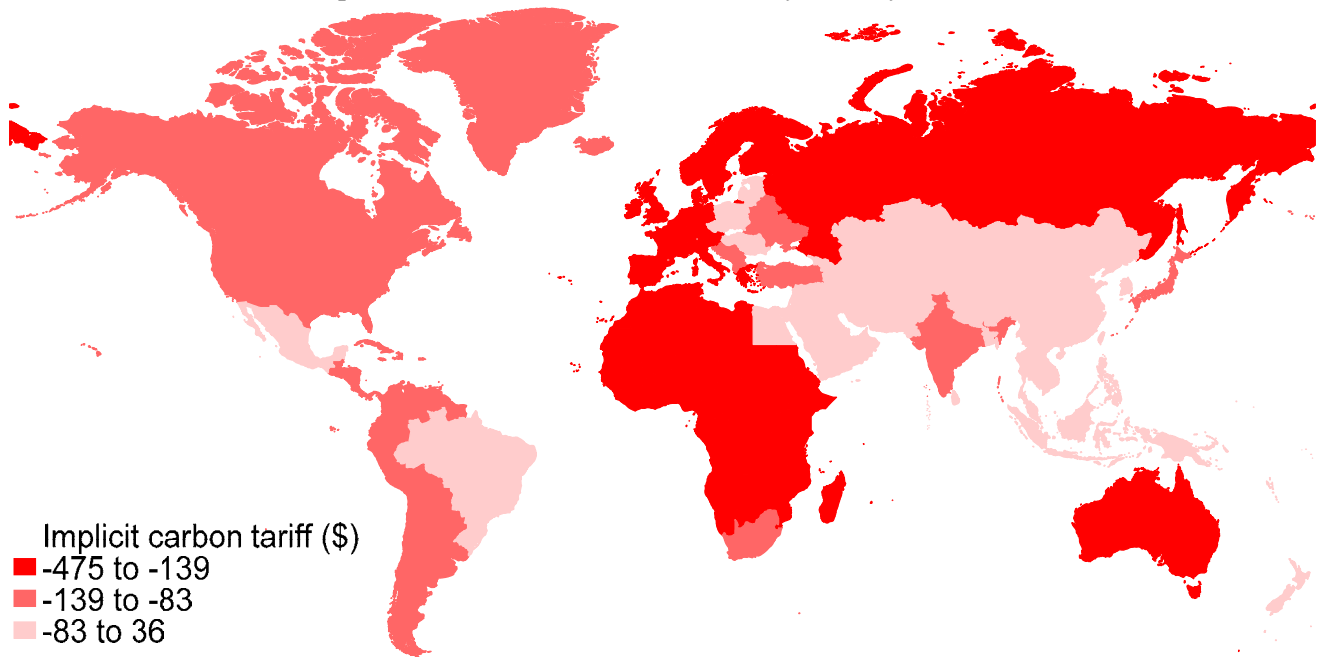
Notes: Implicit carbon tax is the coefficient from a regression of import tariffs on CO₂ emission rates, as in equation (1). Graph shows a separate regression for each year. Emissions intensity is estimated from 2007 input-output tables and applied to all years. Circles show the coefficient estimates, bars show robust 95% confidence intervals. Regressions use instrumental variables; total CO₂ is instrumented with direct CO₂.

FIGURE IV
Covariance of Trade Protection and CO₂ Emission Rates, by Country



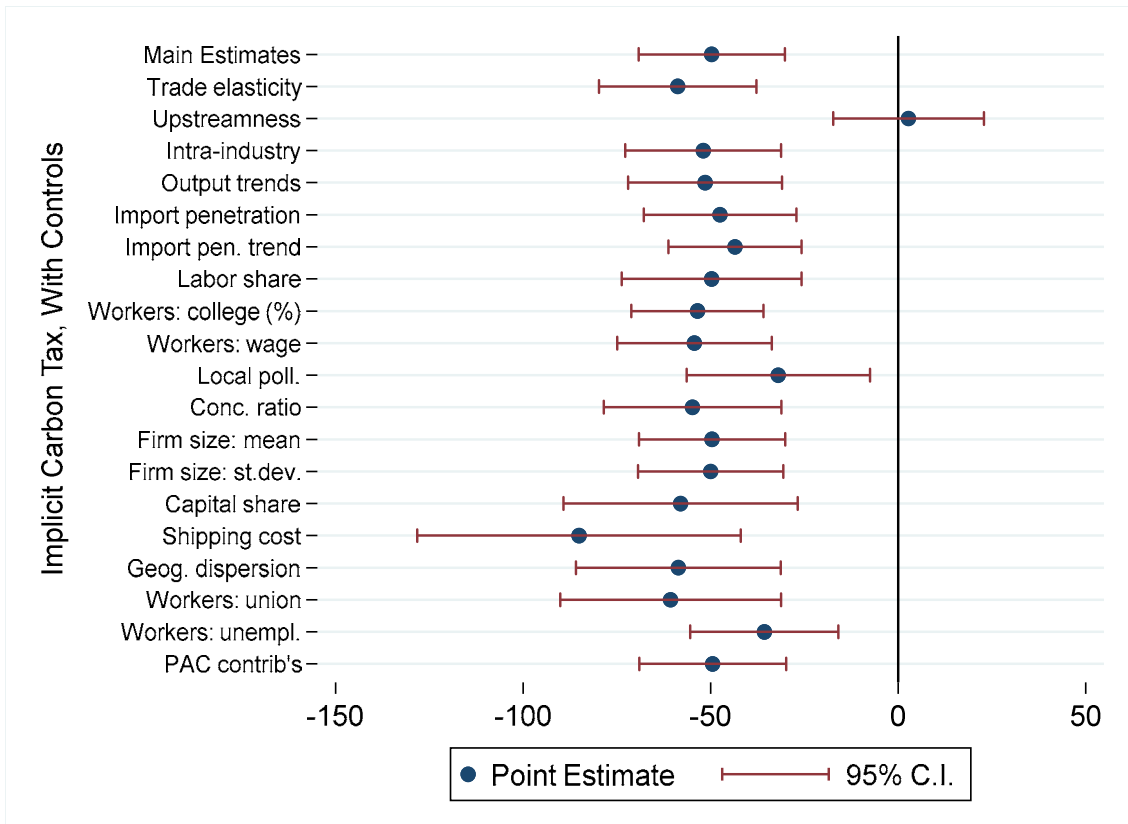
Notes: Implicit carbon tax is the coefficient from a regression of import tariffs plus NTBs (ad valorem equivalent) on a constant and on total CO₂ emission rate (tons/\$), measured from inverting the input-output matrix, which accounts for both primary fossil fuels used in an industry and emissions embodied in intermediate goods used in the industry. A separate regression is run for each country. Total CO₂ is instrumented with the direct CO₂ emissions rate from the input-output table, measured in the same industry but in the ten smallest other countries. Data from year 2007. Graph excludes five Exiobase countries missing NTB data: Bulgaria, Cyprus, Malta, Slovakia, and Taiwan. Red circles are point estimates, vertical bars are robust 95% confidence intervals.

FIGURE V
Implicit Carbon Tax on Traded Goods, by Country



Notes: Implicit carbon tax is the coefficient from a regression of import tariffs plus NTBs (ad valorem equivalent) on CO₂ emission rates and a constant, separately for each country. Data correspond to Figure IV. Graphs include five rest-of-world groups, one per continent.

FIGURE VI
 Political Economy Explanations for CO₂ Subsidies Implicit in U.S. Imports



Notes: Each blue circle represents the coefficient on total CO₂ intensity, instrumented by direct CO₂ intensity, from a regression of tariffs+NTBs on CO₂ intensity. The red bar depicts the robust 95 percent confidence interval. Each regression includes one additional political economy control, indicated at the left part of the graph. Regressions are weighted by the value of imports.

TABLE I
Cleanest and Dirtiest Manufacturing Industries in Global Data

	CO ₂ Rate (Tons/\$)×1000 (1)	Import Tariff Rate (2)	Non-Tariff Barriers (3)
<i>Panel A. Cleanest industries</i>			
Pork processing	0.34	0.10	0.37
Meat products n.e.c.	0.36	0.10	0.37
Sugar refining	0.37	0.20	0.42
Wood products	0.37	0.01	0.03
Motor vehicles	0.40	0.03	0.05
<i>Mean of cleanest 5 industries</i>	<i>0.37</i>	<i>0.09</i>	<i>0.25</i>
<i>Panel B. Dirtiest industries</i>			
Bricks, tiles	1.54	0.02	0.02
Coke oven products	1.64	0.01	0.01
Iron and steel	1.74	0.01	0.02
Phosphorus fertilizer	1.93	0.02	0.11
Nitrogen fertilizer	2.53	0.02	0.11
<i>Mean of dirtiest 5 industries</i>	<i>1.88</i>	<i>0.02</i>	<i>0.05</i>

Notes: CO₂ rates are measured in metric tons of CO₂ per thousand dollars of output, calculated by inverting a global multi-region input output region from Exiobase. Dollars are deflated to real 2016 values using U.S. GDP deflator. Global refers to the mean value across all countries, weighted by the value of output; industries ordered based on global emissions; n.e.c. means not elsewhere classified. Import tariffs are ad valorem and measured in year 2007 CEPII Macmap data. Non-tariff barriers are ad valorem, from Kee et al. (2009).

TABLE II
Association of Import Tariffs and CO₂ Emissions Rates

	FS		RF		OLS		IV	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
<i>Panel A: All global trade (global input-output table)</i>								
CO ₂ rate	1.38*** (0.09)	1.54*** (0.08)	-44.69*** (13.24)	-17.19** (8.16)	-28.28*** (8.42)	-4.48 (6.17)	-32.31*** (8.41)	-11.17** (5.40)
N	2,021	2,021	2,021	2,021	2,021	2,021	2,021	2,021
Dependent Var. Mean	0.001	0.001	0.052	0.028	0.052	0.028	0.052	0.028
K-P F Statistic	—	—	—	—	—	—	228.96	352.59
<i>Panel B: U.S. Imports (U.S. data)</i>								
CO ₂ rate	1.32*** (0.19)	1.58*** (0.51)	-7.52*** (2.00)	-10.35*** (3.71)	-4.89*** (1.40)	-3.23*** (0.94)	-5.69*** (1.44)	-6.55*** (2.29)
N	379	379	379	379	379	379	379	379
Dependent Var. Mean	0.001	0.001	0.018	0.016	0.016	0.018	0.018	0.016
K-P F Statistic	—	—	—	—	—	—	50.33	9.77
Weighted		X		X		X		X

Notes: Table shows regressions of import tariffs on CO₂ rates. Weights are the value of imports. Panel A uses global Exiobase data; Panel B uses U.S. data. Each observation in Panel A is an importer×industry; each observation in Panel B is an industry. Panel A includes importer fixed effects. All regressions include a constant. The endogenous variable is the total CO₂ emissions rate (tons/\$) measured from inverting the input-output matrix, which accounts for both primary fossil fuels used in an industry and emissions embodied in intermediate goods used in the industry. For Panel A, the instrument is the direct CO₂ emissions rate from the input-output table, measured in the same industry but in the 10 smallest other countries. For Panel B, the instrument is the CO₂ emissions rate measured from MECS and CM, which accounts for primary fossil fuels used in an industry and electricity consumed in the industry. Odd-numbered columns are unweighted, even-numbered columns are weighted by the value of the trade flow. Emissions rates measured in metric tons of CO₂ per dollar of output. Output is measured in 2016 US\$, deflated with the U.S. GDP deflator. FS is first-stage, RF is reduced-form, OLS is ordinary least squares, IV is instrumental variables. All data from year 2007. Standard errors clustered by industry are in parentheses. Asterisks denote p-value * < 0.10, ** < 0.05, *** < 0.01.

TABLE III
Association of Non-Tariff Barriers and CO₂ Emissions Rates

	FS		RF		OLS		IV	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
<i>Panel A. All global trade (global input-output table)</i>								
CO ₂ rate	1.38*** (0.09)	1.54*** (0.08)	-124.15*** (40.92)	-116.51** (43.81)	-85.58*** (24.33)	-73.22* (36.75)	-89.78*** (26.75)	-75.67** (29.38)
N	2,021	2,021	2,021	2,021	2,021	2,021	2,021	2,021
Dep. Var. Mean	0.001	0.001	0.126	0.088	0.126	0.088	0.126	0.088
K-P F Statistic	—	—	—	—	—	—	228.96	352.59
<i>Panel B. U.S. imports (U.S. data)</i>								
CO ₂ rate	1.32*** (0.19)	1.58*** (0.51)	-63.34*** (16.68)	-59.13*** (20.78)	-41.04*** (7.44)	-17.98*** (4.15)	-47.96*** (10.03)	-37.41*** (12.33)
N	379	379	379	379	379	379	379	379
Dep. Var. Mean	0.001	0.001	0.109	0.079	0.109	0.079	0.109	0.079
K-P F Statistic	—	—	—	—	—	—	50.33	9.77
Weighted		X		X		X		X

Notes: Table shows regression of NTB rates on CO₂ rates. Columns 1 through 4 are weighted by the value of imports. Panel A uses global Exiobase data; Panel B uses U.S. data. Each observation in Panel A is an importer×industry; each observation in Panel B is an industry. Panels A includes importer fixed effects. All regressions include a constant. The endogenous variable is the total CO₂ emissions rate (tons/\$) measured from inverting the input-output matrix, which accounts for both primary fossil fuels used in an industry and emissions embodied in intermediate goods used in the industry. For Panel A, the instrument is the direct CO₂ emissions rate from the input-output table, measured in the same industry but in the 10 smallest other countries. For Panel B, the instrument is the CO₂ emissions rate measured from MECS and CM, which accounts for primary fossil fuels used in an industry and electricity consumed in the industry. Odd-numbered columns are unweighted, even-numbered columns are weighted by the value of the trade flow. Emissions rates measured in metric tons of CO₂ per dollar of output. Output is measured in 2016 US\$, deflated with the U.S. GDP deflator. FS is first-stage, RF is reduced-form, OLS is ordinary least squares, IV is instrumental variables. All data from year 2007. The dependent variable is the ad valorem NTB rate from Kee et al. (2009). Standard errors clustered by industry are in parentheses. Asterisks denote p-value * < 0.10, ** < 0.05, *** < 0.01.

TABLE IV
Political Economy Explanations for Implicit Carbon Taxes in Trade Policy

	(1)	(2)	(3)	(4)	(5)	(6)
<i>Panel A. All global trade</i>						
CO ₂ rate	-120.55*** (33.73)	-32.90 (25.60)	-120.76*** (33.17)	-121.42*** (35.50)	-120.92*** (34.12)	-120.44*** (33.62)
N	1,990	1,990	1,990	1,990	1,990	1,990
<i>Panel B. All global trade, instrument for political economy</i>						
CO ₂ rate	-120.55*** (33.73)	34.61 (38.88)	-111.66*** (40.04)	-125.64*** (47.61)	-101.50** (43.86)	-119.33*** (33.95)
K-P F Statistic	—	43.29	27.20	41.97	10.15	21.05
N	1,990	1,990	1,990	1,990	1,990	1,990
<i>Panel C. U.S. imports</i>						
CO ₂ rate	-49.72*** (9.90)	2.74 (10.19)	-51.99*** (10.54)	-47.50*** (10.32)	-49.75*** (12.19)	-54.32*** (10.45)
N	358	358	358	358	358	358
Upstreamness		X				
Intra-industry			X			
Import pen. ratio				X		
Labor share					X	
Mean wage						X

Notes: Dependent variable in all regressions is sum of tariffs and NTBs. Each observation is a country*industry (Panels A and B) or industry (Panel C). In all regressions, the CO₂ rate is the total CO₂ rate (tons/\$) from inverting an input-output table, which is instrumented with the direct CO₂ rate. In panel B, political economy variables (upstreamness, intra-industry share, etc.) are also treated as endogenous. The Panel B regressions use a second instrument equal to the mean of each political economy variable in the industry of interest across the ten smallest other countries in the data, measured by gross manufacturing output. Panels A and B use Exiobase data, panel C uses U.S. data. Panels A and B include country fixed effects. All regressions include a constant. Standard errors clustered by industry are in parentheses. Asterisks denote p-value * < 0.10, ** < 0.05, *** < 0.01.

TABLE V
Effects of Setting Tariffs and NTBs to Mean, Model-Based Estimates

	Change in CO ₂ Emissions (%) (1)	Change in Real Income (%) (2)	Change in CO ₂ Intensity = (1) - (2) (3)	Climate benefits (4)	Social welfare (5)
<i>Panel A. Global Total</i>					
Global Total	-3.59%	0.65%	-4.24%	0.08%	0.57%
<i>Panel B. By region</i>					
Pacific Ocean	33.31%	1.02%	32.29%	—	—
Western Europe	23.33%	0.90%	22.43%	—	—
Eastern Europe	0.77%	0.99%	-0.22%	—	—
Latin America	-3.36%	0.74%	-4.10%	—	—
North America	-3.80%	0.26%	-4.06%	—	—
China	0.03%	0.22%	-0.19%	—	—
Southern Europe	54.67%	0.64%	54.03%	—	—
Northern Europe	26.96%	1.06%	25.90%	—	—
Indian Ocean	-5.15%	0.31%	-5.46%	—	—
Rest of World	-14.96%	0.93%	-15.89%	—	—
<i>Panel C. Decomposition</i>					
Scale	0.20%	—	—	—	—
Composition	-1.29%	—	—	—	—
Technique	-2.50%	—	—	—	—
<i>Panel D. By Fossil fuel</i>					
Coal	-2.63%	—	—	—	—
Oil	-4.65%	—	—	—	—
Natural gas	-3.97%	—	—	—	—

Notes: Global change in real income refers to the weighted mean percentage change in countries' real incomes due to a counterfactual policy, where weights equal each country's baseline income. In all baseline and counterfactual scenarios, intra-national tariffs and NTBs are assumed to equal zero.

ONLINE APPENDIX:
THE ENVIRONMENTAL BIAS OF TRADE POLICY

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A Data Details

For most outcomes, I report separate results using U.S. data, primarily for data quality reasons—the U.S. provides a second and independent measure of CO₂ emissions, provides greater industry detail (around 350 NAICS 6-digit industries), reports effective and not just statutory tariff rates, and generally provides higher-quality and better-documented data. The U.S.-only analysis uses U.S. data for both tariffs and CO₂ emissions, and therefore implicitly assumes that emissions rates in other countries are the same as in the U.S. The global analysis does not make this assumption. Online Appendix A.5 describes additional details on data used to measure U.S. CO₂ emissions.

A.1 Concordances

The paper uses several concordances across definitions and years of industry and product codes. As a general guide, raw data on traded goods, tariffs, and NTBs are at the level of a 6-digit harmonized system (HS) code. Raw U.S. data are at the level of a 6-digit North American Industry Classification System (NAICS) code. Exiobase uses industry codes based on the International Standard Industrial Classification, version 3.1. WIOD also uses its own industry codes. I use published concordances between these various industry codes. I use weighted concordance files when possible, i.e., which express the share of an industry's output in one classification which corresponds to each possible industry in a different classification. Ultimately, I concord raw data to the industry definition of the relevant analysis (Exiobase, U.S., or WIOD).

Concording Exiobase files are fairly straightforward. Exiobase industries were constructed to closely reflect ISIC industries, so I construct a concordance by matching names between these two industry classifications.

Linking U.S. industry codes is more complicated. A few concordances link 2007 NAICS codes to other industry codes. Some of the U.S. political economy explanations are from the May 2007 Current Population Survey, which defines industries using 2007 U.S. census codes (i.e., the codes defined for use in the 2007 U.S. Economic Census, which is distinct from the decennial population census; these codes differ from NAICS codes). I use Census Bureau files to link these census industries to 2007 NAICS industries.¹ The unionization coverage data I use as one political economy explanation use industry codes from the 2000 U.S. census, so I use the same concordance file to link these to 2007 NAICS codes. One sensitivity analysis aggregates the U.S. data to 21 ISIC industries; I link NAICS to ISIC codes using a Census concordance.²

Another set of concordances links U.S. industry codes for other years. The 2006 MECS data are at the level of 2002 NAICS codes, so I also link these to ISIC codes using U.S. Census Bureau files.³ U.S. input-output tables use an input-output industry classification

¹Downloaded from <https://www.census.gov/people/io/files/IndustryCrosswalk90-00-02-07-12.xls>, visited 8/18/2017.

²Downloaded from <https://www.census.gov/eos/www/naics/concordances/concordances.html>, visited 8/8/2017.

³Downloaded from <https://www.census.gov/eos/www/naics/concordances/concordances.html>, visited 8/8/2017.

which is similar but not identical to NAICS. I use a file that is part of the 2007 input-output table which contains a concordance between 2007 input-output codes and 2012 NAICS codes. I concord 2012 NAICS codes to 2007 NAICS codes using a concordance file from the U.S. Census Bureau which includes industry shares (file EC1200CBDG1). The PAC contributions data are at the level of 1987 Standard Industrial Classifications (SIC); I link these to NAICS codes using a concordance from the NBER-CES Manufacturing Industry database (Becker et al. 2013). A few datasets report NAICS codes for some observations at 2, 3, 4, or 5 digits; for these more aggregated values, I construct concordances at this more aggregated level and then translate industry codes appropriately.

A.2 Global Input-Output Data

I use Exiobase (specifically, version 2.2.2, industry-by-industry, fixed product sales assumption) because it distinguishes 48 countries and 163 industries, about 50 of which are in manufacturing. Five of the “countries” are actually aggregates that include all countries in a given region that are not separately identified in the data, such as the aggregate, “Rest of Asia.” Exiobase is supported by the European Union. Other global multi-region input-output tables, like the World Input-Output Database (WIOD), typically distinguish only 20-60 industries, only 15-20 of which are tradable manufacturing industries.

Much of the global value chain literature uses the World Input Output Database (WIOD) and related multi-region input-output tables. I focus on Exiobase, which I believe has not been used in this literature, since it has far richer industry detail than WIOD and related datasets. Exiobase is widely used in industrial ecology research (e.g., Tukker et al. 2013; Moran and Wood 2014; Wood et al. 2015). I report some sensitivity analyses using WIOD (Timmer et al. 2015).

Exiobase is built from several primary data sources (Wood et al. 2015). Exiobase combines supply and use output tables for the EU27 via Eurostat, and for 16 other countries that together cover over 90 percent of global GDP. It measures trade using BACI, which is based on the UN’s Comtrade database, and using the UN’s services trade databases. To harmonize data across countries, Exiobase also uses data from FAO and the European AgroSAM, the IEA, and other data sources. National fossil fuel use comes from IEA sources, while some industry detail comes from Pulles et al. (2007). Exiobase uses Euros as its base currency; I convert Euros to dollars using the mean annual exchange rate from the IMF’s International Financial Statistics and deflate to 2016 dollars using the U.S. GDP deflator. The main Exiobase sample is restricted to observations with non-missing tariffs, NTBs, and CO2 rates.

Like all global multi-region input-output tables, Exiobase applies statistical algorithms to harmonize these different datasets. National input-output tables also do this; Horowitz and Planting (2006) describe the process. The final data must satisfy many accounting identities; for example, imports must equal exports, subject to trade imbalances; industry-specific values must add up to national values; the value of intermediate goods plus value added must equal gross output; etc. Harmonization also expresses all countries in the same industries and using the same price concepts.

How does Exiobase compare to other multi-region input-output tables? Several studies compare Exiobase to WIOD and Eora. These studies find that the numbers in these

databases are not especially sensitive to the different algorithms used to construct these tables (Geschke et al. 2014), that consumption-based CO₂ accounts (sometimes called a country’s “carbon footprint”) or raw materials that each country consumes generally differ by less than 10-15 percent across these databases (Moran and Wood 2014; Giljum et al. 2019), and that disaggregation to more industry detail, which is Exiobase’s focus, tends to produce more accurate analysis of CO₂ (Steen-Olsen et al. 2014; de Koning et al. 2015). The Global Trade and Analysis Project (GTAP), which constructs another multi-region input-output table, is widely used in computable general equilibrium (CGE) analyses in part since it incorporates a ready-made CGE model, simplified coding language, online support services, and hundreds of parameters. GTAP, however, also includes only around 20 manufacturing industries, and its data construction are less well documented than some other input-output tables. WIOD is generally seen as having higher data quality, which may be because it has fewer countries (43 in WIOD versus 190 in Eora), which lets WIOD rely on data from higher-quality statistics agencies and require less imputation for the additional countries. Exiobase covers 43 countries plus five rest-of-world aggregates, which is similar to WIOD. The possibility of measurement error in these data is one reason why I report results from three separate input-output tables – Exiobase, WIOD, and U.S. national data – and also obtain completely independent measures of CO₂ emissions for use as an instrumental variable in the U.S. data.

Comparing the U.S. and Exiobase data is complicated by the fact that U.S. NAICS industry codes and Exiobase industry codes do not easily concord to each other and require applying multiple many-to-many concordances. To provide such a comparison while limiting additional measurement error, I select the 30 Exiobase manufacturing industries that have a one-to-one or one-to-many mapping to 4- or 6-digit NAICS codes (thus excluding those with many-to-many links). For these 30 Exiobase industries, I then calculate the mean total emissions rate from the U.S. data (weighting across 6-digit U.S. NAICS industries within an Exiobase industry by the value of shipments). In logs, a regression of the U.S. CO₂ rate calculated from Exiobase data on this rate calculated from U.S. data gets a regression coefficient of 1.035 (robust standard error 0.020), with an R-squared of 0.989. In levels, this regression coefficient is 0.801 (0.210), with an R-squared of 0.56. These are strong correlations, though for a focused sample; since Exiobase is constructed from national input-output tables it is perhaps unsurprising that its patterns for the U.S. are similar to those of the national U.S. input-output table.

I calculate gross output in Exiobase 2.2 (which does not directly report it) as follows. Gross output Y equals the sum of intermediate inputs I and factor payments L , where factor payments are defined to include payments to labor, payments to capital including profits (i.e., including markups), and taxes:

$$Y = I + L \tag{A.1}$$

To measure intermediate inputs I in millions of Euros for each country×industry, I take the sum across rows (within each column) of the Exiobase Use table. To measure factor payments per gross output L/Y , I use the Exiobase Factor Inputs table and exclude entries recording employment in hours per million Euros or in workers per million Euros. I then calculate L/Y as the sum across rows (within each column) of this table. Finally, simple

manipulation of (A.1) shows that gross output for each country×industry is

$$Y = \frac{I}{1 - \frac{L}{Y}}$$

where I and L/Y are calculated from the Use table and Factor Inputs table as described above.

Given this measure of gross output, I follow [Antràs et al. \(2012\)](#) and [Antràs and Chor \(2018\)](#) in calculating upstreamness. In the raw Exiobase input-output table, each row is an origin country×sector and each column is a destination country×sector. Each entry in this table is in terms of Euros of inputs per Euro of output (i.e., the table is in coefficient form). I convert this to Euros by multiplying each entry by the gross output of the destination country×sector. I calculate total international exports X_{ij} from domestic industry i to foreign buyers of industry j as the sum of this table across columns (within a row), excluding columns with the same origin and destination country. I calculate total international imports M_{ij} from foreign industry i to domestic industry j as the sum of this table across rows (within a column) which have the same origin and destination country.

The main results use CO₂ emissions from fossil fuel combustion, which is the best-measured and accounts for most greenhouse gas emissions. I also report results using other greenhouse gas emissions. I incorporate two corrections for outliers in the raw data. First, for each greenhouse gas separately, I replace emissions from nitrogen fertilizer production with emissions from phosphorus fertilizer emissions from the same country. Second, for the crude oil extraction industry, I replace non-combustion methane emissions with combustion methane emissions. In both cases, raw data from Exiobase are outliers and exceed estimates from other sources. For similar reasons, in regressions including non-manufacturing goods, I exclude one mining industry with outlier values of emissions rates, “Extraction, liquefaction, and regasification of other petroleum and gaseous materials,” which is distinct from crude oil or natural gas extraction.

The quantitative model requires data on CO₂ emissions from production of each fossil fuel in each country. I obtain these data from reports using the International Energy Agency containing data from the year 2007 ([IEA 2009a,b](#)), which list the physical units of each fossil fuel produced in each country. I convert these into CO₂ using standard conversion rates of physical units of fossil fuel (i.e., tons or terajoules) to metric tons of CO₂ from the U.S. Environmental Protection Agency ([USEPA 2014](#)).

In the sensitivity analysis using WIOD, I measure environmental outcomes using data on total CO₂ emissions. I replace the roughly 5 percent of WIOD country×industry observations which have missing CO₂ values to instead have the mean global CO₂ emissions rate for that industry, multiplied by the country×industry’s reported gross output. If a country×industry reports zero output, I set CO₂ emissions for that country×industry also to equal zero. To aid computation, I replace the roughly 2 percent of country×industry observations that report zero output to have output 10^{-7} . Because WIOD does not separately distinguish types of mining, in the WIOD estimates all mining activities are combined into one sector, and both electricity generation and transportation are combined into the “other industries” sector. A few WIOD international flows are negative, primarily representing gross fixed capital formation and changes in inventories and valuables. In WIOD estimates that aggregate

over industry categories or countries and use trade values as weights in this aggregation, I assume these negative flows instead have values of zero. As with Exiobase, I exclude the five countries missing NTB data (Bulgaria, Cyprus, Malta, Slovak Republic, and Taiwan).

One adjustment is needed to the data to match the quantitative model outlined below. Both Exiobase and WIOD report inventory adjustments for each country×sector, which in some cases are negative. I interpret negative inventory adjustments as output produced in the prior year, then produced and consumed in the current year. I revise total output and bilateral intermediate goods trade to reflect this adjustment (Costinot and Rodriguez-Clare 2014 apply a similar adjustment).

A.3 Political Economy Variables

I group the political economy variables into those reflecting the demand for versus supply of protection. The global data come from Exiobase, but the U.S.-specific data with greater industry detail come from a range of sources. Optimal tariffs are perhaps the simplest. I use estimates of the export supply elasticity for the U.S. at the 10 digit harmonized system code level from Soderbery (2015); the results are qualitatively similar using estimates from Broda and Weinstein (2006).

A few variables reflect demand for low protection from customers. Industries may lobby for low protection on goods they use as inputs. Industries with a large share of intra-industry trade, i.e., where both exports and imports are common, may have less trade protection since importers lobby for protection while exporters (who are concerned with retaliation) lobby against protection. I measure intra-industry trade using the common measure $1 - \frac{|x_i - m_i|}{x_i + m_i}$, where x_i and m_i represent total exports and imports in industry i (Krugman 1981). These data come from the Census Bureau’s Imports and Exports of Merchandise data series.

Another set of political economy variables reflects an industry’s demand for protection on its own goods. Declining or “sunset” industries may obtain more government support since sunk costs prevent entry and incentivize incumbents to lobby to protect remaining rents. I calculate the change in the value of shipments for each industry between the years 1977 and 2007, adjusted by industry-specific output deflators, using data from the NBER-CES Manufacturing Industry Database. Industries more exposed to foreign trade have more to gain from protection. I measure the import penetration ratio as log of the total imports divided by the value of shipments, in levels for the year 2007 and as a trend over the period 2002-2007, using data from the NBER-CES database for gross output and Imports of Merchandise for imports. Industries with more workers have more stakeholders potentially benefiting from protection; I calculate each industry’s labor share as total workers divided by the value of shipments, using data from the NBER-CES database. Industries with a large share of low skill or low wage workers may obtain protection as a tool for redistribution, either out of general concern for equity or as an alternative to other transfers. I measure mean wages and the share of workers with some college education, using data from the May 2007 Current Population Survey Annual Social and Economic Supplement (CPS-ASEC).⁴

⁴A worker’s industry is defined from her current job for employed workers, or the most recent job for workers who are unemployed or not in the labor force. I measure the share of workers with at least some college education. For wages, I measure the hourly wage for the Outgoing Rotation Group if it is reported.

One additional variable measures the “local” air pollution for each industry. I combine the six major air pollutants that the Clean Air Act targets and that are typically measured: carbon monoxide (CO), nitrogen oxides (NO_x), particulate matter smaller than 2.5 micrometers (PM_{2.5}), particulate matter smaller than 10 micrometers (PM₁₀), sulfur dioxide (SO₂), and volatile organic compounds (VOC). I measure emissions of each pollutant from the year 2008 data of the National Emissions Inventory (NEI), a national dataset created by the Environmental Protection Agency that measures the tons of pollution emitted from each plant or other source. The costs of these emissions vary over space and across pollutants. To provide a scalar measure of these costs, I use a measure of the marginal damage for each pollutant in each U.S. county, from [Muller and Mendelsohn \(2012\)](#). These damages reflect leading estimates of how air pollution affects health, agriculture, amenities, etc. For each industry, I calculate the damage rate as emissions per industry×pollutant×county times damages per pollutant×county, summed across counties and pollutants, and divided by the industry’s revenues.

A separate set of variables reflects the cost of organizing an industry to lobby for protection, i.e., the supply of protection. A challenge in lobbying is overcoming the free-riding problem within each industry to pay for the costs of lobbying ([Olson 1965](#)). Concentrated industries or industries with a few larger firms can better overcome the challenge. I measure industry concentration as the share of an industry’s output accounted for by the four largest firms, using data from the Economic Census (specifically, the Census of Manufacturers). I calculate mean firm size as the total value of shipments for the industry divided by the total number of establishments in the industry, also using data from the Economic Census. Using the same data, I calculate the standard deviation of firm size ([Bombardini 2008](#)). Since capital intensity tends to increase concentration, and is also a primary determinant of comparative advantage and U.S. imports, I also measure the capital share as the value of the capital stock divided by gross output, using the NBER-CES database. High transport costs and geographic dispersion make an industry less geographically or economically concentrated, so more difficult to organize. I measure shipping costs per dollar×kilometer, using data from the U.S. Imports of Merchandise series and CEPII’s measure of geographic distance between countries. I measure geographic dispersion as entropy across states, using data from County Business Patterns.⁵ Disadvantaged industries, including those with a high share of workers who are unemployed, may have greater incentive to lobby since their opportunity cost of doing so is lower. I measure unemployment rates of workers where industry is defined according to the current or most recent industry worked, using data from the May 2007 CPS. Unions provide an organized association to lobby for protection, so I measure unionization rates using processed values from the May 2007 CPS ([Hirsch and MacPherson](#)

Otherwise I calculate hourly wages as total wage and salary income for the previous calendar year, divided by the product of weeks worked last year and usual hours worked per week last year. I calculate wages using the individual (earnings) survey weights, and calculate education using the standard individual survey weights.

⁵Formally, the analysis defines geographic dispersion as $\sum_j y_{ij} \ln y_{ij}$, where $y_{ij} \equiv Y_{ij}/Y_i$, and where Y_{ij} is output of state j and Y_i is total output. In County Business Patterns, each observation lists total employment in a given state×industry. Some values are suppressed due to confidentiality, but identified as falling in one of twelve employment size bins (1 to 19; 20 to 99; etc.). I impute these values as the midpoint of each bin, and impute the top bin (>100,000) as 125,000.

2003). I also use one direct though incomplete measure of lobbying on contributions to Political Action Committees (PACs), using data from the Center for Responsive Politics.

Upstreamness turns out to be the most relevant of these variables. Formally, for a closed economy with S industries, upstreamness is $U = [I - d_{ij}Y_j/Y_i]^{-1}\mathbf{1}$. Here, U is an $S \times 1$ column vector where each entry is the upstreamness value for one industry, I is the $S \times S$ identity matrix, d_{ij} is the input-output coefficient (i.e., the dollars of sector i goods needed to produce a dollar of industry j goods), Y_i is the output of industry i , and $\mathbf{1}$ is a vector of ones. The term $d_{ij}Y_j/Y_i$ represents an $S \times S$ matrix where each entry equals the share of output from industry i that industry j purchases. Antràs et al. (2012) show that this measure, originally from Fally (2012), is analytically equivalent to the upstreamness measure described in Antràs and Chor (2013). Versions of these definitions for global multi-region input-output tables are similar, though each observation is an industry×country rather than just an industry (Antràs and Chor 2018).

For the U.S. data, I measure upstreamness using the 2007 U.S. input-output table after redefinitions. Appendix Figure II, Panel D, plots upstreamness separately for all global production and for U.S. production. In all these graphs, the most upstream industries are on the left and the most downstream industries are on the right. The full measure of upstreamness in Panel D ranges from 5 (most upstream) to 1 (most downstream)

A.4 Trade Policy

Most of the trade policy data are straightforward. The NTB values exclude five countries that are in Exiobase but that I hence exclude from much of the analysis: Bulgaria, Cyprus, Malta, Slovakia, and Taiwan. In cases where tariff data are missing for Luxembourg, I replace them with tariffs for Belgium. I interpret NTBs as applying to all international trade, including between EU countries (Chen and Novy 2012). The country-by-country map in Figure V shows values for many individual countries that are part of regional aggregates like “Rest of Europe” or “Rest of Asia”

The NTB data have some limitations. Unlike tariffs, they are the result of calculations and are not raw data. At the same time, they are widely used in research on trade policy (Irwin 2010; Limão and Tovar 2011; Novy 2013; Handley 2014); Bagwell and Staiger (2011, p. 1250) describe them as “the best [NTB] measures that are available.” These data differ by importer and 6-digit HS code, though not by importer-exporter pair.

The time coverage of the NTB data precedes recent policy changes. Between 2009 and 2016, temporary trade barriers including anti-dumping policies, countervailing duties, and safeguards increased on high income economies’ intermediate goods imports from China. These patterns have been less pronounced for final goods trade with China, trade with other countries, or emerging economies (Bown 2018). The U.S. has also increased tariffs in its 2018-2019 trade war on a wide range of goods—initially on intermediate goods, though eventually covering much trade with China. I report some results analyzing these recent changes in tariffs.

I do not use data on other trade policy instruments since they are not readily available for all countries, though Bond et al. (2019) find some evidence of links between upstreamness and protection using data on export tax equivalents of China’s value added tax rebates.

The U.S. tariff data are reported at the level of a 10-digit Harmonized System (HS) code,

and I use a version linked to six-digit North American Industrial Classification System codes (NAICS; see [Schott 2008](#)). I calculate U.S. effective import tariff rates as the total duty collected, divided by the cost, insurance, and freight (CIF) value of trade.

One sensitivity analysis compares cooperative and non-cooperative tariffs for the U.S., China, and Japan. The U.S. applies non-cooperative tariffs to Cuba and North Korea. China applies non-cooperative tariffs to Andorra, the Bahamas, Bermuda, Bhutan, the British Virgin Islands, the British Cayman Islands, French Guiana, Palestinian Territory (West Bank and Gaza), Gibraltar, Monserrat, Nauru, Aruba, New Caledonia, Norfolk Island, Palau, Timor-Leste, San Marino, the Seychelles, Western Sahara, and Turks and Caicos Islands. Japanese non-cooperative tariffs apply to Andorra, Equatorial Guinea, Eritrea, Lebanon, North Korea, and Timor-Leste ([Ossa 2014](#)).

Appendix Figure II, Panel A, plots the density of tariffs, excluding the top 1% for visual clarity. The mean global tariff is three to five percent, while the 99th percentile globally is sixty percent. U.S. import tariffs are lower, with mean and median around two percent and the 99th percentile at nearly fifteen percent. Appendix Figure II, Panel B, plots the density of NTBs. For all global trade, tariffs and NTBs have somewhat similar values; for U.S. imports, average NTBs exceed average tariffs.

A.5 Emissions

Most emissions data are described in the main text. All tons in this paper refer to metric tons. All discussion of CO₂ refers to CO₂ from fossil fuel combustion, which is best measured and accounts for a large majority of CO₂ emissions, except one sensitivity analysis that includes CO₂ from process emissions and other greenhouse gases (methane and nitrous oxides).

CO₂ accounts for roughly 76 percent of global greenhouse gas emissions, methane (CH₄) accounts for 16 percent, nitrous oxide (N₂O) for 6 percent, and fluorinated gases like hydrofluorocarbons (HFCs) for 2 percent ([IPCC 2014](#)). CO₂ accounts for 82 percent of U.S. greenhouse gas emissions ([USEPA 2019](#)). Methane is emitted from extraction, transportation, and processing of coal, oil, and natural gas, in addition to coming from agriculture and landfills. Researchers have a general consensus on the magnitude of CO₂ emissions, but are still debating and improving measurement of methane emissions, particularly from fossil fuels (e.g., [Alvarez et al. 2018](#)).

For analyses of the U.S. only, the paper uses four other CO₂ datasets. One is the U.S. detailed benchmark input-output table after redefinitions for 2007, produced by the Bureau of Economic Analysis. For this purpose, I use the industry-by-industry total requirements table. The second data source is the U.S. Manufacturing Energy Consumption Survey (MECS), which reports physical quantities of fossil fuels combusted for a large sample of manufacturing plants in the year 2006. (MECS is only conducted every few years.) The third dataset is the Census of Manufactures (CM), which reports expenditure on electricity and on total fossil fuels for each 6-digit NAICS industry in the year 2007. Because MECS is a sample of only 10,000 plants, I use MECS to measure each industry's tons of CO₂ emissions per dollar of fossil fuel expenditure, and multiply this by the CM data on each industry's total fossil fuel expenditure. The fourth is U.S. emissions coefficients reporting mean national tons of CO₂ emitted per dollar of coal, oil, and natural gas input, obtained from the U.S. Energy Information Agency and Environmental Protection Agency.

For the analysis of the U.S. input-output table, I measure price per BTU produced of each fossil fuel (coal, crude oil, and natural gas) from the Energy Information Agency’s year 2016 Annual Energy Review, and I measure metric tons of CO₂ per BTU using EPA emissions factors.⁶ Analysis of the U.S. data excludes observations with missing emissions or trade policy data.

I use the publicly available version of MECS. In measuring energy consumption as fuel in trillion BTU, I assume that suppressed values less than 0.5 (denoted with an asterisk) equal zero. For withheld cells (denoted by Q or W), I impute the value as manufacturing’s overall share of BTU from a fuel, multiplied by the industry’s total BTUs.

As the main text notes, the U.S. analysis uses U.S. data for both tariffs and CO₂ emissions. This approach relying on the U.S. data is similar to how the Waxman-Markey bill, which passed the U.S. House but not the Senate in 2009, and other U.S. CO₂ cap-and-trade proposals would measure CO₂ emissions for border tax adjustments. Some also argue that measuring CO₂ emissions for a carbon border adjustment from domestic emission rates rather than from the CO₂ content of imports would have a stronger legal basis at the WTO ([Staiger 2018](#)). At the same time, this strong assumption of the U.S.-only analysis is important to bear in mind.

The paper’s main approach to measuring total emissions involves inverting an input-output table. The diagonal of an input-output table, which generally has the largest values in an input-output table, describes outputs from an industry that are used to produce output in the same industry. This implies that fossil fuels which are used to produce fossil fuels (e.g., oil used to power a drill that is used to extract oil) are captured in this approach since they appear on the diagonal of the input-output table.

Appendix Figure II, Panel C, plots the density of these total CO₂ emission rates, separately for all global trade and for all U.S. imports. For U.S. and global trade, the median CO₂ emission rate is 0.5 to 1.0 tons CO₂ per thousand dollars of output. Emissions rates for the U.S. have a longer right tail since the U.S. data have more industry detail.

Measuring CO₂ emissions from an input-output table can involve several pitfalls. One pitfall is that using the average national price of a fossil fuel assumes that all industries face this price. Input-output tables measure expenditures in currency (e.g., dollar) terms, while CO₂ emissions are in physical quantities (metric tons of CO₂). The data on CO₂ emissions use the mean national price of each fossil fuel (e.g., dollars per ton of coal) to translate from currency to quantities. Emission rates (e.g., tons of CO₂ emitted per ton of coal) are then used to translate from quantities of fossil fuels to quantities of CO₂. Bulk discounts, transportation costs, market power, and other forces can make fossil fuel prices differ across industries. Another potential pitfall is that one fossil fuel can vary in its CO₂ intensity—different varieties of coal, for example, have modestly different CO₂ emitted per ton of coal. Additionally, some fossil fuels are physically transformed into products (“feedstocks”), rather than being burned, such as crude oil transformed into plastic. Moreover, input-output tables abstract from heterogeneity within a country×industry—large firms, or firms that export to specific destinations, can have different emissions than the average firm ([Lyubich et al. 2018](#)).

⁶Data from https://www.epa.gov/sites/production/files/2018-03/documents/emission-factors_mar_2018_0.pdf, visited 11/19/2019.

I address these pitfalls in a few ways. I address heterogeneity in fossil fuel prices and CO₂ rates in part by constructing instrumental variables for CO₂ rates, described below. I address feedstocks by using measures of CO₂ intensity from Exiobase that exclude fossil fuels used for feedstocks. I abstract from heterogeneity in emission rates within a country×industry.

I am not aware of approaches besides the use of input-output tables that can measure emission rates from all industries and countries, and particularly to account for emissions embodied in intermediate goods. National surveys of firms can measure emission rates directly; as described below, I use one such survey for the U.S., and it does not substantially change estimates. The Intergovernmental Panel on Climate Change (IPCC) describes two other approaches to measuring CO₂—“Tier 2” uses country-specific data on emission factors and other variables, and “Tier 3” uses country-specific specialized engineering models and location specific data that are tailored to national circumstances. Because it is country-specific, Tier 3 is difficult to use for comparisons across all countries and industries, and I am not aware of data for all countries and industries using the Tier 2 approach.

An example may clarify what this approach does and does not measure. The emission rate for the vehicle manufacturing industry includes the coal, oil, and natural gas burned to produce the steel, rubber, engine, and assembly of the vehicle, and transportation of the components between the respective manufacturing plants. The emissions rate for vehicle manufacturing does not account for combustion of goods like gasoline that are complements or substitutes for manufactured vehicles. I report sensitivity analyses which adjust the emission rate for energy-consuming durable goods like cars to account for the energy services used to operate them.

A.6 Tariffs On Intermediate Versus Final Goods

I discuss one exercise that may both provide insight on data quality and a public good for research. Some research defines tariffs on intermediate and final goods based on a United Nations Broad Economic Codes (BEC) classification of roughly a dozen broad industry codes into materials, intermediate inputs, and consumer goods (Mishra and Spilimbergo 2011; Amiti et al. 2014; Brandt et al. 2017).

The data in this paper allow an alternative approach. For each source country in Exiobase, I define the third of industries that are most upstream as “intermediate goods” and the third of industries that are least upstream as “final goods.” For each destination country (importer), I then calculate the mean tariff on “intermediate goods” and the mean tariff on “final goods.” I separately calculate weighted and unweighted averages. An advantage of this approach is that it defines intermediate and final good tariffs based on input-output links between industries, rather than on written industry titles. In case these data are useful for other research, I have posted them, along with the associated BEC averages, online at <http://joseph-s-shapiro.com/data.html>.

My and the BEC definitions obtain similar mean tariffs—mean weighted tariffs for intermediate goods are 2.3 and 2.6 percent in my and the BEC measures, respectively; and tariffs for final goods are 6.5 and 6.3 percent. My measure has more dispersion – tariffs have a standard deviation of 8.8 versus 7.0 percent – in part since Exiobase allows more detailed industry codes than the BEC, and since the set of which industries are upstream varies slightly across countries in my approach but not in the BEC classification. In a dataset

where each observation is an importer×industry (with two industries, “intermediate” and “final”), a regression of my tariff measure on the BEC measure and a constant obtains a regression coefficient of 0.75 (robust standard error 0.11) in levels or 1.28 (0.11) in logs.

B Econometrics

In equation (1) from the main text, trade policy t is the dependent variable and the emissions rate E is the independent variable, for three reasons: this fits with the theoretical interpretation that an industry’s emissions rate is correlated with other political determinants of trade policy; this allows empirical tests of whether the coefficient α represents correlation of CO₂ with omitted political economy variables that determine trade policy; and this allows the coefficient α to be interpreted as the implicit carbon tariff.

Alternatively, one could consider the reverse regression of the emissions rate E on the level of trade policy t . I also show some results using this reverse regression. Trade policy could potentially affect emissions intensities, either through changing import shares (e.g., affecting emissions embodied in intermediate goods) or through affecting productivity (via reallocation, entry, etc.). Some evidence for individual country liberalization episodes suggests that trade liberalization affects plant-level emissions of air or climate change pollution (Martin 2011; Cherniwchan 2017), though I am not aware of any direct evidence on how trade policy systematically affects emissions rates of global bilateral trade flows, which would an interesting subject for for future research.

The instrument is only designed to address attenuation bias due to measurement error. Omitted variables and reverse causality are not problems here because this descriptive analysis estimates the covariance of CO₂ intensity and trade policy within each country, not a causal effect of CO₂ intensity.⁷ First-stage regressions and the associated F statistics can test whether this instrument is strong. Because direct emissions constitute a large part of total emissions, this instrument is likely to be strong.

Because this instrument is designed to address measurement error, the main question for validity is whether any measurement error in direct and total emissions is independent. If so, then this instrument can eliminate attenuation bias due to measurement error. If not, then the IV estimates may be biased towards the OLS (i.e., the IV estimates will still suffer from attenuation bias, though less than OLS).

For the U.S. data, this instrument may help correct measurement error since the instrument is built from a separate dataset, MECS, which measures physical fossil fuel consumption separately by industry. Documentation of U.S. input-output tables does not mention MECS (Horowitz and Planting 2006).

In the global data, the instrument still may help address potential measurement error, but because direct and total emissions are measured from the same dataset, the instrument’s validity is not certain. Many countries’ industrial surveys collect plant-level data on electric-

⁷Since trade policy can change trade volumes, one might wonder whether reverse causality affects the weights X_{ijst} used to calculate E_{js} . This is not a primary concern here for two reasons. First, this does not change the descriptive interpretation of α in equation (1) as the association between trade policy and CO₂ intensity. Second, I report some results at the $i \times j \times s$ level, which do not require averaging over trading partners.

ity and fossil fuel expenditures, which suggests that input-output tables may measure direct emissions with limited measurement error. Usually, these surveys just ask about total expenditures on “materials” without disaggregating by sourcing industry, which suggests they may less accurately measure total emissions. Additionally, energy is typically purchased from a limited number of suppliers (in some countries, state-owned firms), and many countries survey these suppliers. At the same time, the instrument in the global data may not completely eliminate measurement error.

In some settings, using instrumental variables that completely and certainly satisfy the exclusion restriction is central to a paper’s arguments. This is not the case here, and my interpretation is that the U.S. instrument is more likely to satisfy the exclusion restriction than the global instrument is. In part the instruments are not critical here because they are solely designed to address measurement error, which is a possible but not a central concern in input-output data. Little if any prior research constructs instruments for an input-output table exclusively out of concern for measurement error. Moreover, in either the global or U.S. analysis, the qualitative conclusions from OLS are similar to those of IV estimates. The main conclusion from this analysis is that measurement error, if anything, means that the true global subsidies in trade policy could even be somewhat larger in absolute value than the large subsidies I estimate.

In equation (1), the destination country fixed effect μ_j implies that this regression compares trade policy across industries within a country. The thought experiment is a country applying similar trade policy on dirty and clean goods. This counterfactual fits the political economy of choosing trade policy, which is made by national authorities. I also show sensitivity analyses without these fixed effects. The idiosyncratic error ϵ contains all unmodeled determinants of import tariff rates.

Equation (1) does not estimate a causal effect of CO₂ intensity on tariffs. Rather, it is a descriptive regression showing the covariance of carbon intensity and trade policy within each country, and so recovers the carbon tariff implicit in trade policy. As discussed earlier, Section 5 develops the interpretation that underlying political economy forces determine tariffs as a function of variables that are omitted from equation (1); these forces are correlated with CO₂ intensity.

Limiting the main analysis to manufacturing makes the global and U.S. data consistent, since the U.S. MECS data are only available for manufacturing, and is consistent with much of the trade literature. The measure of total CO₂ intensity in all these analysis accounts for emissions embodied in intermediate goods from all sectors, not just manufacturing. I report sensitivity analyses that also include other tradable goods (agriculture and mining).

C Implicit Carbon Tariffs: Sensitivity Analyses

Appendix Table I reports numerous other estimates of the implicit CO₂ subsidies. Row 1 repeats the main estimates from Tables 2 and 3. Row 2 reports marginal effects from a tobit, since some industries have zero tariffs or NTBs. Row 3 reports an instrumental variables tobit where direct CO₂ intensity is the instrument for total CO₂ intensity. Row 4 clusters standard errors by the importing country.

Rows 5-7 report estimates that allow for nonlinear effects of CO₂. Row 5 estimates the

dependent and independent variable in logs, and so estimates an elasticity. This specification excludes observations with zero tariff or NTB. Row 6 specifies the CO₂ rate as a quadratic polynomial, and reports estimates of the slope $\partial t/\partial E$ at the 10th, 50th, and 90th percentile of the distribution of CO₂ values. Row 7 estimates a nonparametric regression (a third-order B-spline) and reports the average marginal effect.

Rows 8-15 report other ways of cleaning and aggregating data. Row 8 replaces the bottom and top percent of the dependent and independent variables as equal to the 1st and 99th percentile values. Row 9 includes non-manufactured goods (agriculture and mining), alongside the manufactured goods analyzed in most of the paper. Row 10 uses a dataset defined at the level of a bilateral trading pair and industry ($i \times j \times s$ rather than $j \times s$). Row 11 uses the same approach but adds exporter fixed effects.⁸ Row 12 aggregates to one industry per observation. Row 13 includes intra-national trade ($i = j$) in the measurement of emissions rates, with an intra-national tariff and NTB rate of zero.

Rows 14-16 use other measures of emissions. Row 14 considers only direct emissions, measured from the input-output table. Row 15 includes both the direct and total emissions, both measured from the input-output table. Row 16 uses data on all greenhouse gases and sources in Exiobase, including nitrous oxide (N₂O), methane (CH₄), and emissions of each greenhouse gas from non-combustion processes.

Rows 17-19 consider other ways of measuring the emissions rate of energy-consuming durable goods. The baseline regressions ignore emissions from goods that are complements or substitutes with the focal good. For example, changing tariffs on cereal might change consumption of milk, but the energy intensity of cereal in this analysis does not account for the energy intensity of milk. While estimating a flexible demand system of many cross-elasticities across goods in the global economy is beyond the scope of this paper, measuring emissions from consumption is potentially most important for durable goods that require energy to operate, including transportation goods like cars and appliances like air conditioners.⁹ For these goods especially, abstracting from the energy that is complementary to consuming these goods provides an incomplete picture of the emissions due to trading these goods. This is relevant because energy-consuming durables are relatively downstream and are relatively clean according to the approach of this paper.

Rows 17-19 take two approaches for energy-consuming durables. Row 17 excludes energy-consuming durable household goods from the analysis, including machinery and equipment not elsewhere classified (a category including appliances), motor vehicles, trailers, semi-trailers, and other transport equipment. Row 18 assumes that the emissions rate for these durable goods is an unweighted average of the emission rate for these durable goods and the emission rate for energy in the importing country. Row 19 assumes that the emission rates

⁸One alternative candidate explanation for tariff escalation is that countries offer preferential market access to developing countries, which specialize in upstream goods. Under this explanation, controlling for exporter fixed effects would attenuate both tariff escalation and implicit tariffs. The estimates of row 11, which include these fixed effects, are actually larger in absolute value than the estimates of row 10, which do not use these fixed effects, which could suggest that this candidate explanation is not the predominant driver of tariff escalation or of the environmental bias of trade policy.

⁹The question of how to account for emissions from consumption versus production of international services trade, such as international airplane flights, is also important. Because tariffs do not apply to trade in services, and because the [Kee et al. \(2009\)](#) data I use on NTBs cover goods and not services, I leave the analysis of NTBs involving services and the environment to future research.

for these goods is a weighted average of the emission rate for these goods and for energy in the importing country, with weights of 5 percent and 95 percent, respectively. The emission rate for energy averages over petroleum refining, natural gas extraction, and all forms of electricity production, where weights equal the gross output of each industry in the importing country. These different weighting schemes reflect evidence on the importance of emissions from manufacturing versus operation for these goods ([Union of Concerned Scientists 2013](#); [Nahlik et al. 2015](#); [Amienyo et al. 2016](#)).

Rows 20 through 25 show other sensitivity analyses. Row 20 shows the reverse regression of emissions rates E on trade policy t . Row 21 replaces the usual tariff measure on goods, dt , with a life cycle measure $(I - A)^{-1}dt$. This accounts for tariffs on inputs, and inputs to inputs, etc. Row 22 estimates the regression without importer fixed effects. Row 23 uses data from the World Input Output Dataset (WIOD). Row 24 adds industry fixed effects. Row 25 excludes manufactured agricultural goods and manufactured food products.

Most results in Appendix Table I are similar to the main estimates, though some vary in their magnitudes. I highlight some of the more important differences here. Tobit estimates obtain larger estimates of implicit subsidies for NTBs but not tariffs, since more observations have zero NTBs. The estimates that allow for nonlinearity in CO₂ rates generally find negative slope, though the magnitude differs across the support of CO₂ rates—the quadratic estimates in row 6, for example, imply a wide range of estimated global subsidies, while nonparametric estimates in row 7 imply a global subsidy of about \$100/ton. Incorporating intra-national trade (row 13) modestly increases the weighted but decreases the unweighted estimates in absolute value. Direct emissions have a similar association with trade policy as total emissions do; when a regression includes both, the coefficient on total emissions accounts for more of the total subsidy, though neither estimate is precise, perhaps in part due to multicollinearity. Excluding energy-consuming durable goods from the analysis or adjusting emission rates of these goods to account for energy used in their consumption does not substantially change the estimated subsidy in absolute value. The reverse regression has smaller coefficients since it reverses the dependent and independent variables. The WIOD data still imply subsidies but are imprecise, partly because they only have 15 tradable manufacturing industries. Adding industry fixed effects nearly eliminates the implicit subsidy. This is perhaps unsurprising since industry-level estimates in row 12 are similar to baseline estimates in row 1, though this does suggest that whatever economic forces create these subsidies operate at the industry level and are similar within an industry and across countries. Excluding agricultural and food manufactured products produces smaller estimates of the implicit subsidies.

Appendix Table I, rows 26-27, focus on the recent trade war by analyzing U.S. import tariffs at the end of 2018. Row 26 estimates the implicit subsidy for U.S. import tariffs using tariff data from 2017, as in Figure II. Row 27 augments these data with the sum of five rounds of tariffs imposed in 2018, which targeted washers, solar panels, aluminum, and Chinese imports. I measure these tariffs using data from [Fajgelbaum et al. \(2020\)](#). Unweighted estimates show a modest decrease in trade policy’s environmental bias, of nearly a dollar a ton, while weighted estimates show a smaller increase. These estimates are mixed because while much attention focused on dirty goods like aluminum or steel, the most CO₂-intensive goods like refined petroleum and cement did not experience tariff changes in this time period. Some goods with larger increases in tariffs in this period, like semiconductor

manufacturing or laundry equipment manufacturing, are not especially CO₂-intensive. Row 28 repeats the estimates of row 27, but controls for each industry’s upstreamness. Even in 2018, controlling for upstreamness still eliminates the estimated association between trade policy and CO₂ intensity.

I also separately analyze subsidies to CO₂ implicit in cooperative versus non-cooperative tariffs. Some non-members of the World Trade Organization face higher tariffs not negotiated cooperatively. The tariff data report non-cooperative tariffs for three importers—the U.S., Japan, and China. The U.S. calls these “Column 2” tariffs; China and Japan call them “general rate” tariffs (see Online Appendix A.4).

Appendix Table II shows evidence of implicit carbon subsidies in both cooperative and non-cooperative tariffs. This suggests that whatever political economy force creates these implicit subsidies must operate for both cooperative and non-cooperative policy. The U.S. has a CO₂ subsidy of \$4.50 to \$6/ton in cooperative tariffs and a subsidy of \$60 to \$80/ton in non-cooperative tariffs. Consistent with Figure IV, China does not have a clear implicit subsidy in most of its tariffs. Japanese tariff rates are similar across the two types of tariffs, and correspondingly, the estimated implicit CO₂ subsidy in Japan is generally similar for non-cooperative and cooperative tariffs.

C.1 Political Economy Causes: Sensitivity Analyses

Appendix Table IV shows sensitivity analyses. Panels A, B, and C show that weighted regressions are qualitatively similar to the unweighted versions. Controlling for upstreamness attenuates the global estimated subsidy in trade policy from -\$87 to \$6. The instruments are strong for upstreamness, the labor share, and mean wages. The weighted estimates have weaker instruments for the other explanations, which may bias these estimates towards the OLS values. One might wonder whether the correlation between total CO₂ and upstreamness reflects measurement error in the input-output table, since both upstreamness and total CO₂ emissions are measured from the input-output table. U.S. direct CO₂ emissions are not subject to this concern, since they are measured from completely distinct data (MECS) and not from the input-output table. Panels D and E show that OLS estimates using direct CO₂ emissions are similar to IV estimates for total CO₂ emissions. Controlling for upstreamness in column (2) attenuates the correlation between CO₂ emissions and trade protection by more than 90 percent. Again, controlling for the other political economy variables matters much less.

Appendix Table V reports regressions controlling for all these political economy explanations at once. Columns (1) through (3) show estimates for all global trade. Columns (4) and (5) show estimates for U.S. imports only. The U.S. has data on more political economy explanations. Columns (1), (2) and (4) use linear instrumental variables regression, while columns (3) and (5) use Lasso with instrumental variables (Belloni et al. 2016). All these regressions instrument total CO₂ intensity with direct CO₂ intensity. To ease interpretation of coefficients for the controls, I have re-scaled all except CO₂ intensity to be z-scores (i.e., subtracting the mean and dividing by the standard deviation). I leave CO₂ intensity in tons/\$ rather than z-scores to facilitate comparison with other tables.

These estimates suggest that other political economy forces, and especially upstreamness, account for an important share of the association between CO₂ intensity and trade policy.

These estimates find negative associations between trade policy and CO₂ intensity that are smaller than in estimates without political economy controls. Controls attenuate the association between CO₂ and trade policy to \$-25 to \$-28 and render it statistically insignificant (Appendix Table V).

All the estimates in Appendix Table V identify upstreamness as a strong predictor of trade policy, even conditional on the other political economy variables. Upstreamness is the only explanation for which this is true. Upstreamness also has large magnitude effects on trade policy. In the global data, Lasso retains only the CO₂ rate and upstreamness. In the U.S. data, Lasso retains only three variables in the selected model: CO₂ intensity, upstreamness, and shipping costs.

D Informal Discussion of Trade Policy Theories

This Appendix informally discusses how theories of trade policy might rationalize the paper's findings. It is useful to distinguish two reasons why countries choose trade policy. One is to exploit market power and terms-of-trade externalities. Another is to satisfy domestic industries which lobby for high tariffs on their output.

Some trade policy instruments, like NTBs and non-cooperative tariffs, are chosen independently by countries and are typically not negotiated with other countries. In theories of explaining such non-cooperative trade policy ([Grossman and Helpman 1994](#); [Goldberg and Maggi 1999](#)), both the terms-of-trade externality and political economy forces determine tariffs. In these frameworks, governments value the welfare of their citizens, which decreases overall with protection, but governments also value campaign contributions and other support from industry, which increases with the protection industries receive. These frameworks can accommodate industries' lobbying for low tariffs on industries they use as intermediate inputs ([Gawande et al. 2012](#)). The finding of implicit carbon subsidies in non-cooperative policy instruments, and the empirical relevance of upstreamness, are consistent with these theories.

Other trade policy instruments, like most tariffs, are cooperatively chosen by countries through negotiation. Research has provided two broad explanations for why countries cooperate on trade policy ([Grossman and Helpman 1994](#); [Maggi and Rodríguez-Clare 1998, 2007](#)). One is that cooperation helps decrease terms of trade externalities, though not necessarily the political economy components of trade policy. A second explanation for cooperation is that governments understand the political pressure of trade lobbies and the welfare costs of protection. In this explanation, governments commit to free trade agreements in order to tie their hands and obtain a more efficient domestic allocation of resources across industries, while limiting the resulting political cost.

In all these cooperative theories, political economy motives like lobbying for low upstream tariffs potentially remain an important determinant of non-cooperative and cooperative trade policy. In [Grossman and Helpman \(1995\)](#), cooperation does not change political economy motives for trade policy. In the commitment theory, negotiation may attenuate but not eliminate political economy's effects on trade policy. These interpretations suggest that lobbying competition between upstream and downstream industries may occur in both cooperative and non-cooperative policies, and extends beyond any single model.

Another general interpretation of this is as follows. A goal of cooperative trade policy negotiation (e.g., through the World Trade Organization) is to eliminate one externality – the terms-of-trade motive for trade policy – which leaves political economy motives remaining. This paper highlights that those negotiations, however, leave a second externality untouched—an environmental externality which arises from political economy forces behind trade policy.

To be concrete about why counter-lobbying might create tariff escalation, consider the example of a fairly upstream industry like steel and a fairly downstream good like cigarette manufacturing. Many industries use steel as an input, either directly (they purchase steel) or indirectly through global value chains (they purchase goods which use steel as an input, or goods which use inputs which use steel as an input, etc.). Hence, many industries will lobby for low tariffs and low NTBs on steel. By contrast, few industries use cigarettes as an input, and hence few industries will lobby for low tariffs or low NTBs on cigarettes. Final consumers might prefer low tariffs and low NTBs on both steel and cigarettes, but final consumers are less well organized than industries, and hence have less lobbying influence. Thus, countries end up with lower tariffs or NTBs on steel, and higher tariffs or NTBs on tobacco products.¹⁰

Finally, it is worth discussing one potential explanation from public finance. [Diamond and Mirrlees \(1971\)](#) consider commodity taxation in a general setting. Even in a second-best world where the government uses (distortionary) linear commodity taxes, which imply that the first-best Pareto optimal outcome is infeasible, they show that the optimal tax system maintains the economy at the production possibilities frontier. A corollary is that optimal commodity taxes apply only to final and not intermediate goods.¹¹

Based on this theorem, one might conjecture that tariff escalation has an efficiency rationale. This interpretation might claim that downstream goods are final goods, and that tariff escalation seeks to maintain production efficiency by putting tariffs on final rather than intermediate goods. In this interpretation, while upstreamness accounts for trade policy's environmental bias, the link between upstreamness and trade policy could be caused by government's desire for an efficient tax system rather than by lobbying. Additionally, if tariff escalation reflected efficiency rather than political economy forces, then harmonizing tariffs between upstream and downstream goods could decrease production efficiency even if it benefited the environment.

Two reasons suggest that production efficiency does not explain the prevalence of tariff escalation. First, I find similar escalation in NTBs as in tariffs. NTBs do not raise revenue, so optimal taxes would not include NTBs, except to the extent that they address market failures. Hence, production efficiency does not explain why NTBs exist or have escalation. Second, the production efficiency theorem does not rank the efficiency of different second-

¹⁰In the global data, weighted across countries by the value of imports, steel has a mean upstreamness value of 3.5, tariff of 1.3 percent, and NTB ad valorem equivalent of 1.5 percent. Tobacco products has upstreamness of 1.2, tariff of 9.8 percent and NTB ad valorem equivalent of 43 percent. These are among the most and least upstream industries in Exiobase.

¹¹One intuitive explanation is that under constant returns to scale, any tax on intermediate goods would appear through changes in final goods prices. Then the government could collect the revenue through this tax on final goods. But because taxing intermediate goods prices distorts firms' input choices, it moves the economy away from production efficiency ([Diamond and Mirrlees 1971](#), p. 24).

best tax systems by the degree to which they tax intermediate goods. This theory does not permit stating that a tax or tariff structure which has more escalation is more efficient; it merely states that the optimal tax system has no taxes on intermediate goods.¹²

E Quantitative General Equilibrium Model

This section resembles the analytical model from the main text, but it allows for many asymmetric countries and industries, specifies the functional form of climate damages, allows for different CO₂ intensity from different industries, allows for deficits, and allows the trade elasticity to vary by industry.

E.1 Model Structure

Assumptions

Preferences are as in equation (5) from the main text. While it is common to assume CES preferences across varieties within a sector and Cobb-Douglas preferences across sectors in a static model, this does impose strong assumptions on the drivers of CO₂ emissions. For example, as mentioned in the introduction, increasing the purchase price of energy-intensive durable good like air conditioners may lead consumers to use existing appliances longer, which is a type of consumption substitution not modeled here. I do report a number of sensitivity analyses involving energy-consuming durable goods specifically, but more broadly, it is important to recognize that the common combination of CES and Cobb-Douglas preferences imposing strong restriction on potential consumption and emissions patterns.

I specify the functional form of climate damages as

$$f(Z) = [1 + \delta(Z - Z_0)]^{-1} \tag{E.1}$$

Here δ represents a damage parameter, Z_0 represents a reference or baseline level of global CO₂ emissions used to calibrate the damage parameter, and Z represents the global emissions in a particular scenario.

Several reasons support using this functional form for climate damages. It makes damages multiplicative, which facilitates the analysis of counterfactuals using ratios. It also makes damages proportional to real income. It permits calibration of the climate damage parameter δ so that a one-ton increase in CO₂ emissions decreases global welfare by \$40 in the year 2007, which corresponds with prevailing estimates from the climate change literature ([IWG 2016](#)). Additionally, it provides a simple functional form to accomplish these objectives. This specification measures damages from emission changes only, since in baseline data, $Z = Z_0$, so the model abstracts from baseline climate damages.

In the data I analyze, shipping represents a separate industry, which is connected through input-output links to other industries (see Appendix Table VII). An alternative approach

¹²A related potential explanation is that distortions in the economy aggregate through upstream input purchases, so an efficient industrial policy would subsidize upstream sectors ([Liu 2019](#)). This interpretation would argue for direct production subsidies rather than trade policies, and it also would not apply to an undistorted economy already at the first-best.

would be to model shipping and associated emissions directly as a component of trade costs, as in Shapiro (2016). I leave shipping as an industry rather than as a component of trade costs since this approach allows shipping costs to adjust endogenously in the model due to counterfactual policies, since this approach still accounts for oil use different energy intensity of shipping across countries and goods (through the technology summarized in input-output links), and since this lets me directly use the input-output table as reported in data, rather than having to manually adjust it to remove shipping as a component of trade costs but not an industry.

Technology is as in equation (7) from the main text. I include a non-traded sector; one could interpret this as a sector within infinite trade costs.

The pollution emitted to sell goods to a particular destination j are

$$Z_{ijs} = \gamma_{is} \frac{X_{ijs}}{c_{is}(1 + t_{ijs})} \quad (\text{E.2})$$

The coefficient γ_{is} equals the CO₂ intensity of output in country i and sector s . This parameter γ equals zero for all industries besides coal extraction, oil extraction, and natural gas extraction. For these three fossil fuel extraction industries, γ equals the metric tons of CO₂ per real dollar of output of a given fossil fuel in a given country.

Equations (14) and (15) from the main text may help clarify one important channel which the analytical model misses but equation (E.2) captures. Traded goods tend to be more pollution-intensive than domestically purchased goods, both due to long-distance transportation and because trade tends to relocate energy-intensive goods production to countries like China which are relatively pollution intensive. This effect tends to amplify the effect of decreasing energy-intensive exports—not only does the counterfactual make countries emit less to produce goods for export, but a dollar of goods produced for export tends to emit more pollution than a dollar of goods for domestic production.

Exports equal imports minus trade deficits:

$$\sum_{j,s} \frac{X_{ijs}}{1 + t_{ijs}} = \sum_{j,s} \frac{X_{jis}}{1 + t_{jis}} - D_i \quad (\text{E.3})$$

Apart from allowing for deficits, equilibrium is as in the main text.

Baseline Equilibrium

The country×sector price index and unit cost function are as in equations (6) and (7).

The data report the value of bilateral trade in intermediate goods between each pair of origin and destination countries i and j and selling and buying industries s and k , \tilde{Z}_{ijsk} . I use the tilde ($\tilde{\cdot}$) to highlight that these raw values from the data exclude tariffs. Data also report final goods trade, indexed by selling but not buying industry, \tilde{F}_{ijs} . Define the value of total bilateral trade as $\tilde{X}_{ijs} = \tilde{Z}_{ijs} + \tilde{F}_{ijs}$. Below, I work with tariff-inclusive values of these variables, $X_{ijs} \equiv \tilde{X}_{ijs}(1 + t_{ijs})$, $Z_{ijs} \equiv \tilde{Z}_{ijs}(1 + t_{ijs})$, and $F_{ijs} \equiv \tilde{F}_{ijs}(1 + t_{ijs})$.

Baseline expenditure is similar to the main text but accounts for trade deficits:

$$X_{js} = \beta_{js}(Y_j + D_j + T_j) + \sum_k \alpha_{jsk} R_{jk} \quad (\text{E.4})$$

Substituting tariff revenues $T_j = \sum_{i,s} X_{ijs} t_{ijs} / (1 + t_{ijs})$ and the gravity equation (9) into the country×sector expenditure equation (E.4) then simplifying gives the following expression that I use for analyzing counterfactuals:

$$X_{js} = \beta_{js} \left(\frac{Y_j + D_j + \sum_{i,l} \frac{t_{ijl}}{1+t_{ijl}} \lambda_{ijl} (\sum_k \alpha_{jlk} R_{jk})}{1 - \sum_{i,l} \frac{t_{ijl}}{1+t_{ijl}} \lambda_{ijl} \beta_{jl}} \right) + \sum_k \alpha_{jks} R_{jk} \quad (\text{E.5})$$

Several terms here deserve explanation. I measure final good expenditure shares as $\beta_{js} = \sum_i F_{ijs} / \sum_{i,s} F_{ijs}$. Value added in a particular country×sector equals the country×sector revenue minus total intermediate inputs: $Y_{js} = R_{js} - \sum_i Z_{ijs}$. Value-added can also be written as the Cobb-Douglas cost share of factors times country×sector revenue:

$$Y_{js} = (1 - \alpha_{js}) R_{js} \quad (\text{E.6})$$

Deficits equal $D_j = \sum_s D_{js}$, where $D_{js} = \sum_i X_{ijs} / (1 + t_{ijs}) - R_{js}$. The intermediate good cost share in country j of industry s in producing goods from industry k is $\alpha_{jks} = Z_{jks} / R_{jk}$, where Z_{jks} is the value of intermediate goods from industry s used to produce goods in industry k and country j . The share of value added from an industry is $y_{js} \equiv Y_{js} / Y_j$. These shares sum to one:

$$\sum_s y_{js} = 1 \quad (\text{E.7})$$

Counterfactual Equilibrium

I rewrite these equations in changes. From equation (7), the cost function is the proportional change in wages and intermediate goods prices, scaled by their Cobb-Douglas expenditure shares:

$$\hat{c}_{is} = \hat{w}_i^{1-\alpha_{is}} \prod_k \hat{P}_{ik}^{\alpha_{iks}} \quad (\text{E.8})$$

The change in trade costs reflects counterfactual tariffs and NTBs:

$$\hat{\phi}_{ijs} = \frac{(1 + t'_{ijs})(1 + n'_{ijs})}{(1 + t_{ijs})(1 + n_{ijs})}$$

From equation (E.5), the counterfactual change in expenditure is calculated from

$$\hat{X}_{js} X_{js} = \frac{\beta_{js} \left(\hat{w}_j Y_j + D_j + \sum_{i,l} \frac{t'_{ijl}}{1+t'_{ijl}} \hat{\lambda}_{ijl} \lambda_{ijl} \sum_k \alpha_{jlk} \hat{R}_{jk} R_{jk} \right)}{1 - \sum_{i,l} \frac{t'_{ijl}}{1+t'_{ijl}} \hat{\lambda}_{ijl} \lambda_{ijl} \beta_{jl}} + \sum_k \alpha_{jks} \hat{R}_{jk} R_{jk}$$

Several terms in this equation deserve explanation. Because I use global GDP as the numeraire, this treats baseline trade deficits D_j as a constant share of world GDP in any counterfactual. Counterfactual revenues equal total bilateral sales to foreign and domestic customers:

$$\hat{R}_{is} R_{is} = \sum_j \frac{X'_{ijs}}{1 + t'_{ijs}} \quad (\text{E.9})$$

From equation (E.6), counterfactual revenues can be calculated as $\hat{R}_{is}R_{is} = \hat{w}_i\hat{y}_{is}y_{is}Y_i/(1 - \alpha_{is})$. From equation (9), bilateral sales can be calculated as $X'_{ijs} = \hat{\lambda}_{ijs}\lambda_{ijs}\hat{X}_{js}X_{js}$. From equation (E.7), counterfactual industry shares are given by

$$\sum_s \hat{y}_{is}y_{is} = 1 \quad (\text{E.10})$$

The numeraire can be expressed as $\sum_i \hat{Y}_i Y_i = 1$.

For baseline data, these equations hold exactly. Under counterfactual tariffs or NTBs, I solve this system to find the values $(\hat{c}_{is}, \hat{y}_{is}, \hat{w}_i)$ that make equations (E.8), (E.9), and (E.10) hold with equality. I use these to find the resulting change in real income, which can be written as

$$\hat{V}_j = \frac{Y_j + \widehat{D_j} + T_j}{\hat{P}_j}$$

From equation (E.2), I calculate the change in pollution and social welfare:

$$\begin{aligned} \hat{Z}_i &= \frac{\sum_s \gamma_{is} \hat{R}_{is} R_{is} / \hat{c}_{is} c_{is}}{\sum_s \gamma_{is} R_{is} / c_{is}} \\ &= \frac{\sum_s (\hat{R}_{is} / \hat{c}_{is}) Z_{is}}{\sum_s Z_{is}} \end{aligned}$$

Finally, the change in social welfare is

$$\hat{W}_j = \frac{\hat{V}_j}{[1 + \delta(Z' - Z_0)]}$$

E.2 General Decomposition

I first show a single equation including all the channels, and then discuss a diagram that highlights each channel separately. We can write the change in pollution emissions due to a counterfactual trade policy as follows:

$$\hat{Z}_s = \left[\sum_i \frac{\hat{X}_{i,s}^F X_{i,s}^F + \hat{X}_{i,s}^I X_{i,s}^I}{\hat{c}_{i,s} X_{i,s}} \hat{\lambda}_{ii,s} \frac{Z_{ii,s}}{Z_s} \right] + \left[\sum_{i,j \neq i} \frac{\hat{X}_{j,s}^F X_{j,s}^F + \hat{X}_{j,s}^I X_{j,s}^I}{\hat{c}_{i,s} X_{j,s}} \hat{\lambda}_{ij,s} \frac{Z_{ij,s} / (\widehat{1 + t_{ijs}})}{Z_s} \right] \quad (\text{E.11})$$

$$\hat{Z} = \frac{\sum_s \hat{Z}_s Z_s}{\sum_s Z_{i,s}} \quad (\text{E.12})$$

Equation (E.11) describes the change in emissions from fossil fuel s (coal, oil, or gas) due to extraction of that fuel in country i . Equation (E.12) shows how the total change in a country's emissions is a weighted sum of changes in emissions across fuels, weighted by baseline emission shares of each fuel. Of course, changing production of other industries affects these three fuels through input-output links, factor prices, and other channels.

Comparing equation (E.11) with equation (14) from the analytical model of the main text shows obvious parallels. Indeed, with two symmetric countries and two industries, and

without separating expenditure into its component on final and intermediate goods, equation (E.11) simplifies to equation (14). The analytical model also discusses a second equation (15) for the change in emissions. While an analogous derivation is straightforward here, with many asymmetric countries the resulting equation is cumbersome and provides less insight.

Appendix Figure IV separates equation (E.11) into several components. This figure describes the equations for coal, but the terms are identical for each fossil fuel. Similarly, I have written out all the terms for domestic coal sales only, but could write out similar terms for coal exports. Each term in this figure represents the proportional change in one channel due to a counterfactual policy. The numbers in parentheses refer to columns in Appendix Table IX.

In Appendix Figure IV, term (1) shows the first breakdown—the change in total emissions from coal can be decomposed into the change in coal that is burned domestically and coal that is exported. This is an exact decomposition because total emissions from coal equal the weighted sum of emissions for domestic sales and exports, weighted by baseline emission shares. These two channels correspond to the two terms in equation (E.11) above.

Terms (2) and (3) of Appendix Figure IV show that the change in emissions due to domestically sold coal combines two channels—one due to the change in coal prices (the “price index channel”) and the other due to change in nominal coal sales (the “nominal revenue channel”). This is not an exact decomposition—one cannot take sums or products of these two channels to obtain the exact change in emissions for domestic sales. One could think of this as turning off certain channels in this general equilibrium model, and assessing how the other channels contribute to the result.

Terms (4) through (6) of Appendix Figure IV show that the change in nominal revenues consists of three channels. Term (4) reflects the change in the share of expenditures going to domestic rather than foreign sellers ($\hat{\lambda}_{ii,s}$). Term (5) reflects the direct effect of the change in tariffs ($1/\widehat{(1+t_{ii,s})}$), which change the wedge between consumer spending and firm revenues. Of course, because I assume intra-national tariffs are zero, this channel does not operate for domestic sales, though it does for exports. Term (6) reflects the change in country×sector expenditure ($\hat{X}_{j,s}$). Finally, terms (7) and (8) separate the change in country×sector expenditure into the change in expenditure on final versus intermediate goods.

Appendix Table IX presents the numerical results of this decomposition. This is a decomposition of the effect of each country harmonizing tariffs and NTBs, as in the main text. Each column number in Appendix Table IX corresponds to the term of the same number in Appendix Figure IV. Panels A, B, and C show patterns for oil, natural gas, and coal separately. Column (9) shows total baseline emissions in billions of metric tons CO₂ (GtCO₂); these values add up to about 30 billion tons, which is close to published measures of total CO₂ emissions from fossil fuel combustion in the year 2007.

Panel A of Appendix Table IX describes how this counterfactual affects emissions from oil, which account for 37 percent of baseline emissions. Column (1) shows that the counterfactual decreases emissions from exported oil by 8 percent, and decreases emissions of domestically sold oil by 1 percent. This is intuitive—because the counterfactual makes trade policy on energy-intensive goods (including oil) more stringent, emissions from trade in these goods declines. Columns (2) and (3) show that most of the change in emissions from exports

reflect a nominal change in spending on oil, rather than a change in the price of oil. This separation is relevant since emissions reflect the real rather than nominal amount of oil crossing international borders. Column (4) shows that the change in oil exports is primarily due to reallocation of spending between foreign and domestic sources, i.e., $\hat{\lambda}_{ijs}$. Column (5) shows that the direct effect of trade policy is a minority of the total change in the value of international trade in oil. Column (6) shows that the total change in spending on oil is small, and columns (7) and (8) show that it is due about equally to lower spending oil as both a final and intermediate good.

These patterns in Pattern A of Appendix Table IX give a rule of thumb to interpret the large decrease in emissions from oil. Recalling that $\hat{\lambda}_{ijs} = (\hat{c}_{is}\hat{\phi}_{ijs}/\hat{P}_{js})^{-\epsilon_s}$ and noting that the price index channel in column (2) has small magnitude, suggest that the direct effect of changing trade costs, $(\hat{\phi}_{ijs})^{-\epsilon_s}$, accounts for a large share of the change in oil sales.

One might expect this decrease in emissions from internationally traded oil to be offset by an increase in domestic sales of oil, yet Panel A of Appendix Table IX suggests that this does not occur. Why? Two forces do increase emissions of domestically sold oil—column (4) shows that the counterfactual makes domestic purchases represent a larger share of expenditure on oil, and column (7) shows that expenditure on oil as a final good increases slightly, due to the additional tariff revenue the increase in oil tariffs provides. However, other forces outweigh these channels: column (2) shows that the price of oil increases, which decreases the real value of spending on oil and thus emissions from it; and column (8) shows that spending on oil as an intermediate good falls, due in part to the decrease in demand from other energy-intensive industries.

Natural gas has fairly similar patterns to oil, though the magnitudes vary. Emissions from traded natural gas fall by 13 percent, while emissions from domestically sold natural gas fall by 1 percent. The direct effect of tariffs on trade in natural gas accounts for much of this change (column 4). The increase in prices of natural gas tends to decrease emissions (column 2), and changes in emissions from natural gas as a final and intermediate goods somewhat offset each other (columns 7 and 8).

Coal has somewhat different patterns, for a specific reason. India's import tariffs on coal in 2007 were 50 percent, higher than most other Indian import tariffs and higher than import tariffs on coal in other countries. In the years since, India has decreased its import tariffs on coal. Nonetheless, because this counterfactual harmonizes tariffs for each importer across industries, this counterfactual decreases India's tariffs on coal by more than 40 percentage points. This single channel is large enough to increase emissions from internationally traded coal substantially, and decrease emissions from domestically purchased coal. Because trade in coal is only about 10 percent of coal in baseline data, however, the rapid percentage growth in exports has limited effects on total global emissions. The decrease in demand for coal as an intermediate good also substantially decreases global emissions.

E.3 Scale, Composition, and Technique Decomposition

Write global pollution Z as the product of total global output X , the share κ of global output that comes from each industry, and the emissions e per unit output for each industry: $Z = X\kappa'e$. Totally differentiating gives $dZ/Z = dX/X + d\kappa/\kappa + de/e$. The first term on the right-hand side here is the scale effect, the second term is the composition effect, and

the third is the technique effect. While this model has no technical change, this is a global decomposition of country×industry data, so the technique effect in part reflects reallocation of production within an industry across countries with different technologies.

I implement this decomposition as follows. I measure composition as the baseline CO₂ intensity of each industry, weighted by the change in the industry’s share of global output:

$$\text{Composition Effect} = \sum_s \left[\frac{\sum_i Z_{is}}{\sum_i R_{is}} \cdot \frac{\sum_i \hat{R}_{is} R_{is} (\hat{P}_{iis})^{-1}}{\sum_{i,s} \hat{R}_{is} R_{is} (\hat{P}_{iis})^{-1}} \right] \left(\frac{\sum_{i,s} Z_{is}}{\sum_{i,s} R_{is}} \right)^{-1} - 1$$

Here R_{is} , Z_{is} , and P_{is} represent a country×industry’s revenue, pollution emissions, and price index, respectively. The first ratio in this expression is the baseline global emissions intensity of industry s . The second ratio is the change in the real global output of this industry, divided by the change in global output of all industries. I multiply these and sum over industries, which provides the change in emissions intensity that would have occurred with observed changes in composition (second ratio) valued at baseline emissions intensities (first ratio). The third ratio is the inverse of the global baseline emissions intensity, so that the composition effect represents a percentage change relative to baseline intensity. I measure the scale effect as the change in real global output:

$$\text{Scale Effect} = \frac{\sum_{i,s} \hat{R}_{is} R_{is} (\hat{P}_{iis})^{-1}}{\sum_{i,s} R_{is}} - 1$$

I measure the technique effect as a residual, equal to the counterfactual change in emissions, minus the scale effect and minus the composition effect:

$$\text{Technique Effect} = \frac{\sum_{i,s} Z'_{is}}{\sum_{i,s} Z_{is}} - 1 - \text{Scale Effect} - \text{Composition Effect}$$

E.4 Other Counterfactual Results

For the main counterfactual, Panel A of Appendix Table VIII reports sensitivity analyses. I report results using trade elasticities from [Caliendo and Parro \(2015\)](#), allowing for a larger elasticity of substitution of two across the energy sectors (coal, gas, petroleum, and electricity; the elasticity in baseline estimates is assumed to be one due to the baseline Cobb-Douglas functional form); and using two alternative numerical algorithms. Most of these estimates find broadly similar results to the main estimates. The change in global emissions is about equally from tariffs and NTBs.

The main text uses the quantitative model to study one counterfactual, and here I discuss several others. In the second counterfactual, only the EU imposes this policy change: $t'_{ijs} = \sum_s t_{ijs} X_{ijs} / \sum_s X_{ijs} \forall i \neq j; j \in EU$; $t'_{ijs} = t_{ijs} \forall j \notin EU$. Harmonizing EU trade policy between clean and dirty industries may be somewhat politically feasible since the EU has a domestic climate change policy, is concerned about leakage, and supports strong environmental policies.

The third and fourth counterfactuals compare the consequences of changing tariffs and NTBs to the levels of clean versus dirty industries. Specifically, for each country separately,

the third counterfactual increases tariffs to the mean tariff for the cleanest third of industries, and the mean NTB to the mean NTB for the cleanest third of industries. The fourth counterfactual undertakes the same exercise, but for the dirtiest third of industries.

In the fifth counterfactual, all countries add a carbon tariff to existing policy: $t'_{ijs} = T_{ijs} + E_{ijs}d$. Here, E_{ijs} is the emission rate and d is damages chosen to reflect the global externality from CO₂ emissions (\$40/ton). In the sixth counterfactual, all countries set tariffs and NTBs to zero: $t'_{ijs} = 0 \forall i, j, s$.

I also investigated a counterfactual which holds trade policies for transportation equipment fixed. This obtains similar results to the main counterfactual—global CO₂ emissions fall 3.8 percent and real income increases 0.7 percent. As emphasized earlier, this model analyzes fossil fuel from production rather than consumption, so the primary policies affecting oil demand in the model are those that affect shipping and that affect heavy-long distance trade which tends to be oil intensive.

Appendix Table VIII presents the results of these other counterfactual analyses. Panel B considers the second counterfactual, in which the EU harmonizes trade policy between clean and dirty goods. The effects of the EU policy resemble those of the global policy from Table V, but the magnitudes are smaller. This counterfactual EU policy would decrease global CO₂ emissions by 1.8 percentage points while increasing global real income by 0.3 percentage points. Although global emissions fall, most of the increase in emissions is from within the EU, which reflects the idea that the subsidies in trade policy this paper highlights are global—low baseline EU tariffs and NTBs on dirty goods increases emissions from outside the EU, and hence increasing those tariffs and NTBs tends to increase emissions from inside the EU (though produce larger decreases from outside the EU).

Appendix Table VIII, Panels C and D, show the effects of harmonizing trade policy to the levels of clean versus dirty goods. Both counterfactuals decrease global CO₂ emissions, by 2.5 to 3.8 percent. Real income increases slightly in both counterfactuals, so global CO₂ intensity falls by 4 percent. These counterfactuals suggest that harmonizing trade policy between clean and dirty goods can decrease global CO₂ emissions, regardless of whether the counterfactual trade policy is changed to the level that clean or dirty goods initially face.

Appendix Table IX, Panel E, considers a counterfactual in which all countries impose a carbon tariff, i.e., increase existing tariffs by the marginal damage of CO₂ emissions embodied in trade policy and leave NTBs unchanged. This decreases global emissions by 2.5 percent.

Appendix Table VIII, Panel F, eliminates import tariffs and NTBs. This policy reform increases real income by 2.6 percent, which is large enough to cause an increase in global CO₂ emissions. Here, the scale effect dominates any other effects of this policy on CO₂ emissions.

Why do some counterfactuals increase real income but decrease global CO₂ emissions? This happens because these reforms address two market failures—trade policy and global CO₂ emissions. Eliminating or harmonizing trade policy across goods can increase real income. Because trade policy encourages consumption and production of dirty goods, eliminating this price signal also decreases consumption and production of those dirty goods.

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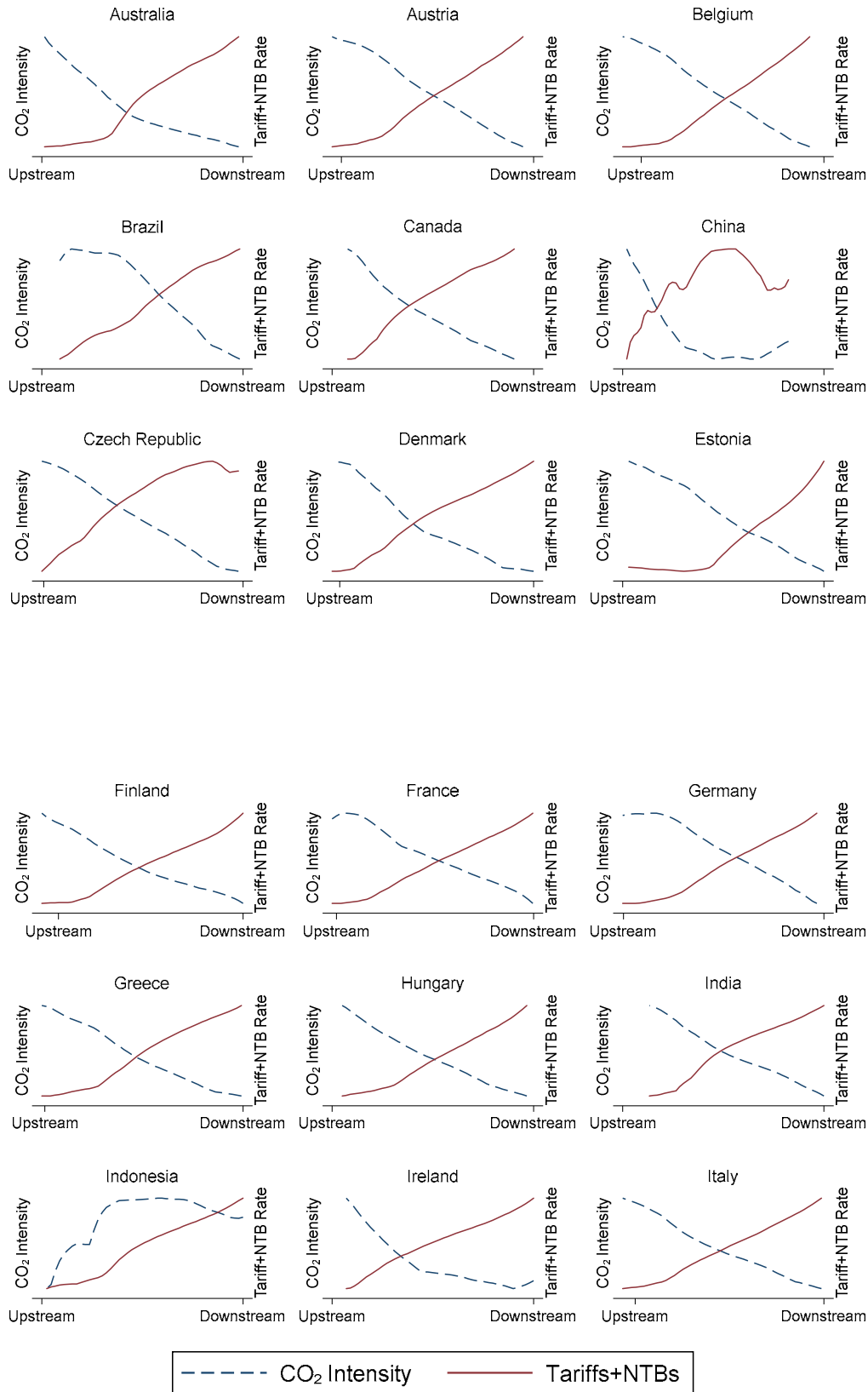
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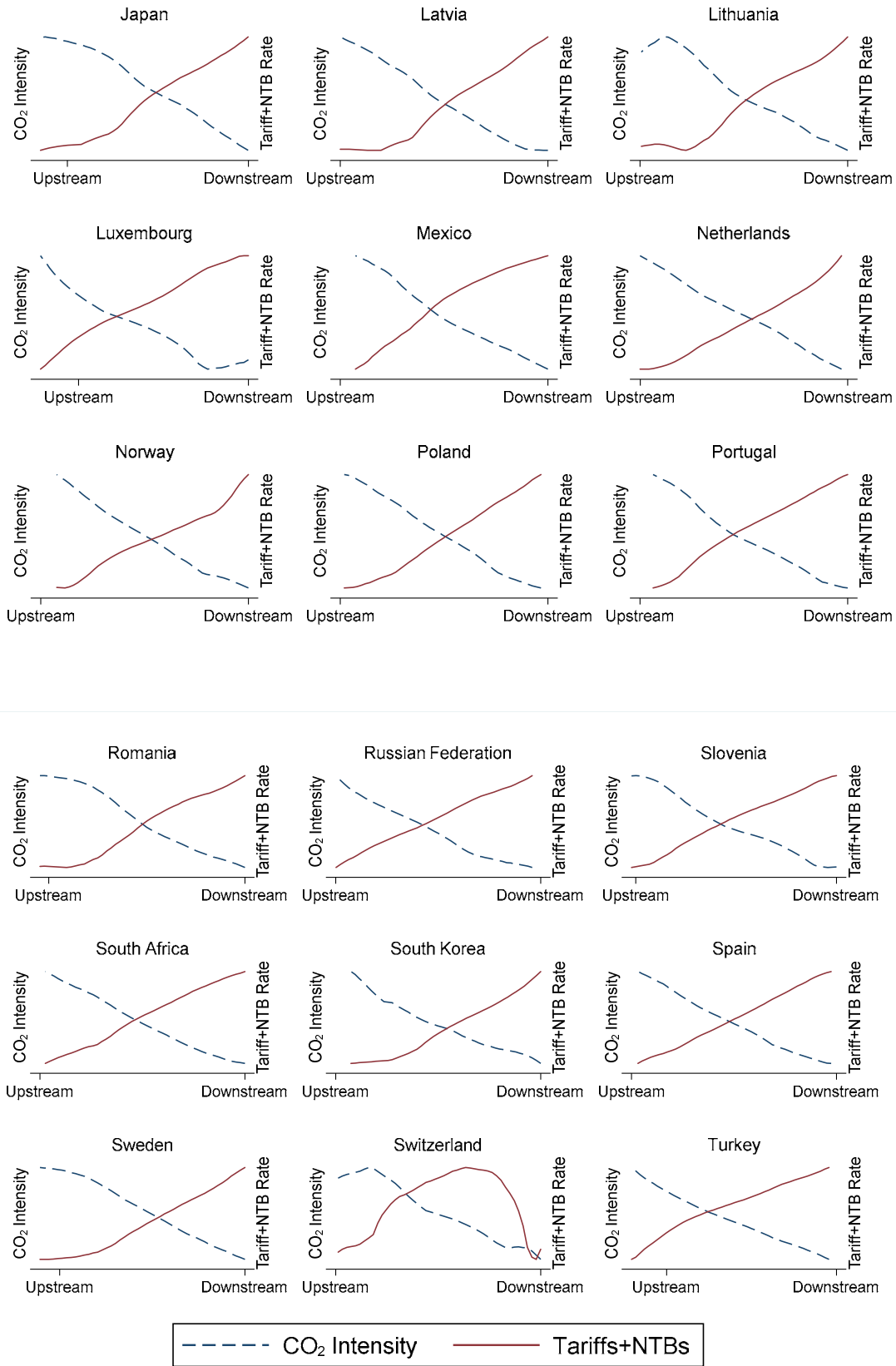
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APPENDIX FIGURE I
Upstream Location, CO₂ Intensity, and Trade Policy, by Country

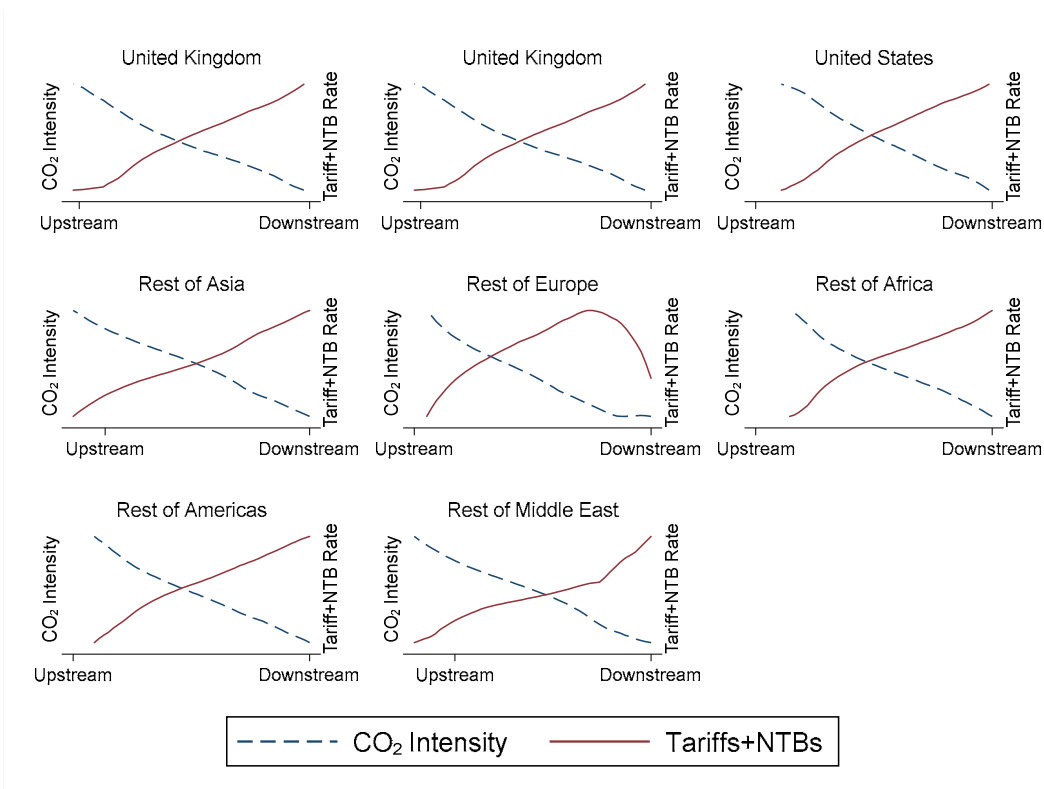


APPENDIX FIGURE I

Upstream Location, CO₂ Intensity, and Tariff Rates, by Country (Continued)



APPENDIX FIGURE I
Upstream Location, CO₂ Intensity, and Tariff Rates, by Country (Continued)

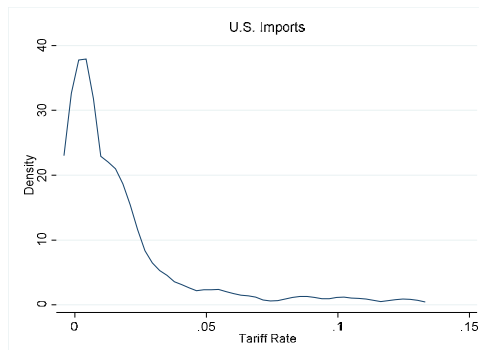
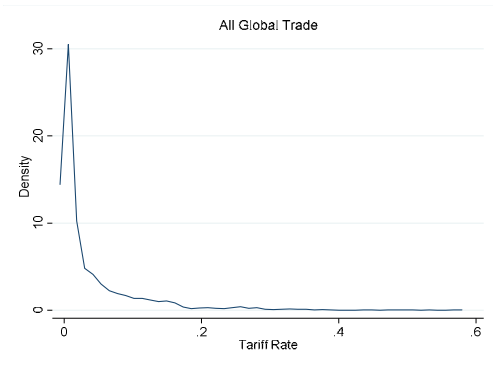


Notes: In each graph, the solid red line is from a local linear regression of import tariffs on the industry's upstreamness. The dashed blue line is from a local linear regression of CO₂ intensity on the industry's upstreamness. Upstreamness is the simple measure of the share of an industry's output sold to other industries as intermediate goods (rather than as final demand). All data from Exiobase. All regressions use an Epanechnikov kernel with bandwidth of 0.75. Bulgaria, Cyprus, Malta, Slovakia, and Taiwan are missing NTB rates, so the red solid line for these countries only includes tariffs.

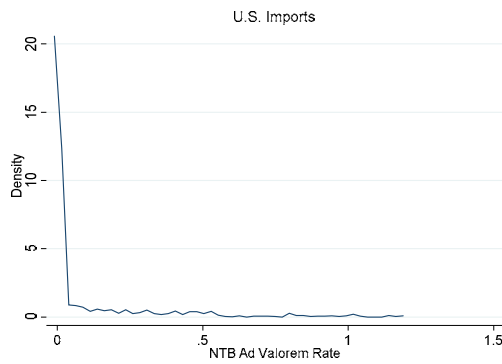
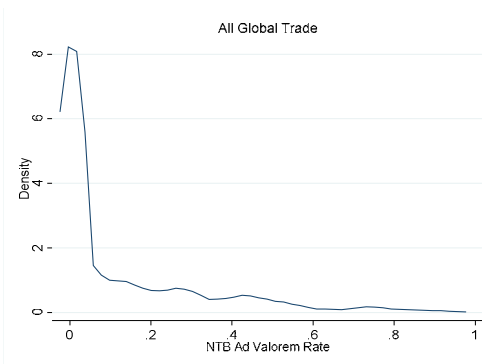
APPENDIX FIGURE II

Densities of Trade Policy, Carbon Intensity, and Upstreamness

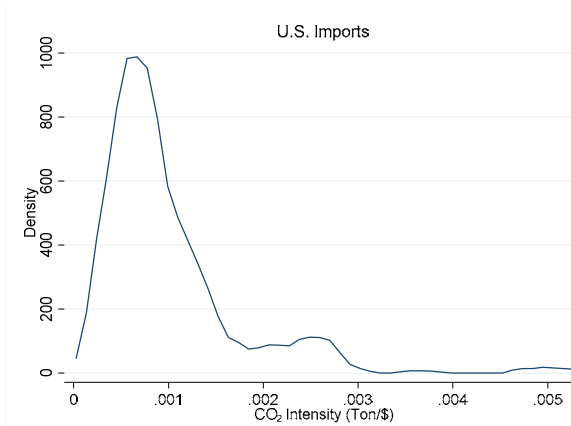
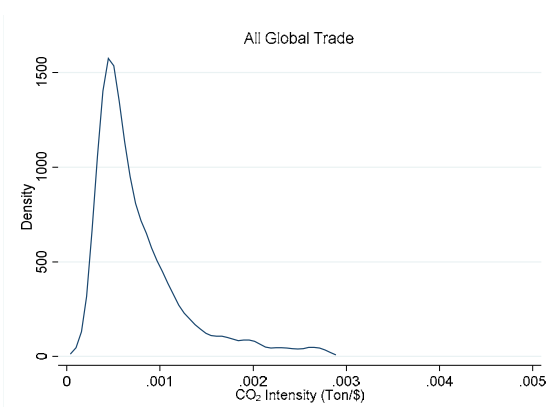
Panel A. Density of tariffs



Panel B. Density of non-tariff barriers



Panel C. Density of Total CO₂ intensity

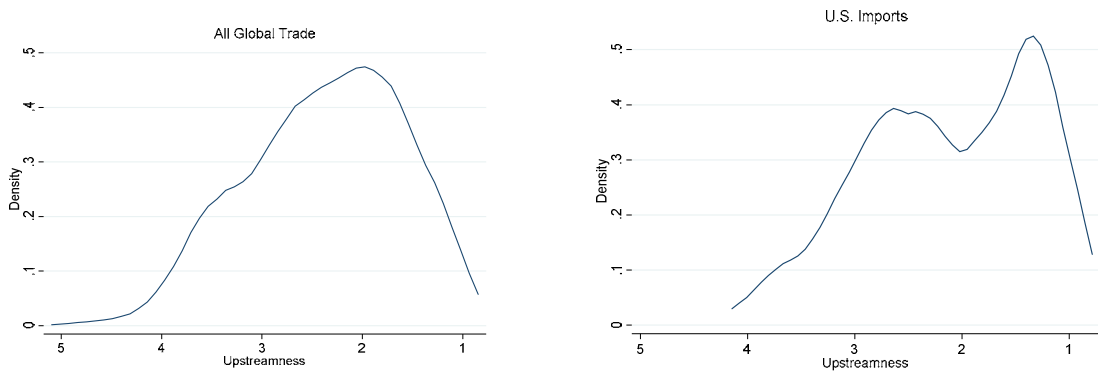


(Continued on next page)

APPENDIX FIGURE II

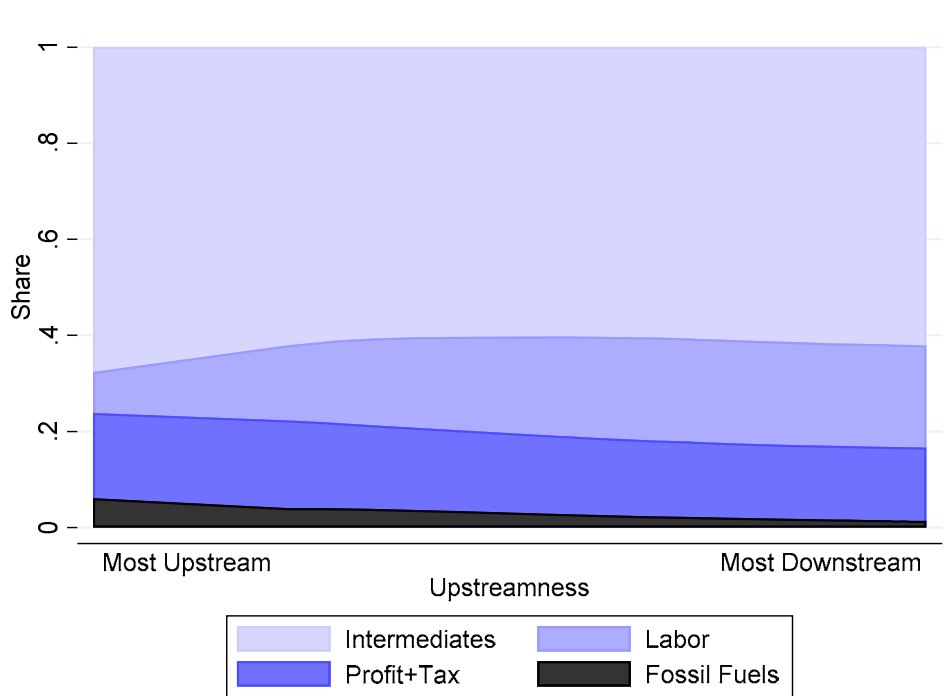
Densities of Trade Policy, Carbon Intensity, and Upstreamness (Continued)

Panel D. Density of upstreamness



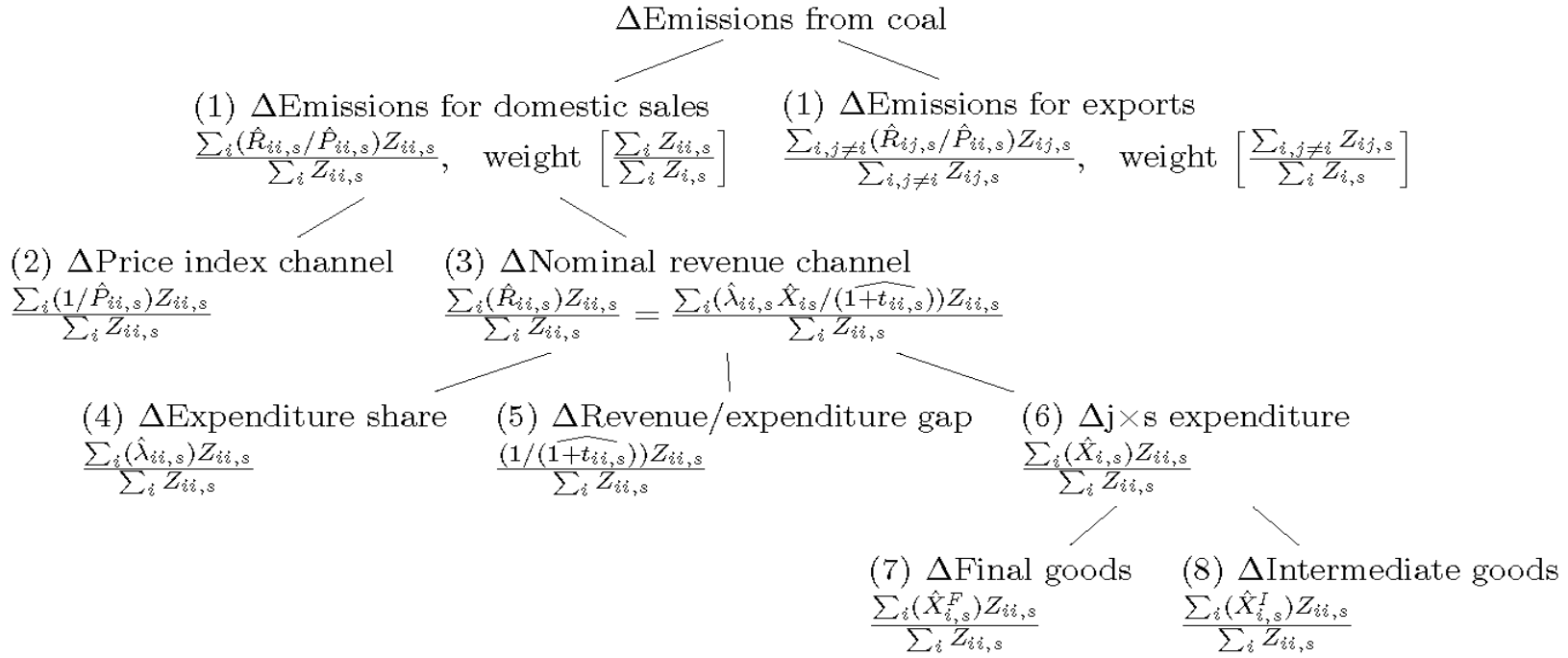
Notes: Graphs exclude top 1% of each variable. The value 5 represents the most upstream, while 1 is the least upstream. Upstreamness measured as in Antràs et al. (2012).

APPENDIX FIGURE III
 U.S. Upstreamness and Components of Revenues



Notes: Data from the U.S. BEA use table for year 2007. Fossil fuel industries include natural gas distribution, oil and gas extraction, electricity generation, petroleum refineries, and coal mining. For smoothness, for each component of output separately, this analysis estimates a local linear regression of the relevant component on upstreamness. The graph shows the fitted values from these regressions. The y-axis is the share of an industry's total value of shipments which is accounted for by each of the four listed components. The graph describes only manufacturing outputs (though counts intermediate inputs from all industries).

APPENDIX FIGURE IV
Decomposition of Quantitative Model



Notes: Equation numbers correspond to columns in Appendix Table IX. The Δ symbols indicate that each channel represents the proportional change due to a counterfactual policy.

APPENDIX TABLE I
Carbon Taxes Implicit in Trade Policy, Sensitivity Analysis

	Global				US Imports			
	Tariffs		NTBs		Tariffs		NTBs	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1. Main estimates	-32.31*** (8.59)	-11.17** (5.52)	-89.78*** (27.33)	-75.67** (30.02)	-5.69*** (1.44)	-6.55*** (2.30)	-47.96*** (10.06)	-37.41*** (12.36)
<u>Other econometrics</u>								
2. Tobit (no IV)	-35.63*** (11.52)	-5.29 (6.09)	-157.58*** (40.74)	-146.00** (59.37)	-6.19*** (1.96)	-3.61*** (1.30)	-270.19*** (60.86)	-156.78*** (56.43)
3. Tobit (IV)	-44.10*** (15.40)	-11.57** (5.74)	-191.05*** (56.30)	-154.37** (70.22)	-7.22*** (2.29)	-10.04*** (3.59)	-480.32*** (132.43)	-369.11** (158.31)
4. Standard errors clustered by importer	-32.31*** (7.71)	-11.17*** (3.30)	-89.78*** (11.67)	-75.67*** (12.84)	—	—	—	—
<u>Nonlinearity</u>								
5. Logs	-0.65 (0.46)	-0.91** (0.43)	-0.09*** (0.03)	-0.02 (0.05)	-0.64* (0.36)	-0.22 (0.59)	-0.07*** (0.02)	-0.04* (0.02)
6. Quadratic in emissions no IV. CO ₂ rate	-58.33*** (20.32)	3.58 (14.81)	-194.52*** (55.98)	-152.31 (113.86)	-10.15** (4.65)	-1.29 (5.63)	-45.45* (25.49)	8.17 (27.49)
CO ₂ rate ²	9,539.88** (4,668.97)	-3,508.35 (4,695.02)	34,582.94* (14,405.20)	34,420.37 (34,372.49)	1,260.10 (807.49)	-355.19 (882.31)	1,055.59 (5,166.68)	-4,798.88 (4,704.39)
fitted slope, 10th pct.	-51.56	1.09	-169.99	-127.89	-9.22	-1.55	-44.67	4.62
fitted slope, 50th pct.	-46.70	-0.70	-152.35	-110.34	-8.22	-1.84	-43.84	0.82
fitted slope, 90th pct.	-30.26	-6.74	-92.77	-51.04	-4.86	-2.78	-41.02	-11.99
7. Nonparametric marginal effect (no IV)	-18.56	—	-81.48	—	-4.89	-4.89	-41.04	-41.04
<u>Other data cleaning and aggregation</u>								
8. Winsorize dependent, independent variables	-25.49*** (6.60)	-10.66* (5.39)	-90.36*** (27.73)	-75.69** (29.95)	-5.75*** (1.62)	-6.42*** (2.29)	-51.40*** (10.45)	-38.01*** (12.69)
9. Include non-manuf. industries	-32.31*** (8.59)	-9.91 (8.96)	-84.77*** (24.07)	-72.96** (33.21)	—	—	—	—
Weighted		X		X		X		X

(Continued on next page)

APPENDIX TABLE I
Carbon Taxes Implicit in Trade Policy, Sensitivity Analysis (continued)

	Global				US Imports			
	Tariffs		NTBs		Tariffs		NTBs	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
10. Multiple partners (i×j×s level data)	-37.33** (16.49)	-11.23* (5.84)	-82.63** (32.19)	-75.70** (29.63)	-6.95*** (2.10)	-6.55*** (2.29)	-55.10*** (12.34)	-37.41*** (12.34)
11. i×j×s level data exporter fixed effects	-38.34** (17.11)	-16.33** (6.88)	-84.46** (33.16)	-93.59** (37.43)	-6.54*** (1.95)	-2.61* (1.41)	-54.23*** (11.87)	-38.40*** (14.13)
12. Industry-level data (no IV)	-21.80** (10.38)	-12.77** (5.14)	-124.16** (52.71)	-78.08* (45.14)	— —	— —	— —	— —
13. Add intra-national trade	-5.80*** (1.39)	-11.90*** (3.90)	-60.48** (23.32)	-81.84*** (21.01)	— —	— —	— —	— —
<u>Other measures of emissions</u>								
14. Direct emissions	-27.48*** (7.91)	-11.53 (8.10)	-78.33*** (22.30)	-104.70*** (34.86)	-7.52*** (2.00)	-10.35*** (3.71)	-63.34*** (16.68)	-59.13*** (20.78)
15. Direct emissions	49.89* (28.79)	-21.03 (24.12)	183.49** (78.40)	6.37 (135.57)	-1.86 (1.81)	-6.09** (2.49)	-15.98 (16.17)	-35.63** (16.04)
Total emissions	-62.72** (26.28)	6.55 (16.00)	-212.24*** (70.42)	-76.56 (100.21)	-4.29** (1.66)	-2.70*** (0.87)	-35.86*** (9.14)	-14.87*** (4.16)
16. Include all greenhouse gases	-16.93*** (4.48)	-6.55** (2.56)	-46.71*** (14.34)	-41.65** (16.95)	— —	— —	— —	— —
<u>Consumption emissions from energy-consuming durable goods</u>								
17. Exclude energy- consuming durables	-35.30*** (9.38)	-16.50** (7.90)	-98.47*** (29.80)	-113.23** (47.39)	-9.60*** (2.10)	-17.40*** (6.50)	-60.92*** (14.00)	-66.09*** (23.26)
18. Adjust CO ₂ rates: 50% goods, 50% energy	-32.91*** (8.73)	-12.33** (6.03)	-91.04*** (27.86)	-83.46** (33.52)	-6.04*** (1.55)	-8.34** (3.32)	-50.89*** (11.11)	-47.66*** (16.07)
19. Adjust CO ₂ rates: 5% goods, 95% energy	-32.71*** (8.69)	-12.02** (5.90)	-90.51*** (27.69)	-81.35** (32.39)	-6.39*** (1.67)	-11.07* (6.29)	-53.86*** (12.31)	-63.25** (30.48)
<u>Additional sensitivity analyses</u>								
20. Reverse regression (no IV)	-0.0004*** (0.0001)	-0.0002 (0.0004)	-0.0006*** (0.0001)	-0.0003** (0.0001)	-0.0040*** (0.0011)	-0.0063 (0.0040)	-0.0003** (0.0001)	-0.0009 (0.0006)
21. Lifecycle tariffs	-7.80** (3.56)	-5.04 (9.31)	-89.68*** (26.99)	-51.46** (25.28)	— —	— —	— —	— —
Weighted		X		X		X		X

(Continued on next page)

APPENDIX TABLE I
Carbon Taxes Implicit in Trade Policy, Sensitivity Analysis (continued)

	Global				US Imports			
	Tariffs		NTBs		Tariffs		NTBs	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
22. No importer fixed effects	-32.05*** (8.42)	-13.51* (7.18)	-99.99 (57.69)	-83.65*** (30.55)	— —	— —	— —	— —
23. WIOD, not Exiobase (no IV)	-11.62 (12.47)	-18.64 (18.57)	-19.54 (40.09)	-126.03 (92.67)	— —	— —	— —	— —
24. Add industry fixed effects	28.80 (25.46)	7.48 (15.32)	-16.09 (13.39)	123.97 (85.56)	— —	— —	— —	— —
25. Exclude manuf. food, ag. goods	-5.29 (6.09)	-5.87 (4.52)	-75.67** (30.02)	-40.81** (17.36)	-5.70*** (1.47)	-6.68*** (2.33)	-36.55*** (8.87)	-37.67*** (12.22)
<u>Trade war in 2018</u>								
26. U.S. tariffs in 2017	— —	— —	— —	— —	-4.80*** (1.68)	-4.14** (1.45)	— —	— —
27. U.S. tariffs including 2018 protectionism	— —	— —	— —	— —	-3.97*** (1.43)	-4.29** (1.75)	— —	— —
28. U.S. tariffs in 2018, ctrl. for upstreamness	— —	— —	— —	— —	0.62 (1.57)	-0.18 (1.75)	— —	— —
Weighted		X		X		X		X

Notes: All regressions are instrumental variables estimates, except where otherwise noted. All regressions include a constant. Parentheses show standard errors clustered by industry except in row 4. Hyphens indicate data which are same as row 1 or which are not available (e.g., MECS survey does not cover non-manufacturing; WIOD versus Exiobase is not relevant for U.S. microdata; all greenhouse gases are not separately reported for these U.S. data). Asterisks denote p-value * < 0.10, ** < 0.05, *** < 0.01.

APPENDIX TABLE II

Carbon Taxes Implicit in Cooperative Versus Non-Cooperative Tariffs

	Cooperative		Non-Cooperative	
	(1)	(2)	(3)	(4)
<i>Panel A. U.S. import tariffs</i>				
CO ₂ rate	-6.03***	-4.49**	-78.32***	-62.39***
	(1.71)	(1.94)	(12.70)	(23.96)
N	374	374	374	374
Dep. Var. Mean	0.020	0.013	0.324	0.275
<i>Panel B. Japanese import tariffs</i>				
CO ₂ rate	-54.72***	-44.70	-46.99**	-9.18
	(16.61)	(27.00)	(19.06)	(13.43)
N	47	47	47	47
Dep. Var. Mean	0.074	0.040	0.072	0.027
<i>Panel C: Chinese import tariffs</i>				
CO ₂ rate	5.25	18.91	-60.50	-3.34
	(10.12)	(12.01)	(54.50)	(68.22)
N	47	47	47	47
Dep. Var. Mean	0.088	0.062	0.547	0.397
Weighted		X		X

Notes: U.S. non-cooperative tariffs apply to Cuba and the Democratic People's Republic of Korea. Chinese non-cooperative tariffs apply to Andorra, the Bahamas, Bermuda, Bhutan, the British Virgin Islands, the British Cayman Islands, French Guiana, Palestinian Territory (West Bank and Gaza), Gibraltar, Monserrat, Nauru, Aruba, New Caledonia, Norfolk Island, Palau, Timor-Leste, San Marino, the Seychelles, Western Sahara, and Turks and Caicos Islands. Japanese non-cooperative tariffs apply to Andorra, Equatorial Guinea, Eritrea, the Democratic People's Republic of Korea, Lebanon, and Timor-Leste. Other countries receive cooperative tariff rates from these countries. See Ossa (2014) for further discussion. All regressions include a constant. Standard errors clustered by industry in parentheses. Asterisks denote p-value * < 0.10, ** < 0.05, *** < 0.01.

APPENDIX TABLE III
Political Economy Variables, Dirty versus Clean Industries

Regression of variable on "Dirty":	Global (1)	U.S. (2)
<u>Panel A: analyzed for all country×industries</u>		
Upstreamness	0.676*** (0.146)	0.756*** (0.098)
Intra-industry trade	-0.152 (0.093)	0.252** (0.105)
Import pen. ratio	0.031 (0.086)	-0.579*** (0.101)
Labor share	-0.146** (0.069)	-0.536*** (0.102)
Mean wage	-0.107 (0.127)	-0.389*** (0.104)
<u>Panel B: analyzed for U.S. only</u>		
Inverse export supply elasticity	—	-0.141 (0.106)
Output trends, 1972-2002	—	0.026 (0.105)
Import pen. ratio 1997- 2002	—	-0.085 (0.105)
Workers: share with college (%)	—	-0.176* (0.105)
Four-firm concentration ratio	—	0.084 (0.106)
Mean firm size	—	0.113 (0.106)
Standard deviation of firm size	—	0.030 (0.106)
Capital share	—	0.058 (0.105)
<u>(Continued next page)</u>		

APPENDIX TABLE III

Political Economy Variables, Dirty versus Clean Industries (Continued)

Regression of variable on "Dirty":	Global (1)	U.S. (2)
Shipping cost per dollar×kilometer	—	0.697*** (0.100)
Geographic dispersion	—	-0.022 (0.106)
Workers: unionized (%)	—	0.669*** (0.100)
Workers: unemployment	—	-0.063 (0.106)
Local pollution		0.601*** (0.102)
PAC contributions	—	-0.188* (0.104)

Notes: Each table entry is the coefficient from a separate regression of the indicated variable on a dummy for whether an observation has above-median total emissions rate and a constant; Column 1 also includes country fixed effects. All variables are measured in z-scores. Regressions are weighted by the value of imports. Standard errors clustered by industry in parentheses. Asterisks denote p-value * < 0.10, ** < 0.05, *** < 0.01.

APPENDIX TABLE IV
Political Economy Explanations for Implicit Carbon Taxes: One at a Time

	(1)	(2)	(3)	(4)	(5)	(6)
<i>Panel A. All global trade, weighted</i>						
CO ₂ rate	-86.60*** (33.44)	6.36 (40.92)	-87.83*** (33.00)	-89.11** (35.71)	-87.02*** (33.64)	-90.90** (37.97)
<i>Panel B. All global trade, instrument for political economy, weighted</i>						
CO ₂ rate	-86.60*** (33.44)	49.78 (52.40)	-76.18* (43.52)	-113.95* (63.04)	-70.84* (38.23)	-98.21* (55.32)
K-P F Statistic	—	28.9	9.6	3.9	21.7	24.8
<i>Panel C. U.S. imports, weighted</i>						
CO ₂ rate	-49.72*** (9.90)	2.74 (10.19)	-51.99*** (10.54)	-47.50*** (10.32)	-49.75*** (12.19)	-54.32*** (10.45)
<i>Panel D. U.S. imports, direct CO₂ only</i>						
CO ₂ rate	-70.12*** (23.88)	-4.75 (17.20)	-71.73*** (19.84)	-61.11*** (21.21)	-48.24*** (17.80)	-95.27*** (27.15)
<i>Panel E. U.S. imports, direct CO₂ only, unweighted</i>						
CO ₂ rate	-65.28*** (16.13)	3.11 (11.66)	-68.47*** (17.16)	-60.83*** (16.32)	-63.07*** (17.95)	-70.97*** (17.34)
Upstreamness		X				
Intra-industry			X			
Import pen. ratio				X		
Labor share					X	
Mean wage						X

Notes: Dependent variable in all regressions is sum of tariffs and NTBs. Each observation is a country×industry (Panels A and B) or industry (Panels C, D, and E). In Panels A, B, and C, CO₂ rate is the total rate from inverting an input-output table, which is instrumented with the direct CO₂ rate. In panel B only, the political economy variables (upstreamness, intra-industry share, etc.) are instrumented with the mean of each political economy variable in the industry of interest across the 10 smallest other countries. Panels A and B include country fixed effects. All regressions include a constant. Standard errors clustered by industry in parentheses. Asterisks denote p-value * < 0.10, ** < 0.05, *** < 0.01.

APPENDIX TABLE V
Political Economy Explanations: All Controls Together

	All global trade			U.S. imports	
	IV (1)	IV (2)	Lasso (3)	IV (4)	Lasso (5)
CO ₂ rate	-29.237 (19.444)	-29.600 (29.641)	-24.780 (18.726)	-112.754* (64.063)	-44.065 (41.779)
Upstreamness	-0.105*** (0.017)	-0.180*** (0.029)	-0.106*** (0.017)	-0.044*** (0.016)	-0.069*** (0.015)
Intra-industry trade	-0.004 (0.010)	-0.051 (0.053)	0 0	-0.007 (0.015)	0 0
Import penetration ratio	-0.027** (0.012)	-0.234*** (0.072)	0 0	-0.016 (0.017)	0 0
Labor share	-0.012* (0.006)	-0.360** (0.159)	0 0	-0.042 (0.026)	0 0
Workers: mean wage	0.003 (0.019)	0.126 (0.078)	0 0	-0.034* (0.020)	0 0
Inverse export supply elast.	—	—	—	-0.023** (0.011)	0 0
Output trends 1972-2002	—	—	—	0.007 (0.011)	0 0
Trend in import pen. ratio	—	—	—	0.026 (0.016)	0 0
Workers: share w/ college	—	—	—	-0.034 (0.028)	0 0
Four-firm conc. ratio	—	—	—	-0.059 (0.038)	0 0
Mean firm size	—	—	—	0.109* (0.061)	0 0
Standard dev. of firm size	—	—	—	-0.120* (0.062)	0 0
Capital share	—	—	—	0.032 (0.025)	0 0
Shipping cost per dollar*km	—	—	—	0.034 (0.033)	0.034 (0.029)
Geographic dispersion	—	—	—	0.083 (0.053)	0 0
Workers: unemployed	—	—	—	0.001 (0.028)	0 0
Workers: unionized (%)	—	—	—	0.025 (0.017)	0 0
Local pollution	—	—	—	0.008 (0.015)	0 0
PAC contributions	—	—	—	0.028 (0.021)	0 0
Instrument political economy		X			

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APPENDIX TABLE V
Political Economy Explanations: All Controls Together (Continued)

Notes: Lasso entries of "0" mean the coefficient is exactly zero. CO₂ intensity refers to total intensity from the input-output table. Total CO₂ rate is instrumented with direct CO₂ rate. In column 2, political economy variables are instrumented with their mean in other countries. Columns 1-3 include country fixed effects. Country fixed effects and excluded instrument are not penalized in Lasso estimates. All regressions include a constant. Standard errors clustered by industry in parentheses.

APPENDIX TABLE VI
Country Aggregation in General Equilibrium Model

Country	Aggregation
Australia	
Japan	
South Korea	Pacific Ocean
Taiwan	
Austria	
Belgium	
Germany	
France	Western Europe
Luxembourg	
The Netherlands	
Bulgaria	
Czech Republic	
Estonia	
Hungary	
Lithuania	
Latvia	Eastern Europe
Poland	
Romania	
Russia	
Slovakia	
Slovenia	
Brazil	
Mexico	Latin America
Canada	
United States	North America
China	China
Cyprus	
Spain	
Greece	
Italy	Southern Europe
Malta	
Portugal	
Turkey	
Denmark	
Finland	
United Kingdom	
Ireland	Northern Europe
Norway	
Sweden	
India	
Indonesia	Indian Ocean
Rest of the World-Asia and Pacific	
Rest of the World-Europe	
Rest of the World-Africa	
Rest of the World-America	Rest of the World
Rest of the World-Middle East	
South Africa	
Switzerland	

APPENDIX TABLE VII
Sectors and Trade Elasticities

Sector	Caliendo				
	Overall	& Parro (2015)	Shapiro (2016)	Bagwell et al. (2018)	Giri et al. (2018)
Agriculture, Hunting, Forestry, and Fishing	9.11 (1.05)	9.11 (2.01)	3.34 (3.63)	22.13 (1.31)	—
Coal and Peat Extraction and Related	5.38 (0.97)	13.53 (3.67)	3.45 (1.27)	5.38 (1.65)	—
Petroleum Extraction and Related	13.53 (1.20)	13.53 (3.67)	3.45 (1.27)	22.38 (11.31)	—
Natural Gas Extraction and Related	8.49 (1.20)	13.53 (3.67)	3.45 (1.27)	—	—
Other Mining	4.13 (0.73)	13.53 (3.67)	3.45 (1.27)	4.13 (0.92)	—
Food, Beverages, and Tobacco	4.42 (0.24)	2.62 (0.61)	5.26 (2.10)	11.01 (1.42)	3.57 (0.27)
Textiles, Textile Products, and Leather	6.36 (0.16)	8.10 (1.28)	18.56 (5.59)	4.62 (0.90)	3.71 (0.16)
Wood; Wood and Cork Products	8.19 (0.97)	11.50 (2.87)	5.90 (2.23)	10.47 (3.00)	4.17 (1.26)
Pulp and Paper	6.85 (0.18)	16.52 (2.65)	5.77 (3.00)	7.93 (2.06)	2.97 (0.18)
Coke, Refined Petroleum, and Nuclear Fuel	8.95 (0.47)	64.85 (15.61)	8.95 (4.01)	—	3.87 (0.47)
Chemicals, Fertilizer, and Basic Plastics	3.44 (0.22)	3.13 (1.78)	1.55 (3.04)	8.15 (2.57)	3.75 (0.22)
Rubber and Plastic Products	2.99 (0.48)	1.67 (2.23)	1.55 (3.04)	9.25 (3.58)	4.31 (0.50)
Glass, Cement, Other Non-Metallic Minerals	3.43 (0.37)	2.41 (1.60)	1.55 (3.04)	8.31 (8.00)	4.44 (0.38)
Basic Metals and Fabricated Metal	7.99 (0.84)	5.45 (1.62)	12.94 (8.35)	9.13 (2.87)	6.84 (1.05)
Machinery N.E.C.	6.23 (0.21)	1.45 (2.80)	10.84 (2.84)	9.18 (2.19)	3.27 (0.21)
Electrical and Optical Equipment	7.92 (0.20)	8.93 (0.93)	10.84 (2.84)	6.91 (3.63)	3.27 (0.21)
Transport Equipment	5.68 (0.51)	1.23 (0.70)	6.88 (3.66)	6.98 (2.88)	4.47 (0.80)
Manufacturing, N.E.C., Recycling	5.25 (0.78)	3.98 (1.08)	12.76 (4.57)	5.25 (1.16)	—
Electricity Generation	6.69 (1.00)	3.98 (1.08)	6.69 (3.17)	10.23 (4.99)	—
Services and all other industries	6.69 (1.02)	3.98 (1.08)	6.69 (3.17)	18.45 (9.45)	—
Land, pipeline, air, and sea transportation	5.34 (1.02)	3.98 (1.08)	6.69 (3.17)	—	—

APPENDIX TABLE VIII
Effects of Counterfactual Tariffs and NTBs on CO₂ Emissions and Welfare, Sensitivity Analysis

	CO ₂ Emissions (1)	Real Income (2)	CO ₂ Intensity = (1) - (2) (3)	Climate benefits (4)	Social welfare (5)
<i>Panel A: Sensitivity Analysis for Main Counterfactual</i>					
1. Baseline estimates	-3.59%	0.65%	-4.24%	0.08%	0.57%
2. Trade elasticities: Caliendo-Parro	-5.66%	0.55%	-6.21%	0.13%	0.42%
3. Larger energy elasticity	-2.53%	0.47%	-3.00%	0.06%	0.41%
3. Harmonize tariffs only	-1.75%	0.13%	-1.88%	0.04%	0.09%
4. Harmonize NTBs only	-2.26%	0.47%	-2.73%	0.05%	0.42%
5. Algorithm: trust-region	-3.59%	0.65%	-4.24%	0.08%	0.57%
6. Algorithm: Levenberg-Marquardt	-3.59%	0.65%	-4.24%	0.08%	0.57%
<i>Panel B: Counterfactual sets EU tariffs and NTBs to mean</i>					
Global total	-1.84%	0.25%	-2.10%	—	—
By region					
Pacific Ocean	-1.63%	0.06%	-1.69%	—	—
Western Europe	20.35%	0.82%	19.53%	—	—
Eastern Europe	1.50%	0.12%	1.38%	—	—
Latin America	-4.65%	0.01%	-4.66%	—	—
North America	-0.12%	0.01%	-0.13%	—	—
China	-0.97%	0.00%	-0.97%	—	—
Southern Europe	50.43%	0.58%	49.85%	—	—
Northern Europe	17.04%	0.96%	16.08%	—	—
Indian Ocean	-1.98%	-0.17%	-1.81%	—	—
Rest of World	-7.51%	0.04%	-7.55%	—	—
<i>Panel C: Counterfactual sets tariffs and NTBs to mean of cleanest third of goods</i>					
Global total	-5.09%	0.06%	-5.15%	0.11%	-0.05%
<i>Panel D: Counterfactual sets tariffs and NTBs to mean of dirtiest third of goods</i>					
Global total	-4.20%	1.13%	-5.33%	0.09%	1.04%
<i>Panel E: All countries add a carbon tariff</i>					
Global total	-2.52%	0.45%	-2.97%	0.06%	0.39%
<i>Panel F: All Countries set tariffs and NTBs to zero</i>					
Global total	1.31%	2.65%	-1.34%	-0.03%	2.68%

Notes: See notes to Table V. Unless otherwise noted, all estimates refer to changes in both tariffs and NTBs. Global change in real income refers to the weighted mean percentage change in countries' real incomes due to a counterfactual policy, where weights equal each country's baseline income. In all baseline and counterfactual scenarios, intra-national tariffs and NTBs are assumed to equal zero.

APPENDIX TABLE IX
Components of Changes in Fossil Fuel Consumption Due to Counterfactual Trade Policy

	Total	Prices	Nominal Revenue						Baseline Emissions	Counterfactual Emissions
			Expenditure			Revenue / Expenditure				
			Total	Share	Revenue / Expenditure	Total	Final Goods	Intermediate Goods		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	
<i>Panel A: Oil</i>										
Domestic Sales	-1.2%	-0.3%	-1.0%	1.3%	0.0%	-0.7%	0.6%	-0.7%	5.7	5.7
Exports	-8.2%	-0.6%	-6.4%	-7.5%	-1.5%	-0.8%	-0.7%	-0.7%	5.7	5.2
<i>Panel B: Natural Gas</i>										
Domestic Sales	-0.9%	-0.5%	-0.5%	0.0%	0.0%	-0.5%	0.6%	-0.6%	4.4	4.3
Exports	-12.8%	-0.5%	-11.0%	-11.6%	-1.5%	0.7%	-0.6%	0.8%	1.5	1.3
<i>Panel C: Coal</i>										
Domestic Sales	-4.7%	0.5%	-5.2%	-3.2%	0.0%	-2.1%	-0.5%	-2.1%	12.6	12.0
Exports	9.1%	0.3%	8.0%	8.0%	-1.1%	1.0%	-0.5%	1.1%	1.2	1.4

Notes: Emissions refer to 2007 baseline emissions in GtCO₂. See text for definitions of each column in terms of the model.