Outsourcing, Trade, Technology, and Greenhouse Gas Emissions

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Abstract

U.S. output has steadily outpaced the rise in greenhouse gas (GHG) emissions over the past several decades. The decoupling of these two trends represents a decline in aggregate GHG emissions intensity. Using recently released national data sets covering industry-specific GHG emissions and shipments, this paper decomposes the relative importance of changes in various channels underlying changes in aggregate GHG emissions in the U.S. from 1997–2015: scale or national output growth, cross-sector composition changes, and a technique effect capturing other factors lowering emissions intensities within the country's productive industries. The results demonstrate that reductions in within-sector techniques explain two thirds, and cross-sector shifting of economic activity towards cleaner industries explains one third of the increasing gap. Using data on industry exports and imports, this paper further investigates the relative environmental effect of trade on GHG emissions. Together, increased exporting, and importing, of both intermediate and final goods, has corresponded to a relatively small expansion of cleaner sectors and appears to have contributed slightly to the relative expansion of cleaner U.S. industries. In 2015 U.S. imports of intermediate and final goods account for the displacement of roughly 290 million metric tons of U.S. GHG emissions, representing less than 5 percent of U.S. GHG emissions in the same year.

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1 Introduction

Climate change, and its primary driver, greenhouse gases (GHGs), have gained increasing public attention, and with reason. Even seemingly small changes in global temperatures can have dramatic consequences for economic development, the access to potable water and for food security (Stern (2008); Schlenker et al. (2006); Roberts and Schlenker (2010)). The U.S. is the second largest global emitter of GHGs and was responsible for 14.5 percent of global carbon emissions 2014 ([dataset] Boden et al. (2017)), so changes in U.S. emission trends can have significant global effects. Furthermore, understanding the factors behind recent observed declines in U.S. emissions may have implications for major emitters. The increased attention and resulting public debate might lead a casual observer to conclude that economic growth is tightly correlated with growth in GHG emissions, and its largest component, carbon dioxide (CO_2). However, the data reveals a decoupling of U.S. GHG emissions and GDP.

Between 1970 and 2015, annual U.S. CO_2 emissions grew 25 percent, however, the trend has not been monotonic. Between 1970 and 2005, CO_2 emissions grew at an annual rate of 1.2 percent but since 2005, have declined at an annual rate of 1.1 percent. During the same 45-year period U.S. real GDP increased at an annual rate of 3.2 percent (Figure 1).[1] This paper analyzes the decoupling of these two trends using a new data set created by combining National Income and Product Accounts data released by the BEA and EPA that allows us to allocate GHG emissions across 56 industries representing a broad share of U.S. economic activity from 1997–2015. The data set facilitates analysis of the relative importance of changes in domestic industry output, emissions intensity and industry mix, as well as an additional analysis of the role of trade on emissions.[2]

[Figure 1 approximately here]

This paper makes two contributions to the study of GHG emissions. The first is a detailed decomposition analysis of U.S. GHG emissions into three channels, facilitated by the development of a new data set linking GHG emissions and industry-level output, covering all

[1] Author calculations using U.S. Bureau of Economic Analysis (BEA) real GDP measures and GHG emissions measures from the U.S. EPA (Environmental Protection Agency, 2017).

Decoupling can take two forms (UNEP (2011); Vavrek and Chovancova (2016)): absolute decoupling and relative decoupling. With relative decoupling, the growth rate of the rate of GHG emissions is lower than the growth rate GDP; that is, the association is still positive, but the elasticity is less than 1. With absolute decoupling, emissions decline even as GDP continues to increase. U.S. CO_2 emission display relative decoupling for the period between 1970 and 2005, then absolute decoupling from 2006 to 2015. See also https://data.worldbank.org/indicator/EN.ATM.GHGT.KT.CE

[2] The data set we develop does not cover residential GHG emissions. See Jiafeng et al. (2013) and Fan et al. (2017) for a related discussion of production vs consumption based CO_2 emissions and flows.

U.S. productive economic activity. The second is an investigation of the impact of industry-level international trade on U.S. GHG emissions.

Various decomposition approaches have been used in related literature to investigate the factors underlying changes in environmental indicators. Two such approaches evaluated by Hoekstra and van der Bergh (2003) are a structural decomposition analysis (which makes use of detailed input-output data) and index decomposition analysis (which generally makes use of sector-level output data). Variants of both approaches seek to understand the meaningful economic channels underlying changes, over time, in an indicator variable of interest, for example, output or emissions. Levinson (2009b), in his seminal work, decomposed changes in several criteria air pollutants released by industries in the U.S. manufacturing sector. Similar analytical techniques have since been used to examine criteria air emissions of European manufacturers (Brunel (2017); Diakoulaki and Mandaraka (2007)), and the CO_2 emissions of manufacturers in India (Barrows and Ollivier (2016); Martin (2011)), Spain (Butnar and Llop (2007)), China (Zhang (2012); Su et al. (2013)), and Japan (Cole et al. (2013)).

The recent release of more detailed GHG data by the EPA, and industry-level input-output account for 71 U.S. industries by the BEA allows us to investigate environmental consequences of changes both within and across industries. To provide a comprehensive summary of U.S. GHG emissions, the EPA aggregates emissions of several leading GHGs (including CO_2, methane, nitrous oxide, and other fluorinated gases) and provides the data as a "CO_2 equivalent" measures (CO_2e) which uses the global-warming potentials of the other measured GHGs to convert to a standardized measure (Hertwich and Peters (2009)),[3] which is the emissions measure used in the following analysis. We focus on 56 industries within four major sectors—agriculture, commercial, mining and manufacturing. These sectors in the aggregate are responsible for 95 percent of U.S. output (both final and intermediate goods) and 37 percent of U.S. GHG emissions.[4] Our approach begins with the industry output measures, and is thus more akin to index decomposition analysis, but combines aspects of the structural decomposition approach to analyze the influence of international trade. Following Levinson (2009b), we first decompose changes in CO_2e emissions into scale, composition and technique effects. The scale effect arises from changes in aggregate economic output, and identifies changes in CO_2e emission resulting from increased output, all else equal. The composition effect identifies the change in emissions resulting from the redistribution of production among industries either toward or away from relatively clean industries. The

[3]From 1990–2017, the average CO_2 share of U.S. GHGs is 82 percent, followed by methane (10 percent), nitrous oxides (6 percent) and other flurorinated gases (2 percent) (https://cfpub.epa.gov/ghgdata/inventoryexplorer/#iallsectors/allgas/gas/all).

[4]Data from Input-Output tables published by the BEA, and GHG emissions data from the EPA (Environmental Protection Agency, 2017).

technique effect measures changes in emissions arising from changes in industries' emissions intensity.

We find that the composition effect is responsible for roughly 35 percent of the decline in aggregate emissions intensity, while within-industry changes to production techniques are responsible for the remaining 65 percent. This is consistent with findings in Levinson (2009b, 2015); Shapiro and Walker (2018); Brunel (2017) who employed a similar analytical approach to study criteria air pollutant emissions by the U.S., and European manufacturing sector.[5] Environmental regulation has been cited as a plausible explanation underlying the declines in the aggregate emissions intensities found by these studies. In contrast, direct regulation is not a plausible explanation for our findings as GHG emissions were subject to only sporadic state action and no federal regulation[6] prior to 2011 (Wallach (2012)).[7] Alternative explanations, explored in relation to U.S. criteria air pollutant declines, include technological progress and competitive responses to increased international trade.[8]

GHG emissions arise from a variety of activities. Emissions of GHGs associated with the residential, and transportation sectors have garnered significant attention over the past decade (Chong (2012); Jacobsen et al. (2012); Bento et al. (2013); Kirkpatrick and Bennear (2014); Holland et al. (2016)). Other work has highlighted the role of hydraulic fracturing in driving down emissions of electricity producers by lowering the cost of relatively cleaner natural gas (Knittel et al. (2015); Holladay and LaRiviere (2017)). A growing body of work, utilizing both decomposition and econometric analysis, has highlighted the importance of energy use, intensity, and substitution underlying changes in manufacturing emissions of both OECD and non-OECD countries (Agnolucci and Arvanitopoulos (2019); Tan and Lin (2018); Wang et al. (2018); Kim and Kim (2012); Dachraoui and Harchaoui (2006); Cole et al. (2005); Liaskas et al. (2000)). Our analysis utilizes relatively detailed industry data on output and energy inputs to identify the relative importance of structural changes in relative industry output and industry emissions intensity across industries to the observed changes in U.S. GHG emissions.

[5]In contrast, Barrows and Ollivier (2016) find evidence of a much stronger composition effect in India, while Lise (2006) and Ipek Tunç et al. (2009) studying data for four aggregated sectors in Turkey, find little evidence of decoupling of output and GHG emissions in Turkey. These results for two less developed countries suggest that the relative importance of the various channels may change as countries develop.

[6]The EPA began making important steps towards regulating GHG emissions in 2007 when the U.S. Supreme Court upheld the EPA's authority to regulate GHG emissions under the Clean Air Act if a threat to public health were demonstrated (*Massachusetts v. Environmental Protection Agency, 549 U.S. 497 (2007)*).

[7]Although the Environmental Protection Agency (EPA) has been gathering data related to U.S. GHG emissions almost since its inception in 1970, the EPA did not begin the process of issuing GHG permits to polluting facilities until 2011.

[8]Cherniwchan et al. (2017) provide a comprehensive overview of related literature and findings.

The U.S. has published detailed toxic emission data for several decades. However, due in part to the historical lack of detailed GHG data, the relative importance of different potential factors driving GHG emissions across different sectors of the U.S. economy are less studied and understood. While various other studies have made use of more aggregated data with broader cross-country coverage (Wiedmann et al. (2007); Tukker and Jansen (2006)), the additional industry-level detail leveraged in the analysis in this paper gives more precise insight into the relative importance of various channels driving recent declines in U.S. GHG emissions. A lack of similarly detailed GHG data for U.S. trade partners inhibits the application of our approach to assess the net global environmental effects of recent changes in U.S. supply chains and consumption patterns–the primary objective of decompositions based on multi-regional input-output models (Turner et al. (2007)). Peters and Hertwich (2006) perform a related analysis for Norway, building a similarly detailed input-output dataset covering 49 industry groups, for both Norway and its seven largest trading partners, to investigate the GHG emissions embodied in Norway's consumption. In contrast, our approach focuses on the drivers of underlying changes in U.S. CO_2e emissions, and estimates how those emissions might have differed by using a counterfactual analysis that considers emissions embodied in both imports and exports over the period.

To extend our baseline decomposition results to investigate the relative importance of international trade for U.S. emissions, we make use of industry data on imports and exports collected by the BEA. Using import-export data facilitates further dis-aggregation of the composition effect due to domestic production, imports of intermediate or final goods, and exports. Our results indicate that substantial increases in exports and imports since 1997 have only driven a small portion (roughly six percent) of the observed compositional shift in U.S. production towards cleaner production. Furthermore, though offshoring of both intermediate and final goods has increased dramatically in recent years, total U.S. imports, of intermediate and final goods, represent roughly 290 million metric tons of off-shored emissions in 2015–equivalent to less than five percent of total U.S. GHG emissions in the same year.

Related work has focused specifically on the environmental effects of trade. Zugravu-Soilita (2018), using a similar decomposition to the approach employed in this paper, and examining a large panel of less developed "transition economies," finds evidence of trade-induced increases in CO_2 due to a large scale-composition effect. Similarly, cross-country analysis by Frankel and Rose (2005) found significant evidence that more stringent U.S. environmental regulation drove CO_2 emissions off-shore (a pollution haven effect), although the evidence of pollution havens was limited for the other pollutants studied.[9] Still, the link

[9] Levinson and Taylor (2008); Levinson (2009a) also find mixed results regarding the importance of pol-

between trade and environmental outcomes remains somewhat in question. For example, work by Levinson (2009b, 2015); Shapiro and Walker (2018); Brunel (2017) has found very little evidence of a link between increased trade and environmental outcomes. In contrast, recent finding by Barrows and Ollivier (2018) and Cherniwchan (2017) point to an important role played by trade potentially working through the industry-level technique effect, driven by firm-level choices regarding product mixes, and production technology, respectively.

A growing literature (Wiedmann et al. (2009); Turner et al. (2007)) seeks to trace out the global environmental consequences associated with changing production and consumption patterns. This literature emphasizes that understanding global GHG consequences of globalization should incorporate industry or even firm-level emissions intensities of the global partners responsible for upstream portions of a country's final consumption (Minx et al. (2009); Andrew et al. (2009); Huppes (2006)). Understanding cross-country differences in the GHG intensity of consumption categories, for example, food, housing, transportation, etc., is important for understanding the factors driving changes in global GHG emissions (Hertwich and Peters (2009)). Due in large part to the lack of similarly detailed industry-level output and emissions data among U.S. trading partners, the current project is narrower in scope, focusing on providing more precise insights into the specific structural economic changes underlying observed changes in U.S. CO_2e emissions, without seeking to fully investigate the global Ecological Footprint effects (Wackernagel and Rees (1996)) of offshoring specific aspects of the U.S. supply chain to particular countries. Our findings indicate that recent expansions of U.S. imports and exports have contributed only a small portion of the observed declines in U.S. emissions of GHGs.

Understanding the underlying dynamics that explain the increasing decoupling of U.S. GHG emissions from U.S. GDP is important for the design of effective and efficient environmental policies. Studying the influence of trade is particularly important for GHG emissions, because GHGs are uniformly mixing pollutants. Thus, GHG emissions at any location contribute equally to global temperature changes and related effects. Consequently, shifts in production to other jurisdictions with less stringent regulations do not actually generate any meaningful environmental gains (Holland (2012); Fell and Maniloff (2018)). In fact, to the extent that production of similar products is more emission intensive in other parts of the world, the apparent U.S. gains could in fact mask an actual reduction in U.S. environmental quality. For example, Hasanbeigi et al. (2016) document substantial variation in the CO_2 emissions intensity of steel production across four of the world's leading steel producing countries. Their results indicate that steel production shifted from the U.S. to China could

lution havens for other pollutants.

generate nearly 25 percent more CO_2 emissions per tonne.[10] This concern is lent additional weight by Jiang and Green (2017); Peters and Hertwich (2006); Shui and Harriss (2006) who link shifts in the global supply chain, to China and other southern-hemisphere countries, to a rise in global CO_2 emissions.

The uniformly mixing characteristic of GHGs makes efficient and effective regulation in a global setting quite challenging, theoretically, and motivates additional investigation regarding relative importance of changes in domestic production, as well as international trade and offshoring, to the observed recent declines in U.S. GHG emissions. If global trade imbalances and supply chain changes, specifically a rise in pollution havens, are contributing substantially to observed changes in GHG emissions, it lends additional weight to the need for cross-country policy responses.

The rest of the paper is organized as follows. Section 2 lays out the methods behind the decomposition theory that provides the basis for the analysis and discusses the data and its application. Section 3 discusses the primary results and conclusions.

2 Methods

This section briefly describes the standard decomposition performed in related literature (see Copeland and Taylor (2003); Levinson (2009b) and Cherniwchan et al. (2017)).

2.1 Economic Composition and Production Techniques

Consider an economy that releases emissions, Z, in a given year. These aggregate emissions, which are the sum of the emissions from each industry, i, can be decomposed into the total value shipped, S, the market share of an industry, Θ_i, and the emissions intensity of each industry, E_i:

$$Z = \sum_i Z_i = S \sum_i \Theta_i E_i \tag{1}$$

where $E_i = Z_i/S_i$, and $\Theta_i = S_i/S$. In vector notation

$$Z = S\boldsymbol{\Theta}'\boldsymbol{E} \tag{2}$$

where Θ and E are $i \times 1$ vectors containing industry market shares and emissions intensities, respectively.

[10] From 1,736 kilogram (kg) CO_2/tonne in the U.S. to 2,148 kg CO_2/tonne in China.

Totally differentiating equation (2) decomposes the change in aggregate emissions into changes driven by the three separate components:

$$\mathrm{d}Z = \mathbf{\Theta}'\boldsymbol{E}\mathrm{d}S + S\boldsymbol{E}'\mathrm{d}\Theta + S\mathbf{\Theta}'\mathrm{d}E \tag{3}$$

The first term gives the change in emissions due to changes in the overall size of economic output, a "scale" effect, holding constant any changes in industry market share or emissions intensity. The second term is a "composition" effect, identifying changes in emissions due to economic activity shifting toward or away from dirtier sectors. The third term captures the change due to changes in industry emissions intensity, the "technique" effect. Equation (3) forms the basis for our analysis.

Our empirical analysis proceeds in three steps. The first step decomposes the change in CO_2e emissions into the scale, composition and technique effects, identified in equation (3). The second step further decomposes the composition effect among shifts between domestic production, and among imports and exports. Lastly, we estimate the CO_2e emissions avoided by offshoring activities.

In the first step, the scale effect is empirically identified as the change in total industry output over time. A combined scale plus composition effect is estimated, holding industry emissions intensity fixed, by multiplying each industry's annual output by its estimated emissions intensity, calculated in a base year, and summing across industries.

The technique effect is calculated as a residual effect after accounting for scale and composition effects, and is the result of the accumulation of numerous micro channels that can affect emissions at the firm level. As is discussed by Cherniwchan et al. (2017), examples of these micro channels include reallocation across firms (as firms enter and exit and firm's market share changes), reorganization within firms, changes in sources of inputs (e.g. offshoring), or changes at the plant-level in the direct emissions intensity of tasks (including the switch to cleaner energy inputs).

The second step in the analysis is to identify the portion of the composition effect that can be attributed to changes in imports and exports. The BEA reports imports as "commodities." To accurately estimate the emissions displaced by imports of these goods and services, we need to know the industry mix that would have produced a unit of each imported commodity if it were, instead, produced domestically. To do so, we follow a similar approach to that used by Levinson (2009b), making use of the BEA's input-output tables to allocate the value added by the imported commodities to each of the domestic industries that would have otherwise produced them. Specifically, we use BEA input-output tables to calculate the annual share of each commodity that is produced by each domestic industry. This becomes our estimate of each industry's output that is displaced by the import of a given commodity each year. We then add the estimated *industry* imports (and subtract each industry's exports) in each year to obtain a no-trade counterfactual estimate of each industry's annual output. The resulting estimates are multiplied by each industry's emissions intensity, from 1997, and summed, to produce a no-trade estimate of the composition effect over time.

Lastly, we extend our counterfactual exercise further by providing a more detailed estimate of the annual U.S. CO_2e emissions actually avoided due to offshoring production. To do so, we multiply annual industry imports by their emissions intensity, calculated in that year, and sum across industries. In this analysis, industry imports, described above, represent an estimate of industry output displaced by intermediate and final goods imports.

2.2 Data

To estimate the relative contribution of of each channel identified in equation (3), we make use of economic data published in the BEA input-output tables and GHG emissions published in the EPA's 2017 publication "Inventory of Greenhouse Gas Emissions and Sinks: 1990–2015" (hereafter, "EPA-report").[11] The BEA input-output tables contain economic data on total shipments (gross output), value added, domestic intermediate inputs, imported intermediate inputs, imported final goods, and exports.[12] The EPA-report provides emissions encompassing several GHGs including CO_2, nitrous oxide (N_2O) and methane (CH_4). The GHG measures are standardized to their CO_2 equivalent (CO_2e) using each gas's 100 year global warming potential (GWP),[13] which are the values used in the following analysis. The EPA-report draws on energy-use data provided by the Energy Information Agency (EIA) to provide CO_2e emissions by six major sectors, Agriculture, Commercial, Electricity, Transportation, Mining and Manufacturing, though the EPA-report generally combines the latter two into a single "Industrial" sector.[14]

The EPA report further breaks down the sector-level emission by activity. We linked the emissions associated with these activities to corresponding industries in the BEA input-output tables, based on industry descriptions. For example, the emissions associated with the industrial activities "Ammonia Production" and "Adipic Acid Production" were matched to the "Chemical products" industry, while emissions associated with "Wastewater Treatment"

[11]Report number: EPA 430-P-17-001, EPA 2017 GHG Report

[12]BEA also provides industry-specific price indices and all of the following results are presented using constant prices.

[13]GWP weights used by the EPA were obtained from the Intergovernmental Panel on Climate Change (Pachauri and Reisinger (2007)). For CO_2 the weight is 1, for N_2O it is 298, and for CH_4 it is 25.

[14]The EPA-report also includes emissions due to Residential and U.S. Territories, but we limit our focus to productive U.S. sectors to match with the BEA economic output data.

and "Human Sewage" activities were matched to the "Waste management and remediation services" industry. Roughly half of the emissions of the commercial, mining and manufacturing sectors are due to "combustion or other fuel use" activities. The EPA-report links those emissions to their respective major sector based on the energy consumption of industries in that sector. We reverse the EPA aggregation, and distribute these combustion and fuel-use related emissions back to the component industries, using each industry's annual share of energy usage, calculated from the BEA's KLEMS (capital, labor, energy, materials, services) database.[15] The entire matching procedure is described in further detail in Appendix B.

The final data set links CO_2e emissions, output, imports, and exports for 58 industries from 1997–2015. These industries (NAICS codes in parenthesis) are agriculture (111), utilities (22), transportation (48), commercial-waste-management (562), thirty-three additional non-waste-management commercial industries, three industries in mining (211-213), and eighteen manufacturing industries (31-33).[16] Table 1 provides sample means and standard deviations for output, imported intermediate inputs (III), imported final goods, exports, and CO_2e emissions data for each major sector.[17]

[Table 1 approximately here]

While utilities and transportation are the two largest CO_2e producing industries, they are responsible for only small shares of national output and for very little international trade, which are major focuses of this study. We, therefore, chose to exclude these two sectors and concentrate our analysis on the 56 industries included in the agriculture, commercial, mining and manufacturing sectors. Our sample panel accounts for an average of 95 percent of output and 37 percent of U.S. CO_2e production from 1997–2015. Results including all 58 industries are qualitatively similar and are presented in Appendix A.

3 Results and Discussion

The results of the initial decomposition analysis are shown in Figure 2. The change captured by each channel is scaled to equal 100 in 1997 and results can be interpreted as cumulative percentage changes from 1997.[18] Using output at constant prices, line (1) documents a 36 percent rise in U.S. output, which is the scale effect. In the absence of cross-industry shifts in

[15] See https://www.bea.gov/data/special-topics/integrated-industry-level-production-account-klems

[16] Two manufacturing industries, petroleum products (324) and plastic products (326), are combined and matched with the EPA activity "Petrochemical Production."

[17] The mean values for each of the 58 sample industries are provided in Table 6 in the appendix.

[18] The percent-change from period 1 to period 2, in each channel, is calculated using the midpoint formula: $(X_2 - X_1)/[(X_2 + X_1)/2]$.

the shares of economic activity or changes in industry emissions intensities, CO_2e emissions of the 56 industries would have risen 36 percent from 1997 to 2015 due to rising production. Line (2) shows the actual change in CO_2e emissions: a decline of 12 percent. CO_2e emissions for the industries in the agricultural, commercial, mining, and manufacturing sectors declined consistently from 1997.

Line (3) represents the combined scale plus composition effect. To identify this channel, we calculate emissions intensity in each industry in 1997, and then multiply that constant value by each industry's annual output, and sum across industries. This captures the change in emissions–an increase of 19 percent–that would have occurred, holding sector emissions intensities constant at their 1997 value, and is thus equivalent to the sum of the first two terms in equation (3). The composition effect alone, identified as the difference between lines (1) and (3), reveals a decline in emissions of 17 percentage-points due to a shift of economic activity towards relatively cleaner industries. The differences between lines (2) and (3) represents the technique effect. Combined changes to scale, composition, and techniques drove a 12 percent decline in GHG emissions. The scale and composition together increased emissions 19 percent. Therefore, changes in the technique effect are responsible for the remaining 31 percentage-point decline in emissions.

[Figure 2 approximately here]

The cumulative results for each channel across the period are summarized in Table 2. As shown in column (4), the technique effect is responsible for 65 percent of the observed cleanup of U.S. CO_2e emissions over the period. The composition effect accounts for the remaining 35 percent of the gap between total output and CO_2e emissions growth over the period. These results indicate that both changes in the composition of U.S. output (as relatively cleaner industries expand), as well as changes in industry production techniques are important factors underlying the recent relative and absolute declines in U.S. CO_2e emissions.

[Table 2 approximately here]

3.1 International Trade

Results pertaining to U.S. international trade are shown in Figure 3. Line (1) in Panel A shows the percentage change in imported final goods and services, which increased by 84 percent. This is a corollary to the broader scale effect identified in Figure 2, representing an increase in CO_2e avoided by importing. Multiplying the transformed industry imports by their baseline 1997 industry emissions intensities, the corresponding composition effect of final imports is positive, approximately 19 percentage points higher than the increase in final goods imports. This indicates that imports whose production process (in the U.S.) is relatively dirtier have been growing more rapidly than imports of relatively cleaner goods and services. This shift magnifies the CO_2e avoided that is implied by considering the change in import volume (scale) alone. Thus, output displacement of relatively dirty products may be contributing a small degree to the domestic compositional shift towards cleaner output. We next follow the same procedure for U.S. exports. Line (1) in Panel B of Figure 3 shows that over the same period, exports have increased by 56 percent. Consistent with the positive composition effect estimated for imports, the composition effect of exports is negative as exports of relatively cleaner goods have been growing faster than exports of dirtier goods, with line (2) representing growth roughly 12 percentage points lower than line (1).

[Figure 3 approximately here]

We combine these import and export results by adding net-imports (imports minus exports) to each industry's annual output, and multiplying by the industry's 1997 baseline emissions intensity, and then summing across industries. This provides a counterfactual estimate of the scale plus composition effect that would have prevailed if domestic U.S. industries had produced the imported commodities, and had not had the opportunity to export. The resulting no-trade counterfactual scale plus composition effect is given by line (4) in Figure 2, and is a corollary to the combined scale plus composition effect identified by line (3) in the same figure. By examining the difference between lines (3) and (4), the emissions represented by the combined scale plus composition effect, in the no-trade scenario, would have been roughly one percentage point higher–this suggests that the trade induced composition effect has driven a small portion, roughly six percent,[19] of the decline in U.S. CO_2e emissions due to relative expansion of cleaner industries.

Although this analysis reveals that international trade has driven only a small percentage decrease in U.S. GHG emissions, since the U.S. economy is relatively large, small percentage changes can represent relatively large aggregate effects. As a final step, we estimate the tons of U.S. CO_2e emissions avoided in each year by shifting production offshore. To do this, we multiply industry imports of intermediate and final goods, used in the previous counterfactual analysis, by each industry's emission intensity estimated in that year.[20] The results, presented in Table 3, provide a more detailed estimate of the implied reductions in emissions due to imports of intermediate and final goods in each year.

[19]Roughly one percentage point of the 17 percentage point decline due to the composition effect, or 5.9 percent of the total output-emissions gap, can be attributed to additional pressure due to trade.

[20]As with the previous analysis, since imports are categorized as "commodities" we first calculates the share of each commodity import that would have been produced by each industry. We then multiply the implied industry output avoided by offshoring by each industry's emissions intensity from that year.

[Table 3 approximately here]

By this estimate, increased imports of intermediate and final goods represent a 28 percent increase in off-shored CO_2e emissions: rising from 227 million metric tons (MMT) in 1997, to 290 MMT in 2015, driven largely by increased imports of relatively dirty final goods. For reference, these displaced emissions would equate to nearly one percent of the 36 billion metric tons (BMT) of CO_2 emissions released globally in 2015 ([dataset] Boden et al. (2017)), and roughly 4.5 percent of the 6.0 BMT of U.S. CO_2 emissions released in the same year. It is important to note that these should not be taken to be estimates of corresponding increases in global emissions among the U.S's trading partners. The U.S.'s top five import partners (China, Canada, Mexico, Japan, and Germany, respectively) exhibit significant variation in terms of their economic development, approach to environmental regulation, energy access and usage patterns, and export industries. Given the large degree of variation in the global emissions intensity of various production processes documented in related research, foreign production of the goods and services that are increasingly imported into the U.S. may entail higher or lower GHG emissions than is implied using U.S. emissions intensities. To precisely assess the effect of this trade on net-global GHG emissions requires accurate emissions intensities by relatively narrow industry groups for each of the U.S.'s trading partners, and is beyond the scope of this analysis. Nevertheless, the relatively small percentage effects estimated here, suggest that domestic changes, within and across industries, are a much more important driver of observed declines in U.S. CO_2e emissions than increased trade and offshoring.

3.2 Additional discussion

Several additional observations should be clarified at this point. First, although our combined data set facilitates analysis across 56 major 2-, 3-, and 4-digit industries whose process and output vary in their CO_2e emissions intensity, the lack of available CO_2e emissions data at an even more dis-aggregated level means that the industry technique effect identified in this analysis could be masking additional within-industry compositional changes.

Second, as in Levinson (2009b), holding industry emissions intensity fixed allows identification of the trade-induced composition effect. However, the decomposition method employed here cannot separately identify a causal role of trade influencing industry emissions intensities from other potential drivers, for example technological upgrading, response to environmental regulation, or plant-level reallocation of economic activity towards cleaner facilities that could be coincident with increased trade. Recent work by Cherniwchan (2017) studies U.S. manufacturing firms' response to trade liberalization to directly estimate the environmental consequences of NAFTA for sulfur dioxide and particulate matter and finds effects large enough to explain roughly two-thirds of the within-industry technique effect documented by Levinson (2015).[21]

Third, we do not identify an immediate cause motivating the within and across industry changes identified. However, it is particularly notable that the gap between output and CO_2e emissions growth has been widening, and CO_2e emissions have been declining across the sample period, even in the absence of significant direct regulation. This suggests either spillovers from other air pollution regulations (Ambec and Coria (2018)), or an endogenous, perhaps unintended, consequence of firms' response to other economic pressures and incentives. Improvements in technology that allow for reduced energy usage is an obvious candidate in this regard.

3.3 Conclusion

GHG emissions pose a particular problem for regulators, relative to other pollutants, because, as a uniformly mixing pollutant, a ton of GHG emitted anywhere in the world has the same basic worldwide effect. This means that regulation that merely results in shifting economic activity and emissions to another region or country will actually not generate any meaningful improvements for the regulated region, and may even result in a global rise in GHG emissions.

Combining two relatively new data sets released by the BEA and EPA, we examine 56 industries representing a broad share of U.S. economic activity. Our analysis documents a 12 percent overall decline in U.S. GHG pollution (measured as CO_2 equivalents, CO_2e) emitted by the industries in our sample. We then decompose changes over time in CO_2e emissions into scale, composition, and technique effects. The results document that the main channel driving the wedge between output growth and falling aggregate CO_2e emissions is within-industry reductions in emissions intensity, a technique effect, which is responsible for nearly two-thirds of the gap between output and CO_2e emissions growth, the remainder being driven by shifts in the composition of U.S. output towards cleaner industries. This is a similar finding to papers studying the factors driving reductions in other forms of pollution in the manufacturing sector and could be a response to various changes to the economic environment including spillovers from environmental regulation or increased competitive pressure.

Another finding is the relative environmental contributions of a substantial increase in international imports and exports. The results indicate that increased trade, in both final and intermediate goods and services, contributed approximately six percent of the decrease in

[21] This result stands in contrast with findings by Shapiro and Walker (2018) suggesting that the majority of clean-up in manufacturing emissions is consistent with substantial increases in environmental regulation.

U.S. CO_2e emissions working through the composition effect. The large size of the U.S. economy means that the increased importation of intermediate inputs and final goods avoided roughly 290 MMT of CO_2e in 2015–representing less than five percent of total U.S. CO_2e emissions released in the same year. Of course, increased international trade could have an even greater impact on global emissions if foreign industries produce with higher emissions intensities. A detailed assessment of the net-global-effect of U.S. offshoring activity, comparable to the approach employed in this analysis, requires accurate estimates or measures of industry-level emissions intensities for each of the U.S.'s trading partners at a more dis-aggregated level than are generally available. Understanding the drivers underlying the relative and absolute decline in CO_2e emissions in the U.S. is important for the efficient design of policies intended to reduce such emissions and may provide implications for other major emitters. Our results suggest that international offshoring is unlikely a leading factor in the recent observed declines in U.S. CO_2e emissions. Our results are particularly interesting given the lack of direct environmental regulation of GHG emissions in the U.S. prior to 2011. Future work in this area may help to uncover the potential role of spillover effects from other environmental regulation or international trade and globalization working to influence the relatively large technique effect estimated here, and thus better inform regulators working to design policies to combat the growth, and cross-country shifts, of GHGs.

Acknowledgments

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Appendix A: Additional Results

In the main text, the analysis is limited to industries in four major sectors: Agricultural, Commercial, and the Mining and Manufacturing sectors (the latter two are generally combined, in the EPA-report into a singe "Industrial" sector). Results presented in Figure 4 (analogous to Figure 2, discussed in the main text) are estimated using emissions and output data covering 58 industries from six (instead of four) major productive U.S. sectors, by adding output, trade, and CO_2e data for the Utilities and Transportation sectors. The data set covers nearly 100 percent of U.S. output. The interpretation of each channel identified in Figure 4 is identical to the interpretation discussed for Figure 2 in the main text. Adding in the output and emissions of the largely non-traded electric-utility and transportation industries, the absolute decline in CO_2e emissions does not begin until 2007/2008. Consequently, the overall decline in CO_2e emissions is smaller than the decline documented in Figure 2 (a seven percent decline compared to a 12 percent decline). In general, though, the results are qualitatively similar to those presented in the main text.

[Figure 4 approximately here]

Appendix B: Matching Procedure

Annual BEA economic input-output (I-O) and trade data purport to cover all of the economic activity in the United States. These data, along with associated price indices, are publicly available and have been dis-aggregated by 71 industries back to 1997. The EPA-report details GHG emissions used in this paper, drawn primarily from tables 2-3 and 2-10. The EPA-report relies in part on energy-use data from the EIA which reports CO_2 emissions data across six major productive U.S. sectors: Mining and Manufacturing (which together comprise the "Industrial" sector), Agriculture, Commercial, Transportation, and Utilities.[22] The EPA-report additionally decomposes sector-level emissions into various specific *activities* that are responsible for significant shares of the sector totals.

To accomplish a more detailed industry-level match of GHG emissions and economic activity, we first aggregated the I-O data of seven 3-digit industries (481-487), provided by the BEA, to a single 2-digit (48) "Transportation" industry. We also aggregated the five industries covering federal, state, and local activity to a single "Government" industry (G). Finally, we combined the data for two manufacturing industries, "Petroleum and Coal

[22] The EPA report also includes GHG emissions for the Residential sector, as well as U.S. Territories. We focus on emissions associated with productive activity for which we have corresponding economic activity data from the BEA.

Products" (324) and "Plastic and Rubber Products" (326), which, together, were matched to to GHG emissions associated with the "Petrochemical Production" activity. This aggregation reduced the 71 BEA industries to 60. Due to the lack of associated GHG emissions data, we dropped two BEA industries, "Forestry" and "Construction", from the analysis,[23] resulting in a final set of 58 industries which we matched to GHG emissions data in the EPA-report. The primary analysis in the paper omits the two Utilities and Transportation industries. Results including all 58 industries are included in Appendix A.

Using definitions and glossaries provided by the EIA and BEA, we manually matched the BEA industries and EPA/EIA activities as shown in Table 4. Column (1) lists the parent EIA sectors associated with the reported GHG emissions data. Column (2) lists the activity descriptions by which the GHG emissions are decomposed. Column (3) lists the industry descriptions from the BEA I-O tables to which each GHG activity was matched. Column (4) lists the BEA I-O codes (which align with 2007 NAICS codes) associated with each BEA industry description. In a few instances, the sector-to-industry match was one-to-one: all Agricultural sector emissions were matched to the "Farming" industry (111), all emissions from the Electricity sector were matched to the "Utilities" industry (22), and all Transportation sector emissions were matched to the "Transportation" industry (48).

In addition to decomposing the GHG emissions of the various sectors by various specific emissions-intense activities, the EPA report decomposes emissions into other energy and fuel uses, including "CO_2 from Fossil Fuel Combustion," "Mobile Combustion," "Stationary Combustion," and "Non-Energy Use of Fuels." Emissions from these activities were assigned by the EPA to the respective sectors based on industry energy consumption data from the EIA.[24] For industries in the commercial and industrial (mining and manufacturing) sectors, we reverse the EPA aggregate approach,[25] by assigning emissions associated with these combustion activities in each sector to BEA industries based on each industry's annual share of energy usage, taken from the BEA's KLEMS database (capital, labor, energy, materials, services). We distributed industrial combustion-related emissions in this manner to all 22 mining and manufacturing industries, and we similarly distributed commercial combustion-related emissions to all 34 "Commercial" industries in the BEA data.[26] Table 5 provides

[23] The only GHG emissions associated with construction in the EPA report are assigned to the "Industrial" sector, and are included in the industrial activity "Mobile Combustion" (see EPA-report pp. 3-38 and 3-40). In total, the emissions associated with this industrial activity (which includes both construction and non-construction related mobile combustion), never exceed 0.1 percent of industrial emissions.

[24] Described in the EPA-report pp. 2-12 and 3-4.

[25] Additional description of the EPA approach is discussed in the EPA-report (pp. 3-4 and 3-18).

[26] The EPA-report attributes both mining and manufacturing activities to the "Industrial" sector. The BEA I-O data includes three mining sectors (211, 212, 213), and 19 manufacturing sectors (31-32). We used the same approach to distribute emissions from the Commercial sector's "Energy and Fuel Use" activity to "Waste management and remediation services" (562) as well as the other 33 commercial industry I-O codes:

associated industry descriptions from the BEA.

The GHG emissions activities that were matched, in Table 4, to the I-O Code "Other" for commercial and industrial sectors were dropped from the analysis due to the lack of a clear corollary in the BEA industry descriptions. These "Other" emissions represent less than one percent of total emissions, and less than 4.1 (0.1) percent of Industrial (Commercial) emissions.

Table 6 provides the average, from 1997–2015, of the annual industry measures of output, imports, exports, and GHG emissions for each of the 58 industries in the data set. This table is an expanded version of the data summarized in Table 1.

[Table 4 approximately here]

[Table 5 approximately here]

[Table 6 approximately here]

42, 44, 45, 4A, 49, 51-81 (including real estate and housing services: ORE and HS), and G.

Tables and Figures

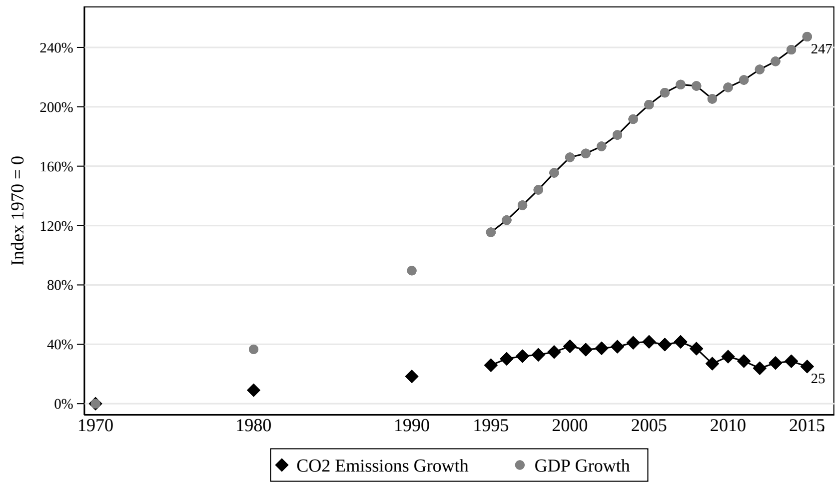

Figure 1: Growth in U.S. GDP and CO_2 Emissions: 1970–2015

Source: EPA Air Quality Trends Report (2017).

Note: This figure presents the percent change, normalized to 0 in 1970, in total annual GDP, and CO_2 emissions from all major U.S. sectors: residential, utilities, agricultural, commercial, industrial, and transportation.

Table 1: Average Output, Trade, and CO_2e data by major sector 1997 - 2015

	1997-2015				
Major Sector	Gross Output	III	Imported Final Goods	Exports	CO_2e
Agriculture	288,698	13,654	10,049	30,224	546
	16,012	*3,887*	*1,635*	*6,600*	*23*
Commercial	16,735,090	362,656	114,981	515,014	393
	2,043,002	*96,065*	*23,608*	*136,502*	*17*
Industrial (mining and manufacturing)	5,422,996	600,449	720,132	750,085	1,494
	262,918	*79,013*	*159,226*	*136,266*	*97*
Electricity	429,491	21,363	976	1,862	2,234
	55,124	*8,206*	*271*	*407*	*144*
Transportation	749,097	36,016	19,036	84,321	1,821
	50,738	*4,836*	*3,101*	*13,528*	*75*
Total	23,625,372	1,034,138	865,174	1,381,505	6,487
	Shares				
Agriculture, Commercial, and Industrial	95%	94%	98%	94%	37%
Electricity	2%	2%	0%	0%	34%
Transportation	3%	3%	2%	6%	28%

Note: This table includes mean annual values for each sector from 1997-2015. Standard deviations are in italics below each average value. Gross-output, Imported Intermediate Inputs (III), Imported Final Goods, and Export data are in millions of dollars and are provided at constant prices using industry-specific price indices from the BEA (base year is 2009). GHG data are measured in Million Metric Tons (MMT) CO_2 equivalents (CO_2e). The shares are the values for each sector, or group of sectors, divided by the total.

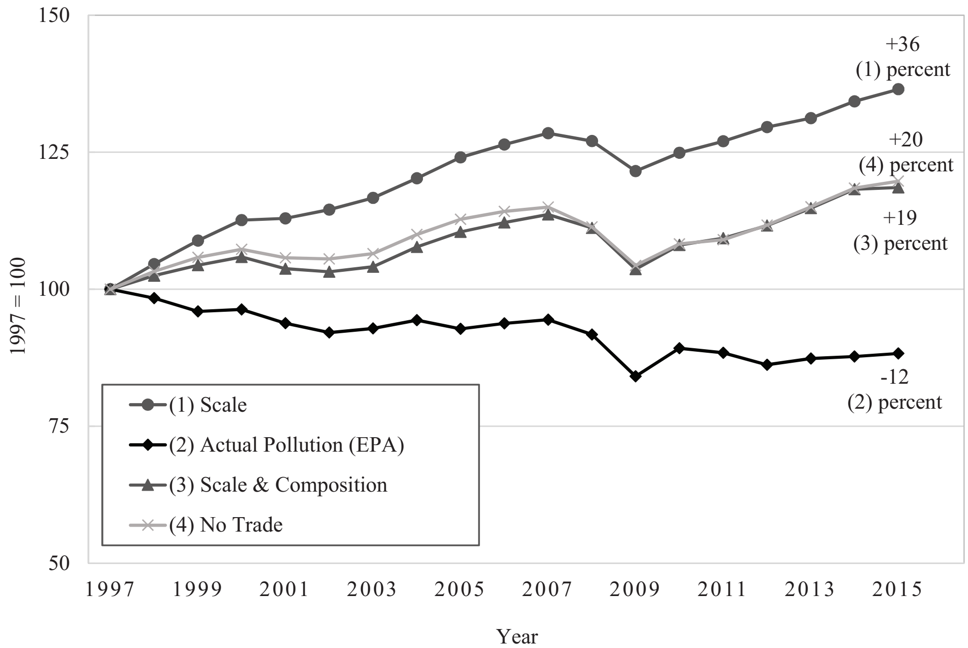

Figure 2: Change in U.S. CO_2e Emissions

Note: This figure presents the percent change in each of three channels contributing to CO_2e emissions in the U.S. The scale effect, captured by line (1) is the change in total output. This is the change in emissions that would have occurred over the period if there were no changes in the market shares or emissions intensity of any of the sample industries. Line (2) shows the actual change in CO_2e emissions. Line (3) is the combined scale + composition effect, and shows how emissions would have changed if industry emissions intensity were unchanged over the period. From equation (3), the difference between lines (1) and (3) is the composition effect. The difference between lines (2) and (3) is the technique effect. Line (4) is the scale + composition effect under a no-trade counterfactual analysis, in which each industries net imports (of final and intermediate goods) has been subtracted. Figure results are based on emissions and output data from 56 industries from the Agricultural, Commercial, Mining and Manufacturing sectors.

Table 2: Scale, Composition, and Technique Effects for U.S. CO_2e Emissions: 1997–2015

Pollutant	Scale (1)	Scale, and Composition (2)	Actual Change in Emissions (3)	Fraction of cleanup due to Technique (4)
GHG Emissions	0.36	0.19	-0.12	0.65

Note: This table presents the scale, composition, and technique effects estimated for U.S. CO_2e emissions. Column (4) presents the share of the total cleanup due to the technique effect, given by [(2)-(3)]/[(1)-(3)].

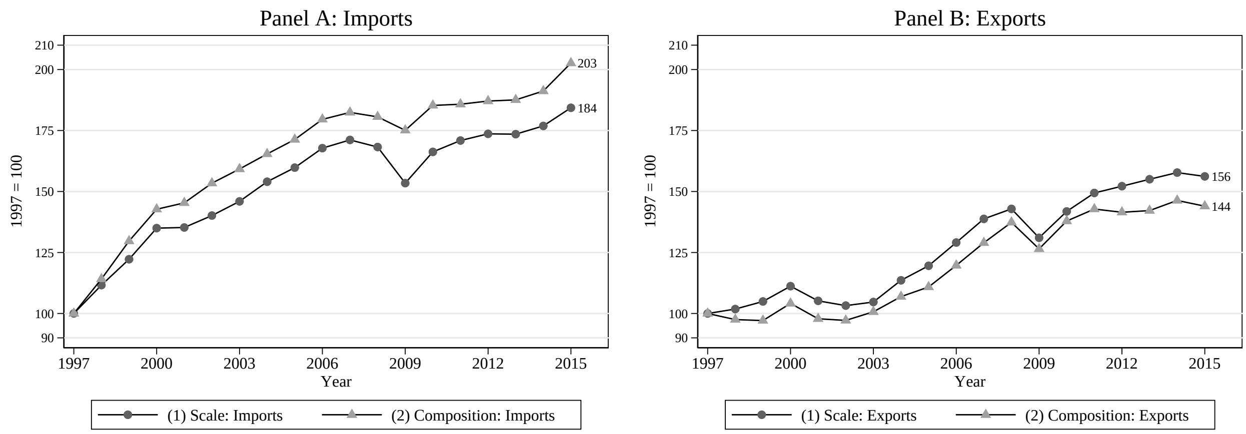

Figure 3: Change in Trade and Associated CO_2e Emissions

Note: These figures present the scale and scale+composition effects of trade. Line (1) of Panel A shows the percentages increase from 1997–2015 in imports of final goods, the scale effect. Line (2) captures the scale+composition effect and is obtained by multiplying industry values by the industry emissions intensity in 1997. From equation (3), this yields the percentage change in emissions holding emissions intensity fixed, which is the scale+composition effect. The difference between lines (1) and (2) represents the composition effect. Panel B shows the percentages changes for each of these measures, over the same period, for U.S. exports. Data underlying each figure is taken from the BEA input-output tables for industries from the Agriculture, Commercial, and Industrial sectors.

Table 3: Estimate of Annual CO_2e Avoided by Offshoring

	Imports (Constant Prices)		Associated CO_2e MMT (flexible emissions intensity)	
Year	Intermediate Inputs	Final Goods	Intermediate Inputs	Final Goods
1997	6,828	4,843	150	77
⋮	⋮	⋮	⋮	⋮
2000	8,585	6,875	167	103
2001	7,875	6,892	150	107
2002	8,202	7,238	153	110
⋮	⋮	⋮	⋮	⋮
2008	11,637	9,588	205	104
2009	9,224	8,266	147	104
2010	10,483	9,397	182	109
⋮	⋮	⋮	⋮	⋮
2015	11,096	11,260	157	133

Note: This table presents estimates of U.S. GHG emissions (measured in million metric tons (MMT) CO_2e) avoided by offshoring in each year. Industry output displaced by imports is measured in millions of dollars (in constant, 2009 prices) and is obtained using BEA input-output (IO) tables. BEA IO tables are used to determine the share of each commodity import that would have been produced by a domestic industry. Estimated CO_2e emissions avoided by offshoring are obtained by multiplying industry imports (of both final and intermediate goods and services) by the corresponding industry-emissions-intensity measure in that year. Annual values omitted to conserve space are monotonically increasing.

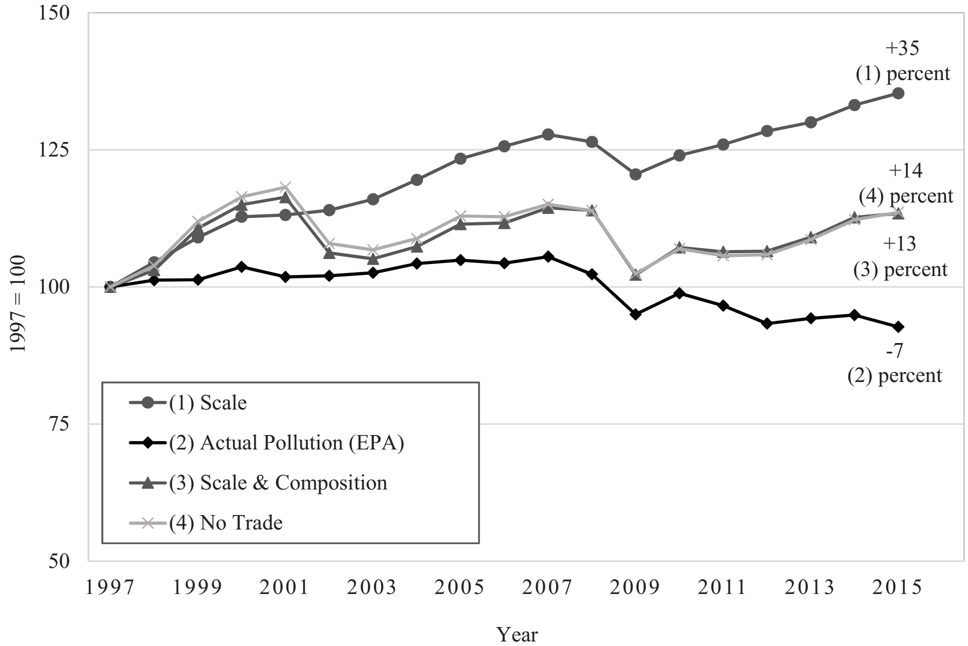

Figure 4: Change in U.S. CO_2e Emissions: All 5 Productive Sectors

Note: This figure is the corollary to Figure 2. The results presented in this Figure are, instead, based on data from 58 (instead of 56) industries, are obtained by adding in output, trade, and CO_2e data from the Utility and Transportation industries. The interpretation of each numbered channel is otherwise identical to Figure 2.

Table 4: EPA and BEA Sector Matching

Parent Sector (EIA) (1)	Activity Description (2)	BEA I-O Industry Description (3)	I-O Code (2007 NAICS codes) (4)
Agriculture	N2O from Agricultural Soil Management	Farms	111
Agriculture	Enteric Fermentation	Farms	111
Agriculture	Manure Management	Farms	111
Agriculture	CO2 from Fossil Fuel Combustion	Farms	111
Agriculture	Rice Cultivation	Farms	111
Agriculture	Urea Fertilization	Farms	111
Agriculture	Liming	Farms	111
Agriculture	Mobile Combustion (all mobile, non-transportation sources) [3-45]	Farms	111
Agriculture	Field Burning of Agricultural Residues	Farms	111
Agriculture	Stationary Combustion (CH4 and N2O, MMT CO2 eq.) [3-38]	Farms	111
Commercial	Landfills	Waste management and remediation services	562
Commercial	Wastewater Treatment	Waste management and remediation services	562
Commercial	Human Sewage	Waste management and remediation services	562
Commercial	Composting	Waste management and remediation services	562
Commercial	CO2 from Fossil Fuel Combustion	-	Energy and Fuel Use*
Commercial	Stationary Combustion (CH4 and N2O, MMT CO2 eq.) [3-38]	-	Energy and Fuel Use*
Commercial	Substitution of Ozone Depleting Substances	-	Other
Electricity	CO2 from Fossil Fuel Combustion	Utilities	22
Electricity	Stationary Combustion (CH4 and N2O, MMT CO2 eq.) [3-38]	Utilities	22
Electricity	Incineration of Waste	Utilities	22
Electricity	Other Process Uses of Carbonates	Utilities	22
Electricity	Electrical Transmission and Distribution	Utilities	22

Continued on next page

Table 4 – *Continued from previous page*

Parent Sector (EIA) (1)	Activity Description (2)	BEA I-O Industry Description (3)	I-O Code (2007 NAICS codes) (4)
Industrial	Natural Gas Systems	Oil and gas extraction	211
Industrial	Petroleum Systems	Oil and gas extraction	211
Industrial	Abandoned Underground Coal Mines	Mining, except oil and gas	212
Industrial	Coal Mining	Mining, except oil and gas	212
Industrial	Petrochemical Production	Petroleum and coal products; Plastic and Rubber Products	324; 326
Industrial	Adipic Acid Production	Chemical products	325
Industrial	Ammonia Production	Chemical products	325
Industrial	HCFC-22 Production	Chemical products	325
Industrial	Nitric Acid Production	Chemical products	325
Industrial	Phosphoric Acid Production	Chemical products	325
Industrial	Soda Ash Production and Consumption	Chemical products	325
Industrial	Titanium Dioxide Production	Chemical products	325
Industrial	Urea Consumption for Non-Agricultural Purposes [4-25]	Chemical products	325
Industrial	Cement Production	Nonmetallic mineral products	327
Industrial	Glass Production	Nonmetallic mineral products	327
Industrial	Lime Production	Nonmetallic mineral products	327
Industrial	Silicon Carbide Production and Consumption	Nonmetallic mineral products	327
Industrial	Aluminum Production	Primary metals	331
Industrial	Ferroalloy Production	Primary metals	331
Industrial	Iron and Steel Production	Primary metals	331
Industrial	Lead Production	Primary metals	331
Industrial	Magnesium Production and Processing	Primary metals	331
Industrial	Zinc Production	Primary metals	331
Industrial	Semiconductor Manufacture	Electrical equipment, appliances, and components	335

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Table 4 – *Continued from previous page*

Parent Sector (EIA) (1)	Activity Description (2)	BEA I-O Industry Description (3)	I-O Code (2007 NAICS codes) (4)
Industrial	CO2 from Fossil Fuel Combustion	-	Energy and Fuel Use*
Industrial	Mobile Combustion (all mobile, non-transportation sources) [3-45]	-	Energy and Fuel Use*
Industrial	Non-Energy Use of Fuels (includes LPG) [3-45]	-	Energy and Fuel Use*
Industrial	Stationary Combustion (CH4 and N2O, MMT CO2 eq.) [3-38]	-	Energy and Fuel Use*
Industrial	Carbon Dioxide Consumption	-	Other
Industrial	N2O from Product Uses	-	Other
Industrial	Other Process Uses of Carbonates	-	Other
Industrial	Substitution of Ozone Depleting Substances	-	Other
Transportation	CO2 from Fossil Fuel Combustion	Transportation	48
Transportation	Substitution of Ozone Depleting Substances	Transportation	48
Transportation	Mobile Combustion (all mobile, non-transportation sources) [3-45]	Transportation	48
Transportation	Non-Energy Use of Fuels (includes LPG) [3-45]	Transportation	48

Note: This table lays out the activity-to-industry matching procedure for the five sectors distinguished in the EPA-report: Agriculture, Commercial, Electricity, Industrial (which combines Mining and Manufacturing), and Transportation.
*"Energy and Fuel Use" emissions are distributed to all 22 manufacturing and mining industries (the eight listed with additional activity-specific emissions, plus 14 others from the BEA I-O tables) and 34 commercial industries (the one listed, 562, plus 33 others from the BEA I-O tables), based on their energy consumption share, calculated using energy-use measures from the BEA's KLEMS database.

Table 5: 71 BEA Industries and Descriptions

71 BEA I-O Codes	Industry Description	BEA I-O Codes, cont.	Industry Description
111CA	Farms	486	Pipeline transportation
113FF	Forestry, fishing, and related activities	487OS	Other transportation and support activities
211	Oil and gas extraction	493	Warehousing and storage
212	Mining, except oil and gas	511	Publishing industries, except internet (includes software)
213	Support activities for mining	512	Motion picture and sound recording industries
22	Utilities	513	Broadcasting and telecommunications
23	Construction	514	Data processing, internet publishing, and other information services
311FT	Food and beverage and tobacco products	521CI	Federal Reserve banks, credit intermediation, and related activities
313TT	Textile mills and textile product mills	523	Securities, commodity contracts, and investments
315AL	Apparel and leather and allied products	524	Insurance carriers and related activities
321	Wood products	525	Funds, trusts, and other financial vehicles
322	Paper products	HS	Housing Services
323	Printing and related support activities	ORE	Other Real Estate
324	Petroleum and coal products	532RL	Rental and leasing services and lessors of intangible assets
325	Chemical products	5411	Legal services
326	Plastics and rubber products	5415	Computer systems design and related services
327	Nonmetallic mineral products	5412OP	Miscellaneous professional, scientific, and technical services
331	Primary metals	55	Management of companies and enterprises
332	Fabricated metal products	561	Administrative and support services
333	Machinery	562	Waste management and remediation services
334	Computer and electronic products	61	Educational services
335	Electrical equipment, appliances, and components	621	Ambulatory health care services
3361MV	Motor vehicles, bodies and trailers, and parts	622	Hospitals
3364OT	Other transportation equipment	623	Nursing and residential care facilities
337	Furniture and related products	624	Social assistance
339	Miscellaneous manufacturing	711AS	Performing arts, spectator sports, museums, and related activities
42	Wholesale trade	713	Amusements, gambling, and recreation industries
441	Motor vehicle and parts dealers	721	Accommodation
445	Food and beverage stores	722	Food services and drinking places
452	General merchandise stores	81	Other services, except government
4A0	Other retail	GFGD	Federal general government (defense)
481	Air transportation	GFGN	Federal general government (nondefense)
482	Rail transportation	GFE	Federal government enterprises
483	Water transportation	GSLG	State and local general government
484	Truck transportation	GSLE	State and local government enterprises
485	Transit and ground passenger transportation		

Note: This table lists the 71 industry input-output (I-O) codes and corresponding descriptions covered by the BEA output and trade data. The codes and descriptions are copied from BEA input-output (I-O) tables, "https://www.bea.gov/industry/input-output-accounts-data".

Table 6: EPA and BEA Sector and Industry Matching

	1997-2015				
BEA Industry IO Code	Gross Output	III	Imported Final Goods	Exports	GHG
			Agriculture		
111	288,698	13,654	10,049	30,224	546
			Industrial (Mining and Manufacturing)		
211	235,666	11,841	565	7,828	277
212	111,736	4,872	707	9,827	130
213	57,440	2,027	123	1,260	10
311	755,329	41,347	32,893	45,504	116
313	71,334	6,352	15,407	9,131	15
315	42,833	4,121	92,916	5,696	5
321	86,261	6,613	1,323	4,405	19
322	181,806	16,722	2,550	19,187	93
323	99,601	6,070	3,774	3,566	12
324	673,131	195,996	24,100	64,455	112
325	671,094	45,324	75,494	116,982	236
327	113,623	6,081	4,599	8,120	118
331	214,718	28,633	519	22,050	188
332	334,154	22,976	10,636	27,994	45
333	341,658	35,794	61,292	91,499	24
334	340,301	33,925	124,576	96,364	23
335	126,960	12,960	27,515	25,825	15
3361	497,996	71,330	142,137	76,536	27
3364	243,842	30,784	22,032	85,761	13
337	78,911	7,276	21,774	3,494	7
339	144,601	9,402	55,199	24,604	9
			Commercial		
42	1,204,458	14,320	1,288	109,469	6
441	217,558	3,848	85	365	1
445	200,192	2,462	378	755	3
452	172,415	2,107	137	172	2
459	685,880	8,008	1,709	1,353	6
493	64,138	875	2	2,997	1
511	290,178	6,153	3,381	33,600	1
512	133,715	1,373	2,917	14,114	0
513	614,581	25,563	928	14,428	2
514	119,568	4,600	628	4,113	0
521	610,497	5,879	96	30,905	2
523	372,101	17,618	39	30,950	1
524	636,295	36,019	320	10,629	0
525	95,450	495	2	4	0
5310	1,493,021	1,988	0	3	0
5319	735,912	6,919	3	3,093	49
532	267,077	3,443	4	33,564	2
5411	280,653	2,206	666	8,777	0
5412	957,118	20,098	10,007	49,687	4
5415	247,799	4,948	3,326	7,182	1

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Table 6 – *Continued from previous page*

BEA Industry IO Code	1997-2015 Gross Output	III	Imported Final Goods	Exports	GHG
Commercial, cont.					
55	431,830	9,880	153	687	3
561	559,739	10,009	189	2,488	5
562	73,385	2,972	1	57	169
61	234,892	4,110	576	2,755	7
621	711,313	14,406	8	548	3
622	545,234	15,364	1,799	759	6
623	176,515	3,780	0	17	2
624	131,735	2,680	1	3	1
711	122,637	1,105	379	2,687	1
713	106,589	2,031	7	100	2
721	188,548	3,933	3	186	3
722	530,866	17,682	0	1,652	7
81	555,614	13,514	665	369	4
9	2,967,585	92,272	85,284	146,547	96
Electricity					
22	429,491	21,363	976	1,862	2,234
Transportation					
48	749,097	36,016	19,036	84,321	1,821

Note: This table includes mean annual values for each industry in the data set from 1997-2015. Industry descriptions are given in Table 5. The industry values have been grouped by their parent sector. Gross-output, Imported Intermediate Inputs (III), Imported Final Goods, and Export data are in millions of dollars and are provided at constant prices using industry-specific price indices from the BEA (base year is 2009). GHG data are in Million Metric Tons (MMT) CO_2 equivalents.

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