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# Import Competition and Firm-Level CO2 Emissions: Evidence from the German Manufacturing Industry

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# Import Competition and Firm-Level $CO_2$ Emissions: Evidence from the German Manufacturing Industry

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**Abstract**

Using the German census of the manufacturing industry, I analyze the impact of import competition on carbon emissions per unit of deflated sales (emission intensity). I combine precise information on firm-level $CO_2$ emissions with sector-level trade flows. Looking at the period 1995 until 2017, I focus on the impact of the rise of Eastern Europe and China while addressing the endogeneity of trade flows with an instrumental variable approach. The baseline results suggest that a 1pp increase in the import penetration ratio caused a reduction of the average firms' emission intensity by approximately 0.3%. This result implies that the rise of the joint East kept the average firm emission intensity 6% below the level it would have had in the absence of the East's rise. I do not find strong indication for reallocation of production towards more efficient firms. Finally, I supplement the analysis by examining the effect of export opportunities due to the East's rise. The results indicate that exporting to the East increased sales and, through that channel, lowered emission intensities.

**Keywords:** $CO_2$ Emission Intensity, Energy Efficiency, Import Competition, Manufacturing Firms, Environment, Germany
**JEL Classification:** F18, Q54, L60, D22

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# 1 Introduction

How trade and globalization affect environmental performance and, in particular, climate change is an important and widely discussed topic (cf. Copeland and Taylor, 2004; Cherniwchan et al., 2017). While older studies have mostly focused at country or sector level effects (cf. Copeland and Taylor, 1994; Cole and Elliott, 2003) more recent works have emphasized the importance of the underlying firm-level response to trade and globalization (cf. Barrows and Ollivier, 2018; Gutiérrez and Teshima, 2018; Cherniwchan, 2017; Forslid et al., 2018). For instance, this research has explored the role of Foreign Direct Investment on firms' energy use (Brucal et al., 2019) or the effect of firms' exporting status on $CO_2$ intensity of production (Richter and Schiersch, 2017). However, little is known about how import competition affects firms' $CO_2$ emissions and emission intensity. My paper addresses this gap by analyzing the effect of import competition on $CO_2$ emissions per unit of sales in the German manufacturing industry.

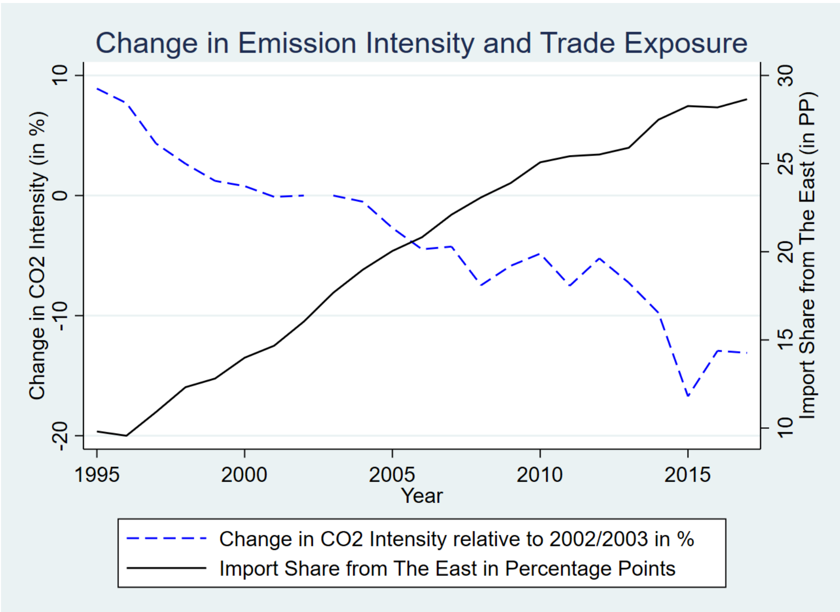
The role of competition in general and import competition in particular on firm-level productivity has received much attention in the literature. For example, Schmidt (1997) argues that increasing competition threatens firms' survival and thus forces managers to reduce slack. Indeed, previous empirical research that looks at firms in Europe has established a positive link between import competition and productivity and innovation (cf. Holmes and Schmitz, 2001; Bloom et al., 2015; Shu and Steinwender, 2019; Chen and Steinwender, 2021). Since the environmental and energy economics literature has identified energy use as particularly inefficient ("energy efficiency paradox"; cf. DeCanio, 1993), improvements in energy efficiency might appear as a "low-hanging fruit" from the perspective of a manager who needs to cut costs to ensure the firm's survival. Therefore, I expect fierce competition to affect the $CO_2$ intensity of production negatively.

For the empirical analysis I combine the German census of the manufacturing industry with sector level trade flows. The census data spans more than two decades from 1995 until 2017, covers the universe of manufacturing plants with more than 20 employees ($\approx$ 40.000 plants annually), and provides, among other things, detailed information on plant-specific fuel use. This information allows calculating $CO_2$ emissions based on fuel-specific conversion factors.[1]

[1] In recent years, the German manufacturing sector emitted approximately 200 million tons of $CO_2$ annually, roughly one-quarter of total emissions in Germany, absorbed more than 15% of Germany's labor force and contributed approximately one-quarter to Germany's gross domestic product. These figures reflect the central role of the manufacturing sector in the German economy.

To identify the effect of import competition on emission intensity, I exploit the rise of China and Eastern Europe as major actors in the world economy. A rising share of imported manufacturing goods in Germany originating from these regions is a manifestation of this process (cf. Figure 1). Indeed the rise of the East coincided with a substantial decline in the ratio of total $CO_2$ emissions to deflated sales.[2] For example between 1995 and 2017 $CO_2$ emissions per unit of sales declined by approximately 25% in my sample, while the share of imports from the East rose from 10% to almost 30% (cf. Figure 1). To uncover causal effects, I exploit the across sector variation in exposure to imports from the East, and I address the endogeneity of imports with an instrumental variable approach following Autor et al. (2014) and Autor et al. (2020).

**Figure 1:** Emission Intensity and Trade Exposure




Notes: The Figure shows the evolution of total emission intensity (i.e. $CO_2$ emissions per unit of deflated sales) relative to 2002/2003 and the change in the share of imports from China and Eastern Europe (i.e. imports from "the East" divided by total imports) Source: Research Data Centres of the Federal Statistical Office and the Statistical Offices of the Länder: AFiD-Panel and BAKI trade data, 1995-2017.

This paper relates to several strands in the literature. First and foremost it contributes to the literature on trade, globalization, and its effect on the environment.[3] By looking at the effect of import competition on $CO_2$ emission intensity in Germany, it relates closely to Gutiérrez and Teshima (2018) who study the effect of import competition on firms' energy efficiency,

[2]To deflate sales I use the 4-digit sector specific producer price indices published by the German statistical office ("Statistisches Bundesamt, Index der Erzeugerpreise gewerblicher Produkte (Inlandsabsatz) - Lange Reihen der Fachserie 17 Reihe 2").

[3]See Cherniwchan (2017) and Copeland et al. (2021) for recent reviews of the literature linking trade to the environment.

abatement expenditures and air pollution in Mexico. Using a measure of firms' exposure to output tariffs between 2000 - 2003, they find that energy efficiency increases with import competition while abatement expenditure decreases. Pollution levels around plants decrease when import competition increases, suggesting that the net effect of competition on environmental performance is positive. Cherniwchan (2017) studies the effect of trade liberalization in the context of the North American Free Trade Agreement (NAFTA) on US manufacturing plants' emissions of local pollutants (sulfur dioxide and particulate matter). He finds that lower Mexican tariffs lead to fewer emissions of $SO_2$ and PM10, which he attributes to the increased availability of emission-intensive intermediate inputs and export opportunities for American manufacturers. A related paper by Shapiro and Walker (2018) shows that within product changes in emission intensity explain most of the reduction in emission intensities in US manufacturing between 1990 and 2008. An environmental exporter-premium, like in Cherniwchan (2017), has been documented in various other contexts, e.g., Richter and Schiersch (2017) show that exporting firms in Germany are less emission-intensive and that emission intensity decreases with an increasing export share. Similarly, Barrows and Ollivier (2021) show that emission intensity among manufacturing firms from India decreases when demand in their export destinations goes up. However, the decline in emission intensity only partially off-sets the increase in total emissions resulting from higher production levels caused by the demand expansion. A related literature studies the effect of export opportunities on local pollution. For example, Kong et al. (2022) leverage differential cuts of export tariffs for Chinese firms to show that firms whose export tariffs dropped more released fewer local pollutants and Bombardini and Li (2020) study the effect of export opportunities on pollution and infant mortality at the regional level in China. Exploiting the differential exposure of regions to better export opportunities as a consequence of China's accession to the WTO, they find that export opportunities per se improve environmental conditions and lower mortality due to a positive income effect. However, if, due to the initial specialization of a region, particularly emission-intensive sectors start expanding, pollution levels and hence mortality can increase.

The paper further relates to the literature on the determinants of energy efficiency and the so-called "energy efficiency paradox" (cf. DeCanio, 1993; Jaffe and Stavins, 1994; Gerarden et al., 2017). As described above, the paradox refers to a seemingly sub-optimal firm behavior regarding energy use. It further manifests itself in a large dispersion of energy intensities within narrowly defined sectors. The literature has identified several potential explanations for inefficient energy use such as managerial inability (cf. Bloom et al., 2010; Martin et al., 2012), capital constraints (cf. Levine et al., 2018; De Haas et al., 2021) or market conditions such as size (Forslid et al., 2018). By linking changes in the level of competition to changes in $CO_2$ intensity, I investigate a further determinant of energy efficiency.

More broadly, my paper contributes to the literature investigating the effect of import competition from China and Eastern Europe on the manufacturing sector in western industrialized countries.[4] For instance, Bloom et al. (2015) relate changes in the share of Chinese imports at the sector level to firm-level innovation measures, documenting "trade induced technical change," i.e., technological upgrading, more patenting, and higher Total Factor Revenue Productivity (TFPR) among European firms. Chen and Steinwender (2021) find positive effects of import competition on productivity among initially unproductive family-owned firms in Spain. They provide evidence that competition forces unproductive firms to eliminate X-inefficiencies and improve material usage.[5] These results for firms operating in Europe stand in some contrast to findings by Autor et al. (2020) who analyze the change in imports from China on innovation measures among manufacturing firms in the US. They find a negative effect of increasing import competition on R&D expenditure and patenting. Indeed, the literature on import competition and innovation summarized by Shu and Steinwender (2019) finds "largely positive evidence for such [import competition increasing innovation] in Europe, and mixed evidence for such in Northern America".

Starting with a motivating exercise at the aggregate level, I decompose the three-digit-sector-level emission intensity in the average emission intensity across all firms in a sector (the "within-firm" component) and the covariance between firms' market shares and their emission intensities (the "between-firm" component) (cf. Olley and Pakes, 1996). The results show that total sector-level emission intensity is negatively related to imports from the East. The decomposition reveals that within-firm changes drive the efficiency-enhancing effect of import competition on sectoral emission intensity. If at all, the reallocation of market shares towards more productive firms played only a minor role.

[4] An abundant literature studies the labor market consequences, both on the regional and individual level, e.g., Autor et al. (2013), Acemoglu et al. (2016) and Autor et al. (2014) look at the US and Dauth et al. (2014) analyze the case of Germany. These papers document negative effects of import competition on employment. For the US, the China shock appears to be most relevant, whereas, for Germany, the rise of Eastern Europe was more critical.

[5] Chen and Steinwender (2021) refer to "X-inefficiency" when describing firm behavior that is suboptimal with regard to maximizing monetary profits resulting from managers having preferences that go beyond profit maximization.

The main firm-level analysis confirms the result from the sectoral decomposition. Baseline estimates imply a decrease of emission intensity in the range of 0.3%-0.4% in response to a 1pp increase in the share of imports from the East relative to baseline absorption (import penetration ratio). The negative effect of import competition on emission intensity is in line with findings for Mexico by Gutiérrez and Teshima (2018) which I introduced above. By looking separately at firms' $CO_2$ emissions and sales, I show that both decline due to increased import competition. However, the response of emissions is larger in magnitude, causing emission intensity to decline. The effect is centered on firms with above-median emission intensity, underlining the relevance of the effect for aggregate emissions and among firms operating in sectors with low import penetration in 1995. The results are robust to alternations of the regression specification. In the discussion section, I analyze the effect of import competition on emissions per unit of value-added, which can be calculated for a sub-sample of firms. This analysis yields quantitatively similar results and at least partly address the concern that "leakage" explains reductions in emission intensity of sales. The baseline results are also robust to an alternative identification strategy based on gravity residuals presented in the paper's appendix.

I supplement the main analysis of import competition's effect on emission intensity by examining the effect of new export opportunities to the East. This analysis relates closely to the literature that studies the effect of exporting on firms' energy use and emissions (cf. Richter and Schiersch, 2017; Barrows and Ollivier, 2021; Kong et al., 2022). My findings suggest a reduction of the average firms' emission intensity in response to better export opportunities. Unlike the main results, a rise in sales drives the decline in emission intensities. Furthermore, I find strong evidence for a reallocation of market shares towards more productive firms within sectors more exposed to improved export opportunities to the East.

The remainder of the paper is structured as follows: in section 2 I outline the empirical approach, and section 3 introduces the data-set, shows descriptive statistics, and provides first results at the sectoral level to motivate the main analysis. The main results from the firm-level analysis are presented in section 4 together with robustness checks and effect heterogeneities. Section 5 presents additional results to complement the main analysis and finally, section 6 discusses the findings and concludes.

## 2 Empirical Approach

To estimate the effect of import competition on firm-level outcomes consider the following regression specification.

$$y_{itz} = \beta_0 + \alpha IPR_{zt}^{East} + \nu_i + \epsilon_{itz} \tag{1}$$

The dependent variable $y_{itz}$ can be any outcome of firm $i$ in year $t$ operating in sector $z$. The coefficient of interest $\alpha$ captures the effect of an industry's exposure to imports from the East defined as total imports from the East in year $t$ scaled with initial absorption (cf. Autor et al., 2020). Concretely, the "import penetration ratio" (IPR) is defined as follows:

$$IPR_{zt}^{East} \equiv \frac{Imp_{zt}^{East}}{Y_{z,1995} + Imp_{z,1995} - Exp_{z,1995}} \tag{2}$$

Finally, $\epsilon_{itz}$ in eqation 1 is a random error term. I follow Bloom et al. (2015) by taking long differences (four years) which eliminates the firm fixed effect $\nu_i$. The differenced equation reads as follows:

$$\Delta y_{itz} = \beta_0 + \alpha \Delta IPR_{zt}^{East} + \Delta\epsilon_{itz} \tag{3}$$

The regressions I take to the data may or may not include additional sets of fixed effects, e.g. year dummies or year by emission intensity decile dummies, to control for annual shocks or shocks occurring along the energy-intensity distribution.

To estimate a causal effect of the trade exposure of a sector on firm-level outcomes, requires addressing the endogeneity of trade flows. For instance, demand conditions in Germany are expected to affect imports and domestic firms' behavior simultaneously. Suppose the demand for some goods, e.g. heat pumps and solar panels, suddenly increases in Germany. That will affect the imports of respective goods but also affect domestic firms producing those goods. For example, their production will increase, they will need more energy inputs and their energy intensity might increase since expanding production beyond the efficient level will still be profitable given high demand and thus higher prices. I employ an instrumental variable (IV) strategy similar to Autor et al. (2013) and Dauth et al. (2014) to address this concern and isolate the supply-driven increase in imports form the East, i.e. the component of the change in imports caused by the arguably exogenous rise of China and Eastern Europe. To instrument the change in imports from the East to Germany in industry $z$, I use the change in trade flows from the East in industry $z$ to a set of other countries.[6]

$$IPR_{zt}^{Other \leftarrow East} \equiv \frac{Imp_{zt}^{Other \leftarrow East}}{Y_{z,1995} + Imp_{z,1995} - Exp_{z,1995}}$$

The idea is that part of the variation in the imports from the East to Germany is due to a rising comparative advantage of the East or lower trade costs. The instrument is relevant for this part of the variation as the rise of the East also affects trade flows to the other countries. The other part of the variation is due to domestic conditions inside Germany. As explained above, I need to separate out this component of the total change in the IPR. Under the assumption that demand conditions in Germany are orthogonal to the demand conditions in the chosen set of other countries, the instrument separates the exogenous component of trade flows to Germany from the endogenous. Moreover, for the instrument to be valid, I need to assume that trade flows between the set of other countries and the East have no direct effect on German firms (exclusion restriction). These considerations need to guide the selection of an appropriate set of countries for the instrument group. I follow Dauth et al. (2014) who included Australia, Canada, Japan, Norway, New Zealand, Sweden, Singapore, and the United Kingdom. All of which are high-income countries but neither directly border Germany nor is any of them a member of the European Monetary Union (EMU). Dauth et al. (2014) argue that demand conditions among neighboring countries are too similar and that the fixed exchange rate within the EMU might cause a violation of the exclusion restriction if changes in trade flows between other countries and the East directly affect German industries.[7] Finally, for the instrument to work, it needs to be relevant, which can be tested however, and is indeed confirmed by the first-stage results reported in section 4.

[6]Ideally, I would like to use lagged absorption from the period before the rise of the East in the denominator of the instrument. Due to data limitations this was not possible, however. The statistical office provides production data at the economic sector level, based on the sector classification from 1993, only since 1995. Before 1995 information on sectoral production is available for the sector classification from 1979. The statistical office could not provide a mapping between the classifications.

[7]A further concern in the context of this application might relate to global energy price shocks simultaneously affecting a specific sector in Germany and exports from the same sector in the East to the instrument countries. Table A3 in the appendix correlates changes in sectoral energy prices in Germany with export flows from the East to the instrument countries. Conditional on year fixed effects sectoral energy prices in Germany and exports from the East to the instrument countries do not co-move.

# 3 Data, Descriptive Statistics and Motivating Exercises

## 3.1 Data

The main data source is the German census of the manufacturing industry called AFiD (Amtliche Firmendaten für Deutschland). The census data covers the universe of German industrial plants with more than 20 employees. The data consists of different "modules" of which I combine *"AFiD Modul Industriebetriebe"* (industrial plants module) with *"AFiD Modul Energieverbrauch"* (energy use module).[8] The "industrial plants module" contains economic variables such as sales, sales abroad, number of employees and investment. I use the 4-digit sector-specific producer price indices published by the German statistical office to deflate the monetary values. The energy use module details plant-specific energy use by fuel type. Energy use is reported in physical units (kWh) and can thus be converted to $CO_2$ emissions based on fuel-specific conversion factors (cf. Richter and Schiersch, 2017; Petrick et al., 2011).

For the conversion of energy from primary sources, I draw upon the emission factors provided by the Umwelt Bundesamt (a Federal Agency).[9] To account for indirect emissions resulting from the generation of electricity that firms buy from the grid, I take the average carbon content of the German electricity mix, which varies by year (cf. Umweltbundesamt, 2018). The sum of direct and indirect emissions is total emissions.

A major caveat with the energy data is a break in the reporting between 2002 and 2003. The time series before and after 2003 is internally consistent. In my estimation, I make sure to exclude variation that results from the break in the reporting by excluding years from the sample in which subtracted lags, used in difference calculations, predate 2003.[10] Finally, I aggregate plant-level information to the firm-level. The final firm-level data set is an unbalanced panel covering 1995 until 2017.

I supplement the main data with the so-called "*cost structure survey*" which is also part of the German census.[11] The cost structure survey provides information on intermediate input expenditure, which allows calculating value-added. I estimate the effect of import competition

[8]AFiD-Modul Industriebetriebe: Source: DOI: 10.21242/42111.2021.00.01.1.1.0, own calculations.
AFiD-Modul Energieverbrauch: Source: DOI: 10.21242/43531.2021.00.03.1.1.0, own calculations.

[9]A with the relevant information can be found here, last retrieved 18.11.2020. The table gives the fuel-specific time-varying $CO_2$ content per terajoule. This unit can be converted to $CO_2$ per kWh. We then multiply the fuel use in kWh with the respective conversion factor to obtain the $CO_2$ emissions.

[10]For a detailed description of the energy use module as well as the change in reporting, see Petrick et al. (2011)

[11]AFiD-Modul Kostenstrukturerhebung: Source: DOI: 10.21242/43221.2021.00.01.1.1.0, own calculations.

on the emission intensity of value-added for comparison. Since the cost structure survey is an unbalanced panel, including most firms for four consecutive years only, the analysis of the effect of import competition on value-added is only feasible for a subsample of firms. This sampling procedure also dictates the choice of the differencing, i.e. taking longer than four-year differences would not be feasible with this data.

I rely on the BAKI database for information on bilateral trade flows, which is constructed from the United Nations Commodity Trade Statistics Database (Comtrade) and provided by CEPII. The database reports trade flows at the 6-digit product level from the Harmonized System (HS) nomenclature. To merge the trade information to the firm-level data, I aggregate from the product level to the 3-digit economic sector level using the classification from 1993 (equivalent to NACE industry codes).[12] I fix firms' economic sector to the sector from the first year in which the firm appears in AFiD.

The final dataset is cleaned from outliers. Specifically, I drop firms with either $CO_2$ emission intensity, the four-year change in $CO_2$ emission intensity or sales below the $1^{st}$ percentile or above the $99^{th}$ percentile. I also omit the economic sectors *"Manufacture of office machinery and computers"* (WZ 30) and *"manufacturing of radio, television and communication equipment and apparatus"* (WZ32). Over the period 1995 to 2017, both sectors have been subject to rapid technological changes, quality upgrading, and falling prices. Because of this development, the producer price index in these sectors are outliers making a comparison of deflated sales as measures of physical output over time difficult.[13] In a robustness check I show results obtained from a sample that includes both sectors.

### 3.2 Descriptive Statistics

Table 1 shows summary statistics from the estimation sample for firm-level variables pooled over the period 1995 until 2017. The average firm in the data has close 116 employees and generates approximately 23 million euros annual turnover. The median for both - employees and sales

[12]To be precise, I first convert the product-level information from HS92 to SITC3 (conversion table was downloaded here) and then I map from SITC3 to the 3-digit industry classification using the same mapping as Dauth et al. (2014). The industry classification from 1993 was in place until 2008 with minor modifications in 2003. Therefore, I omit all firms from the analysis that were first observed only after 2008 since the economic sector based on the classification from 1993 is unknown for these firms.

[13]The average PPI in the manufacturing sector increased moderately from 94 in 1995 to 107 in 2017 (indexed to 100 in 2010), while the average PPI in WZ 30 collapsed from 307 to 81 and in WZ 32 from 217 to 89 in the same period.

- is considerably lower than the average (54 employees and 6.7 million turnover), indicating a right-skewed distribution. Similarly, the average export share amounts to 18%, while the median export share is only 7%. At the $90^{th}$ percentile, exports account for the majority of total sales (56%). Information on value-added comes from the cost structure survey, which covers only about 40% of the manufacturing sector. The average firm's value added amounts to 24 million euros, more than the average sales in the primary dataset, reflecting the oversampling of large firms in the cost structure survey. The share of value-added, i.e., value-added divided by sales, amounts to 60% on average. In addition to indicators of economic performance, Table 1 summarizes total energy use in megawatt-hours (Mwh), electricity use in Mwh, as well as total $CO_2$ emissions in tons (t). On average, firms used 11048 Mwh annually, of which approximately one-third was electricity purchased from the grid (3619 Mwh). The average firm's energy use caused 3722 tons $CO_2$ emissions. Comparing the median firm's energy use with the energy use at the $90^{th}$ percentile indicates that energy consumption and related emissions appear to be very concentrated (even more right-skewed than the econ. variables with a p90 to p50 ratio of approximately 10). Indeed, averages are close to the $90^{th}$ percentile, indicating a long-tailed distribution of energy consumption. Finally, the table's last row shows the average firm's import penetration ratio from the East amounting to $\approx$ 9pp. This average masks strong dynamics over time, similar to the evolution of the import share from the East shown in Figure 1 and described further by Table A2 introduced below.

**Table 1:** Descriptive Statistics - Firm Level Information

| Variable | Mean | Std. Dev | p10 | p50 (Median) | p90 | N |
|---|---|---|---|---|---|---|
| Number of Employees | 116 | 188 | 24 | 54 | 255 | 744062 |
| Sales | 22923.2 | 53710.3 | 1729.5 | 6705.33 | 51559.5 | 744062 |
| Export Share | 0.18 | 0.24 | 0 | .07 | 0.56 | 744062 |
| Value Added | 23726.5 | 56173 | 1668.8 | 7398.2 | 58492.91 | 297241 |
| Value Added Share | 0.60 | 0.17 | 0.37 | 0.61 | 0.82 | 297241 |
| Total Energy (in MWh) | 11048.7 | 103877.5 | 155.8 | 933.5 | 12400 | 744062 |
| Total CO2 Emissions (in t) | 3722.4 | 31634.2 | 65.9 | 381.7 | 4823.46 | 744062 |
| Total electricity (in Mwh) | 3619.55 | 29104.7 | 64.4 | 423.3 | 5351.5 | 744062 |
| IPR | 8.85 | 9.94 | 1.04 | 5.26 | 20.44 | 744062 |

Notes: The table shows the average of respective variables from the period 1995-2017. Delflated sales and value added are in 1000 Euro, energy use (total and electricity) is in MwH and $CO_2$ emissions in tons. Source: Research Data Centres of the Federal Statistical Office and the Statistical Offices of the Länder: AFiD-Panel Industriebetriebe, 1995-2017, own calculations.

Table A2 in the appendix provides further information regarding the exposure of the German manufacturing sector to imports from the East. The table shows summary statistics for imports from China and Eastern Europe from 22 two-digit industries and respective shares. For instance, in 1995, the average sectoral import volume of goods from China amounted to $\approx$ 350 Mio USD;

hence, the total value of manufacturing imports from China in 1995 was just 8 billion USD ($\approx$ 22*350 Mio USD). This amount corresponds to an import share of 2%. Until 2017 this share rose to 10%, corresponding to imports worth 89 billion in total ($\approx$ 4 billion from the average two-digit sector). Similarly, imports from Eastern Europe rose from 32 billion USD ($\approx$8% of total imports) in 1995 to 200 USD in 2017, corresponding to an import share of nearly to 20%. These averages mask substantial variation across the 22 two-digit economic sectors: the share of imports from the least exposed sector ("Manufacture of tobacco products", NACE Rev.1 16) was merely 1.4% in 1995. In contrast, the most exposed sector's import share amounted to 27% already ("Manufacture of wearing apparel; dressing and dyeing of fur", NACE Rev.1 18). Twenty-two years later the import share from the East ranged from 11% in "Manufacture of chemicals and chemical products" (NACE Rev.1 24) to 58% in "Manufacturing of office machinery and computers" (NACE Rev.1 30). The initial import share in the chemical industry was 6.5% in 1995 and in "Manufacturing of office machinery and computers" only around 3%. The rise in this sector was driven by imports from China after its WTO accession. The import share in "Manufacturing of tobacco products" increased to $\approx$ 51% in 2017 driven mainly by Eastern Europe. This increase started in 2004 when the Eastern enlargement of the European Union happened. Indeed, between 1995 and 2017 the share of imports from the joined East rose in all sectors.

### 3.3 Motivating Exercise: Sectoral Decomposition of Emission Intensity

Before I turn to the actual firm-level analysis of the effect of import competition on firms' emission intensity, I describe the evolution of aggregate sectoral emission intensity from 1995 until 2017. Following Olley and Pakes (1996) and Brucal et al. (2019), I decompose aggregate sector-level-emission-intensity in an unweighted mean and a covariance term. The latter captures the association between firms' market shares and their emission intensities. The following expression describes the decomposition:

$$\underbrace{W_{zt} = \sum_{i \in Z} s_{it} lnE_{it}}_{\substack{\text{Weighted } CO_2 \text{ Intensity} \\ \text{in Sector Z}}} = \underbrace{\overline{lnE_{zt}}}_{\substack{\text{Unweighted avg.} \\ \text{Intensity}}} + \underbrace{\sum_{i \in Z} (s_{it} - \overline{s_t})(lnE_{it} - \overline{lnE_t})}_{Covariance} \tag{4}$$

where $s_{it}$ is the share of sales by firm $i$ in total sales in sector $z$ ($i'$s market share) at time $t$, $\overline{lnE_{zt}}$ is the average emission intensity from all firms in sector $z$ and $\overline{s_t}$ is the average market share in sector $z$.

The aggregate weighted emission intensity in sector $z$ ($W_{zt}$) can be re-written as the average emission intensity from all firms in sector $z$ ($\overline{lnE_{zt}}$) and the covariance term. A negative covariance implies higher market shares for more carbon-efficient firms (the inverse of carbon intensity) and thus reflects a more efficient allocation of economic activity across firms. Changes in this term capture a reallocation of market shares across firms with different carbon efficiency, e.g. a decrease implies a reallocation of market shares towards firms with a lower carbon intensity (higher carbon efficiency). Changes in the unweighted average emission intensity reflects changes in carbon efficiency within firms.

Figure 2 shows the evolution of the weighted average, the unweighted average, and the covariance term averaged across economic sectors. One can see that the weighted average decreased by approximately 40% between 1995 and 2017 as indicated by the solid black line. Interestingly, within-firm changes (dotted red line) drive this process almost entirely. Reallocation has played only a minor role in decreasing the weighted emission intensity, contributing at most four percentage points, as seen from the dashed blue line. The most visible drop in the covariance term happened between 2007 and 2009, coinciding with the financial crisis. The financial crisis caused the most significant contraction in manufacturing output in the history of the Federal Republic of Germany - and thus quite plausibly forced the least efficient firms to exit the market.

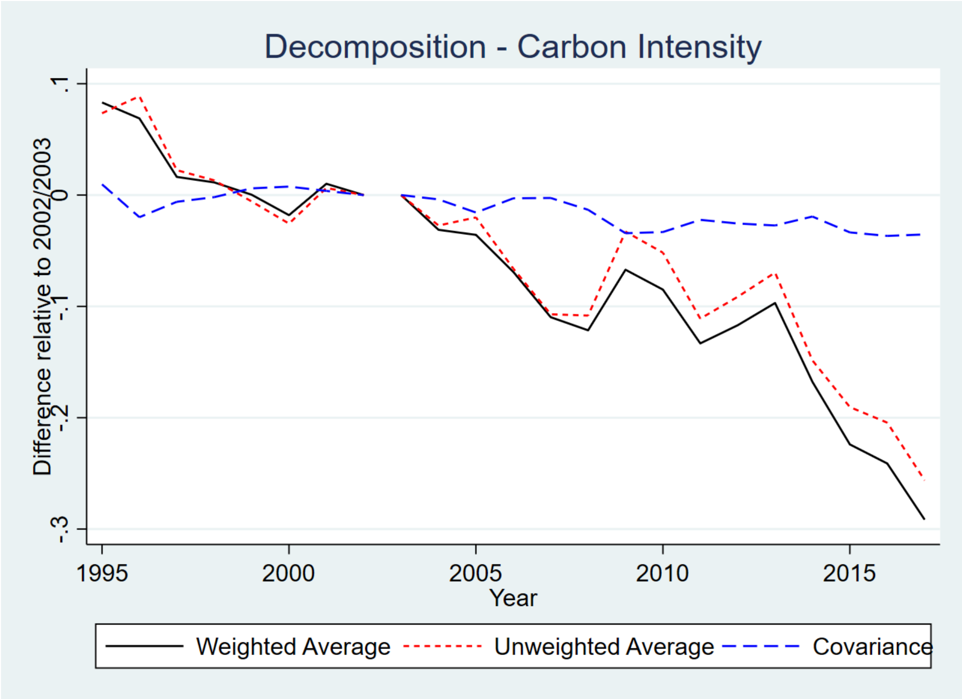
I regress changes in the log of weighted sector-level emission intensities and their components against changes in sector-specific IPRs from the East to gauge the carbon efficiency-import competition link. The estimating equation is given below.

$$\Delta y_{zt} = \beta_0 + \beta_1 \Delta IPR_{zt}^{East} + \tau_t + \Delta\epsilon_{zt} \tag{5}$$

Each regression includes year dummies ($\tau_z$) as controls. Table 2 shows results from an OLS estimation and the IV approach introduced in section 2. The Kleibergen-Paap F-statistic provided at the bottom of the table indicates a strong first stage.

Looking at the effect of imports on the weighted mean, one can see that the OLS result and the IV result go in the same direction, indicating a statistically significant decrease in sectoral emission intensity by 0.41% (IV) and 0.35% (OLS) in response to a 1pp increase in the IPR from the East.

**Figure 2:** Decomposition of Sectoral Emission Intensity




Notes: The figure shows the average across three-digit sectors from a decomposition of total emissions (weighted average) in the unweighted average and the covariance between market share and $CO_2$ intensity. Source: Research Data Centres of the Federal Statistical Office and the Statistical Offices of the Länder: AFiD-Panel and BAKI trade data, 1995-2017.

Looking at the components of the total effect, one can see that within-firm changes, i.e., changes in the unweighted mean, explain more than 75% of the total effect. The IV and OLS results are negative and statistically significant and point to a within-firm improvement in emission intensity by 0.33% and 0.28%, respectively. By construction, the point estimate capturing the effect of import competition on the covariance term explains the difference between the effect on the weighted mean and the effect on the unweighted mean. Hence, respective IV and OLS estimates are negative but small and statistically insignificant. Specifically, the IV estimate implies that a 1pp higher IPR from the East depresses the covariance term by 0.09% and thus suggests a small within-sector reallocation effect at most.

## 4 Main Results: Firm-level Effects

In this section I first present baseline results on the effect of import competition on firms' emission intensity. I then conduct a series of robustness and sensitivity checks. Finally effect heterogeneities are analyzed.

**Table 2:** Import Competition from the East and Log $CO_2$ Intensity - Sectoral Effects

| | Weighted Mean | | Unweighted Mean | | Covariance | |
|---|---|---|---|---|---|---|
| | (IV) | (OLS) | (IV) | (OLS) | (IV) | (OLS) |
| **Panel A – 3. Digit Sector Level** | | | | | | |
| $\Delta$ Imports | -0.0041** | -0.0035** | -0.0033** | -0.0028*** | -0.0009 | -0.0007 |
| | (0.0021) | (0.0016) | (0.0014) | (0.0009) | (0.0016) | (0.0012) |
| Number of Observations | 1,290 | 1,290 | 1,290 | 1,290 | 1,290 | 1,290 |
| Kleibergen-Paap $F$-Statistic | 52.15 | | 52.15 | | 52.15 | |
| Year dummy | Yes | Yes | Yes | Yes | Yes | Yes |

*Notes:* * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$. The table shows IV and OLS regression results from a long difference regression estimated at the 3-digit sector level for three dependent variables (given at the top). The dependent variables are the corresponding four-year changes. "Weighted mean" is total emissions divided by total sales in sector z. "Unweighted Mean" is the average firm's $CO_2$ intensity in sector z. "Covariance" is the covariance between a firm's market share and a firm's $CO_2$ intensity. The years 2003 - 2006 were excluded due to a break in the reporting of energy variables between 2002 and 2003. The explanatory variable is the four-year change in imports from China and Eastern Europe scaled with domestic absorption in 1995 for each three-digit industry. The instrument is the four-year change of exports from China and Eastern Europe to other countries in each three-digit industry. Source: Research Data Centres of the Federal Statistical Office and the Statistical Offices of the Länder: AFiD-Panel Industriebetriebe, 1995-2017, own calculations.

## 4.1 Baseline Results

Table 3 presents the baseline results. The dependent variable in Panel A of the table is the four-year change in the logarithm of firms' $CO_2$ emission intensities. Panel B and C report results with the four-year change in the logarithm of firms' $CO_2$ emissions and firms' sales as dependent variables. The explanatory variable is the corresponding change in the IPR from China and Eastern Europe. Specifications reported in columns (1) to (5) are IV estimates, and columns (6) and (7) show OLS estimates for comparison. At the bottom of the table, I detail the fixed effects included in each specification. The fixed effects are interactions between emission intensity-, sales- and export share-decile dummies and years. First-year values determine the assignment of firms to respective deciles.[14] Column (5) and (7) show the most demanding specification which controls for trends within twelve broadly defined industries (cf. Autor et al., 2014; Autor et al., 2020). Standard errors were clustered at the firm level to account for within-firm auto-correlation and at the year-3-digit-sector-level (two-way clustering). In a robustness check, I show results with standard errors clustered at the 3-digit-sector-level only. At the bottom of the table, I report first-stage results (coefficient, standard errors and Kleibergen-Paap F-statistic). Recall also that I excluded the years 2003, 2004, 2005 and 2006 to accommodate the break in the reporting of energy variables between 2002 and 2003.

[14]For emission intensities, I updated the deciles in 2003 since the new energy use survey that was introduced in 2003 incorporates new fuels that were previously not captured.

**Table 3:** Baseline Results - Logs of Emission Intensity, Emissions and Sales

| | IV Estimates | | | | | OLS Estimates | |
|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
| **Panel A – Log of $CO_2$ Emission Intensity** | | | | | | | |
| $\Delta$ Imports | -0.0009 | -0.0036$^{***}$ | -0.0035$^{***}$ | -0.0028$^{***}$ | -0.0018$^{**}$ | -0.0031$^{***}$ | -0.0006 |
| | (0.0007) | (0.0007) | (0.0007) | (0.0007) | (0.0008) | (0.0005) | (0.0005) |
| Number of Observations | 403,367 | 403,367 | 403,367 | 403,367 | 403,367 | 403,367 | 403,367 |
| **Panel B – Log of $CO_2$ Emissions** | | | | | | | |
| $\Delta$ Imports | -0.0033$^{***}$ | -0.0058$^{***}$ | -0.0059$^{***}$ | -0.0065$^{***}$ | -0.0018$^{**}$ | -0.0010$^{**}$ | 0.0013$^{***}$ |
| | (0.0008) | (0.0010) | (0.0010) | (0.0010) | (0.0007) | (0.0005) | (0.0004) |
| Number of Observations | 403,367 | 403,367 | 403,367 | 403,367 | 403,367 | 403,367 | 403,367 |
| **Panel C – Log of Sales** | | | | | | | |
| $\Delta$ Imports | -0.0024$^{**}$ | -0.0022$^{**}$ | -0.0024$^{**}$ | -0.0037$^{***}$ | 0.0000 | 0.0021$^{***}$ | 0.0019$^{***}$ |
| | (0.0011) | (0.0010) | (0.0011) | (0.0011) | (0.0010) | (0.0006) | (0.0006) |
| Number of Observations | 403,576 | 403,576 | 403,576 | 403,576 | 403,576 | 403,576 | 403,576 |
| **First Stage Results** | | | | | | | |
| $\Delta$ Instrument | 0.3731$^{***}$ | 0.3687$^{***}$ | 0.3690$^{***}$ | 0.3615$^{***}$ | 0.3463$^{***}$ | | |
| | (0.0264) | (0.0264) | (0.0264) | (0.0265) | (0.0292) | | |
| Kleibergen-Paap $F$-Statistic | 200.38 | 194.99 | 195.43 | 186.61 | 140.31 | | |
| Adjusted $R$-Squared | 0.46 | 0.47 | 0.47 | 0.48 | 0.60 | | |
| Number of Observations | 403,576 | 403,576 | 403,576 | 403,576 | 403,576 | | |
| Year dummy | Yes | | | | | | |
| $CO_2$ intensity-decile-year-dummy | | Yes | Yes | Yes | Yes | Yes | Yes |
| Sales-decile-year-dummy | | | Yes | Yes | Yes | Yes | Yes |
| Export share-decile-year-dummy | | | | Yes | Yes | Yes | Yes |
| Sector-dummy | | | | | Yes | | Yes |

*Notes:* * p $<$ 0.1; ** p $<$ 0.05; *** p $<$ 0.01. Columns (1) to (5) show results from 2SLS estimations and columns (6) and (7) from an OLS estimation. The dependent variable is the four-year change in the log of firms' $CO_2$ emissions scaled with firms' deflated sales (emission intensity) (Panel A.), the log of firms' $CO_2$ emissions, and the log of firms' deflated sales (Panel C.). The explanatory variable is the four-year change in imports from China and eastern Europe scaled with domestic absorption in 1995 for each three-digit industry. The instrument is the four-year change of exports from China and eastern Europe to other countries in each three-digit industry. The sample period is 1995 until 2017, but 2003 - 2006 were excluded due to a break in the reporting of energy variables in 2003. Standard errors were clustered both at the firm and at the three-digit-industry-year level. First-stage coefficients, standard errors and the Kleibergen-Paap F-statistic is reported for each specification. Source: Research Data Centres of the Federal Statistical Office and the Statistical Offices of the Länder: AFiD-Panel Industriebetriebe, 1995-2017, own calculations.

The point estimate from the specification in column (1) of Panel A, which includes only year-fixed effects, yields a negative but small and statistically insignificant effect of import competition on emission intensity. Looking at first-stage results, one can see that the coefficient is well behaved, i.e., exports from the East to other countries are positively associated with German imports from the East. The Kleibergen-Paap F-statistic exceeds any conventional threshold values underlining the instrument's relevance. In column (2) I add $CO_2$ intensity-decile-year fixed effects to purge shocks that might occur along the energy/$CO_2$ intensity distribution. Indeed one can see that controlling for emission intensity increases the point estimate to 0.0036. The effect is significant and implies that a 1pp increase in the IPR reduces emission intensity by 0.36%. The first-stage results are very similar across all specifications in columns (1) to (4). I consecutively add sales- and export share-decile-year fixed effects (columns 3 and 4) to control for differential trends along size-classes and for shocks that depend on firms' internationalization. Adding the exporter effect depresses the coefficient slightly, indicating a reduction of emission intensity by 0.28% in response to a 1pp increase in the IPR, but the effect remains highly significant.

Finally, column (5) presents the most demanding specification, including trends for twelve broadly defined industries. In the aggregation of industries, I follow Autor et al. (2014) and Autor et al. (2020) closely who control for trends within 11 industries. Given that they were able to map imports to a much narrower definition of industries (almost 400 as opposed to less than 90 three-digit industries in Germany), specifications in column (5) are rather demanding.[15] Controlling for industry trends also absorbs useful variation to identify the effect. Losing this variation also causes first stage results to become weaker; for example, the first stage coefficient drops slightly, and the F-statistic drops by approximately one quarter to around 140. The second stage results drop by 1% but remain negative and significant. The point estimate suggests that a 1pp increase in the IPR causes a reduction of firms' emission intensity by 0.18%.

For comparison, columns (6) and (7) shows the results from an OLS regression which includes

[15]Specifically, I combine *"Manufacture of food products and beverages"* with *"Manufacture of tobacco products"*; *"Manufacture of textiles"* with *"Manufacture of wearing apparel; dressing and dyeing of fur"* and *"Tanning and dressing of leather; manufacture of luggage, handbags, saddlery, harr"*; *"Manufacture of pulp, paper and paper products"* with *"Publishing, printing and reproduction of recorded media"*; *"Manufacture of coke, refined petroleum products and nuclear fuel"* with *"Manufacture of chemicals and chemical products"*; *"Manufacture of basic metals"* with *"Manufacture of fabricated metal products, except machinery and equipment"*; *"Manufacture of office machinery and computers"* with *"Manufacture of electrical machinery and apparatus n.e.c."* and *"Manufacture of radio, television and communication equipment and apparatus"* and *"Manufacture of medical, precision and optical instruments, watches and clocks"*; *"Manufacture of motor vehicles, trailers and semi-trailers"* and *"Manufacture of other transport equipment n.e.c."*. Further industries are *"Manufacture of furniture; manufacturing n.e.c."*, *"Manufacture of machinery and equipment n.e.c"*, *"Manufacture of other non-metallic mineral products"* and *"Manufacture of wood and of products of wood and cork, except furniture; manufacture"*.

the same set of fixed effects as the IV estimations in column (4) and (5). The OLS coefficient in column (6) happens to land close to the corresponding IV specification, whereas the OLS result in column (7) is close to zero and statistically insignificant. A positive bias of the OLS appears plausible: as domestic demand expands, increasing production beyond cost-efficient quantities can still be profitable for firms. Similarly, firms might also offer products that are not part of their core competencies in periods of high demand. Therefore, emission intensity is likely to increase as demand expands and at the same time, imports will increase too, causing a positive OLS bias.

These first results indicate that import competition from the East caused a reduction of firms' emission intensity. In principle, import competition could affect the nominator, i.e., energy use and related emissions, and the denominator of emission intensity, i.e., sales. As hypothesized in the introduction, import competition is expected to make firms search for margins to optimize and reduce costs to remain competitive. Therefore, I expect energy use and emissions to decrease due to tougher competition. As not all firms might be able to sustain their market shares, sales could also be depressed. To unpack the effect on emission intensity, Panel B and C of Table 3 report the effect of import competition on the log of $CO_2$ emissions and the log of sales separately.

All IV estimates in Panel B of Table 3 are negative, statistically significant and larger than the corresponding point estimates in Panel A For example, controlling only for year fixed effects yields a point estimate of -0.0033, implying that a 1pp increase in the IPR decreases $CO_2$ emissions by 0.33%. Note that the same specification with emission intensity as the dependent variable was insignificant. The inclusion of year dummies by emission-intensity-decile almost doubles the point estimates to -0.0058. The point estimates in columns (3) and (4) are somewhat larger, indicating a decline of $CO_2$ emissions by 0.59% and 0.65% in response to a 1pp increase in the IPR. As before the inclusion of sectoral trends cuts the point estimate to -0.0018 as seen from column (5). Still, the effect remains significant at the 95% level. The OLS results in column (6) of Panel B is much smaller than the corresponding IV estimates and the OLS coefficient in column (7) even switches sign compared to the IV coefficient. As explained above, a positive OLS bias is very plausible: higher domestic demand increases imports and domestic production and therefore emissions.

Panel C of Table 3 reports how increased import competition affects firms' sales: as expected from the results in Panel A and B, specifically from the fact that point estimates in Panel A were smaller than in Panel B, increased import competition is associated with a decline of domestic firms' sales. The estimates in columns (1) to (4), which range from -0.0022 (column 2) to -0.0037 (column 4), are all statistically significant. Once I control for industry trends, the negative effect vanishes almost completely and becomes insignificant. In contrast to the IV estimates, both OLS results are positive and statistically significant showing that an increase in the IPR is associated with higher sales domestically. Again, omitted domestic demand is likely to increase both. Note from Panel B and C. that the baseline IV estimates in Panel A and the baseline OLS estimate from Panel A just happened to be similar.

### 4.2 Robustness and Heterogeneities

***Full Sample*** As explained in section 3, the evolution of producer price indices in the economic sectors *"Manufacture of office machinery and computers"* (WZ 30) and *"manufacturing of radio, television and communication equipment and apparatus"* are an outlier. Between 1995 and 2017 they collapsed, which makes comparing firms' sales over time difficult. Therefore both sectors were omitted from the final data set. In Panel A of Table 4 I include firms operating in corresponding sectors. Their inclusion increases the number of observations moderately to roughly 410000. Point estimates across all IV specifications become larger in absolute terms. The positive OLS bias also remains. The larger effect on emissions intensity is driven by a positive effect of import competition on deflated sales, i.e. the denominator of emission intensity (results not reported in the paper). This effect could recover variation introduced by the deflators. In light of these results, my approach to exclude WZ30 and WZ32 stands out as conservative.

***Single Plant Firms*** The assignment of multi-plant firms to one sector is not always unambiguous, e.g., if plants of the same firm are of similar size and operate in different sectors. To ensure that the results do not depend on multi-plant firms and the choice of their economic sector, I re-estimate the effect of import competition on emission intensity for single-plant firms only. Single plant firms constitute the vast majority of firms in the sample ($\approx$ 90%). Panel B of Table 4 reports corresponding results. Upon comparing results for single plant firms with those from the full sample, it can be ruled out that multi-plant firms affect the results in any meaningful way. Indeed, the point estimates obtained from single plant firms are almost identical to the full sample results as reported in 3. I, therefore, proceed with the sample that includes multi-plant firms.

***Never-Generator*** One of the salient features of industrial energy use during the past decade has been the increase in self-generated electricity. This trend is at least partly related to incentives provided by favorable tax treatments of self-generated electricity (cf. Gerster and Lamp, 2022). A shift towards self-generation and resulting changes in firms' energy mix have implications for carbon emissions. Therefore concerns about this trend potentially confounding the analysis might arise. I address this by estimating the effect of import competition on the subsample of firms that never generated any electricity. The results in Panel C closely match the main results from Table 3 and thus raise no concern that trends towards self-generation confound the analysis.

***Non-Overlapping Differences*** In Panel D I do not allow differences to overlap, i.e. I stack the difference between 2001 and 1997, 2008 and 2004, 2012 and 2008 and 2016 and 2012. The results are quantitatively very similar and statistically significant despite higher standard errors. The increase in standard errors is related to a weaker first stage.

***Sector Level Clustering of Errors*** To test whether results are robust to a more conservative clustering of standard errors, I report estimates and standard errors from the baseline specification as reported in 3 with standard errors clustered at the three-digit industry level. Naturally, the point estimates remain the same while standard errors increase. Their size almost doubles, resulting in a marginally significant effect in the specification that controls for sectoral trends, as shown in column (4). Given that the number of clusters reduces to 83 only and that the number of firms exceeds 50.000 this approach is probably overly conservative.

***Alternative Instrument Group*** To check the sensitivity of the results towards the choice of the instrument group, I omit the United Kingdom and Sweden from the group. Both countries are EU members, which might raise the concern that economic conditions in these countries could be correlated with those in Germany. Moreover, the UK is the largest trading partner among the countries in the instrument group; hence one could be concerned that exports from the East to the UK displace German exports to the UK, violating the exclusion restriction. Panel F presents results based on the altered instrument group. Reassuringly all estimates remain similar and statistically significant. Only the estimate in column (4) drops by approximately one-third compared to the benchmark instrument group and loses its significance. Overall, these results increase confidence that the results are robust to the exact specification of the instrument group.

***Post 2002 Observations*** Finally, I estimate the main result based on post-2002 data only.

As explained earlier, a break exists in the energy data between 2002 and 2003. This break is due to a change in companies' reporting of energy use information to the statistical office. The results shown in Panel G confirm that the main result also holds in the post-2002 sample.

***Alternative Regression Specifications*** I estimated the main effects using three and five-year differences and specifications based on firm fixed effects instead of differencing the data, to check the sensitivity of my results towards alternative specifications. Table A4 in the appendix reports the results. Columns (1) and (2) show the results for three-year differences, columns (3) and (4) for five-year differences and columns (5) and (6) show the results from the fixed effects estimator. Regarding controls, the specifications correspond to those shown in columns (4) and (5) of Table 3. One can see that, if anything, the point estimates are slightly larger compared to the main results. [16]

***Confounding Factors***

A further concern in this analysis is the role of export opportunities and their effect on firms' emission intensity. Dauth et al. (2014) emphasize that new export opportunities represent one of the significant changes brought about by the rise of the East for the German economy.[17] Since new export opportunities lead to an expansion of market size, they could be expected to decrease emission intensity (cf. Forslid et al., 2018; Richter and Schiersch, 2017). Dauth et al. (2014) also point out that import competition and export opportunities correlate, especially in the context of the integration with Eastern Europe. To control for the effect of exporting on emission intensity, I condition on changes in firms' export shares. Table A5 in the appendix reports the results for the baseline IV specification and the specification with sectoral dummies. As expected from the discussion above, an increase in exports correlates with a decline in emission intensity. The point estimate suggests that a 1pp increase in firms' export share is associated with a reduction in emission intensity by 0.23%. An increase in sales accompanied by a less-than-proportional increase in emissions drives this negative association between exports and emission intensity. Importantly the main effect, i.e. the point estimates capturing the effect of import competition on emission intensity, remain unchanged in both IV specifications (cf. results in Table 3).

[16] To implement the fixed-effects estimator given the break in the reporting between 2002 and 2003, I gave each firm that I observed before and after the break two separate firm fixed effects: one before and one after the break. Standard errors are still clustered at the firm level and not at the level of the firm-fixed effects. In the fixed effects regression the sector dummy is a year-sector dummy.

[17] Indeed, in their analysis, positive labor market effects resulting from the rise of the East dominate the adverse effects of import competition.

In the context of the discussion of export opportunities to the East as a potential confounder, it is also worth noting that in the main analysis, emission intensity declined because emissions shrank faster than sales in response to intensifying import competition. The decline in sales is not what one would expect from new export opportunities but from tougher competition. Eventually, subsection 5.3 pays close attention to the role of export opportunities.

A concern briefly touched on in the introduction to the empirical approach refers to the exclusion restriction in the particular context of this analysis. If shocks in the global oil and/or gas market simultaneously affect the instrument countries' imports of goods from sector $z$ in the East and the energy intensity of production in sector $z$ in Germany, the exclusion restriction would be violated. Information about total energy expenditure in the cost structure survey combined with physical energy use allows for constructing a measure for sectoral energy prices. To estimate the effect of import competition on emission intensity conditional on energy prices, I include changes in the log of average energy prices at the three-digit sector level as a control variable. Table A6 in the appendix reports the results, which show that the primary effect of imports on emission intensity remains unchanged conditional on sectoral price changes. The results further indicate a negative correlation between changes in sectoral prices and emission intensity, as expected.

**Table 4:** Robustness and Sensitivity

| | IV Estimates | | | | OLS Estimates | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| **Panel A – Full Sample** | | | | | | |
| Δ Imports | -0.0060*** | -0.0059*** | -0.0054*** | -0.0038*** | -0.0035*** | -0.0018** |
| | (0.0011) | (0.0011) | (0.0010) | (0.0010) | (0.0009) | (0.0008) |
| Number of Observations | 410,304 | 410,304 | 410,304 | 410,304 | 410,304 | 410,304 |
| Kleibergen-Paap $F$-Statistic | 80.36 | 81.08 | 78.20 | 56.50 | | |
| **Panel B – Single Plant Firms** | | | | | | |
| Δ Imports | -0.0035*** | -0.0034*** | -0.0027*** | -0.0018** | -0.0030*** | -0.0006 |
| | (0.0007) | (0.0007) | (0.0007) | (0.0008) | (0.0005) | (0.0005) |
| Number of Observations | 371,837 | 371,837 | 371,837 | 371,837 | 371,837 | 371,837 |
| Kleibergen-Paap $F$-Statistic | 182.59 | 182.90 | 175.02 | 131.00 | | |
| **Panel C – Never Self-Generator** | | | | | | |
| Δ Imports | -0.0034*** | -0.0032*** | -0.0025*** | -0.0017** | -0.0030*** | -0.0006 |
| | (0.0008) | (0.0007) | (0.0007) | (0.0008) | (0.0005) | (0.0005) |
| Number of Observations | 337,067 | 337,067 | 337,067 | 337,067 | 337,067 | 337,067 |
| Kleibergen-Paap $F$-Statistic | 165.78 | 166.08 | 159.10 | 119.49 | | |
| **Panel D – Non-Overlapping Intervals** | | | | | | |
| Δ Imports | -0.0045*** | -0.0045*** | -0.0038*** | -0.0039*** | -0.0037*** | -0.0015** |
| | (0.0011) | (0.0011) | (0.0010) | (0.0012) | (0.0008) | (0.0006) |
| Number of Observations | 108,342 | 108,342 | 108,342 | 108,342 | 108,342 | 108,342 |
| Kleibergen-Paap $F$-Statistic | 46.19 | 46.31 | 44.23 | 36.07 | | |
| **Panel E – Sector-Level Clustering** | | | | | | |
| Δ Imports | -0.0036*** | -0.0035*** | -0.0028** | -0.0018* | -0.0031*** | -0.0006 |
| | (0.0012) | (0.0012) | (0.0011) | (0.0011) | (0.0009) | (0.0007) |
| Number of Observations | 403,367 | 403,367 | 403,367 | 403,367 | 403,367 | 403,367 |
| Kleibergen-Paap $F$-Statistic | 52.37 | 52.68 | 50.56 | 40.42 | | |
| **Panel F – Alternative Instrument Group** | | | | | | |
| Δ Imports | -0.0035*** | -0.0034*** | -0.0028*** | -0.0011 | -0.0031*** | -0.0006 |
| | (0.0008) | (0.0008) | (0.0007) | (0.0008) | (0.0005) | (0.0005) |
| Number of Observations | 403,367 | 403,367 | 403,367 | 403,367 | 403,367 | 403,367 |
| Kleibergen-Paap $F$-Statistic | 328.63 | 332.55 | 311.61 | 243.34 | | |
| **Panel G – Post 2002 Observations** | | | | | | |
| Δ Imports | -0.0029*** | -0.0028*** | -0.0025*** | -0.0006 | -0.0026*** | -0.0003 |
| | (0.0007) | (0.0007) | (0.0007) | (0.0007) | (0.0005) | (0.0005) |
| Number of Observations | 290,464 | 290,464 | 290,464 | 290,464 | 290,464 | 290,464 |
| Kleibergen-Paap $F$-Statistic | 492.12 | 492.03 | 463.85 | 291.84 | | |
| $CO_2$ intensity-decile-year-dummy | Yes | Yes | Yes | Yes | Yes | Yes |
| Sales-decile-year-dummy | | Yes | Yes | Yes | Yes | Yes |
| Export share-decile-year-dummy | | | Yes | Yes | Yes | Yes |
| Sector-dummy | | | | Yes | | Yes |

*Notes:* * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$. Columns (1) to (4) of the table show results from 2SLS estimations and columns (5) and (6) from an OLS estimation. The dependent variable is the four-year change in the log of firms' $CO_2$ emissions per unit of sales. The explanatory variable is the four-year change in imports from China and Eastern Europe scaled with domestic absorption in 1995 in each three-digit industry. The instrument is the four-year change of exports from China and Eastern Europe to other countries in each three-digit industry. The sample period is 1995 until 2017 but the years 2003 - 2006 were excluded due to a break in the reporting of energy variables in 2003. Standard errors were mainly clustered at the firm and the three-digit-industry-year level. Panel (A) shows results from the whole panel, i.e. it includes the NACE1 sectors 30 and 32. Panel (B) uses the subsample of single plant firms only. Panel (C) reports estimates from a subsample of firms that never generated electricity themselves. Panel (D) uses only non-overlapping intervals, specifically the difference between 2001 and 1997, 2008 and 2004, 2012 and 2008 and 2016 and 2012. Panel (E) clusters standard errors only at the sector level and Panel (F) relies on an alternative set of countries in the instrument group, i.e. Great Britain and Sweden were omitted and Panel G uses only data from 2003 onward, i.e., from after the break in the reporting of energy variables. Source: Research Data Centres of the Federal Statistical Office and the Statistical Offices of the Länder: AFiD-Panel Industriebetriebe, 1995-2017, own calculations.

### 4.3 Effect Heterogeneity

The subsequent paragraphs shed light on heterogeneities. First, I distinguish between imports from Eastern Europe and imports from China. Second, I analyze heterogeneities regarding firm characteristics by interacting the trade shock with dummies, e.g. indicating firms' emission intensity, export share or size. These exercises can indicate the effect's quantitative significance and help to get an indication of potential mechanisms.

#### 4.3.1 Eastern Europe vs. China

Panel A in Table 5 focuses on the effect of changes in the IPR from China and Panel B on Eastern Europe. One can see that the effect of imports from China closely resembles the main effect as reported in Table 3. The coefficients in columns (1) to (3) indicate a decrease of emission intensity between 0.49% and 0.37% due to the IPR increasing by 1pp. The effect drops to 0.18% after accounting for sectoral trends. In Tables A7 and A8 in the appendix I show results for $CO_2$ emissions and sales as dependent variables. Across all IV specifications, the effect on $CO_2$ emissions is negative and significant while the effect on sales is negative and significant in columns (1) to (3) but insignificant in column (4) of Table A8. Throughout, the Kleibergen-Paap F-statistic is large and exceeds conventional threshold values.

Looking at the effect of imports from Eastern Europe, as reported in Panel B, one can see a large and highly significant negative effect on emission intensities across all IV specifications. However, these effects need to be qualified: first, as one can see from the bottom of Panel B, the first stages are weak with the F-statistics below 10. Second, when looking at the effect on sales in A8, I find positive point estimates which become quantitatively larger after conditioning on industry trends.[18] Dauth et al. (2014) emphasize the role of intra-industry trade between Germany and Eastern Europe and the correlation between industry imports from the East and German exports to the East in the same industry. Therefore, the positive effect on sales which depresses emission intensity might partly result from correlated German export opportunities. The integration of Eastern European economies in German firms' value chains, for example, via FDI from Germany, further challenges the identification. For instance, productivity improvements in Germany might increase exports from German foreign affiliates in Eastern Europe. Given the weak first stage in

[18] Concretely, the point estimate without industry trends is 0.0015 with a standard error of 0.0049. Once I condition on industry trends, the point estimate equals 0.0085 with a corresponding standard error of 0.0049 and hence is marginally significant. The point estimate with $CO_2$ emissions as dependent variable equals -0.0046 without and -0.0002 with industry trends.

the IV specification for Eastern Europe and the limitations mentioned above, the magnitude of the effect for imports from Eastern Europe should be interpreted with some caution.

**Table 5:** Eastern Europe (EE) and China Separately: Log Emission Intensity

| | IV Estimates | | | | OLS Estimates | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| **Panel A – Imports from China** | | | | | | |
| $\Delta$ Imports | -0.0049*** | -0.0047*** | -0.0037*** | -0.0018* | -0.0019*** | 0.0001 |
| | (0.0012) | (0.0011) | (0.0010) | (0.0011) | (0.0007) | (0.0007) |
| Number of Observations | 403,367 | 403,367 | 403,367 | 403,367 | 403,367 | 403,367 |
| Kleibergen-Paap $F$-Statistic | 212.66 | 214.05 | 205.98 | 182.10 | | |
| **Panel B – Imports from EE** | | | | | | |
| $\Delta$ Imports | -0.0074*** | -0.0073*** | -0.0062*** | -0.0088** | -0.0056*** | -0.0019** |
| | (0.0024) | (0.0024) | (0.0024) | (0.0040) | (0.0008) | (0.0008) |
| Number of Observations | 403,367 | 403,367 | 403,367 | 403,367 | 403,367 | 403,367 |
| Kleibergen-Paap $F$-Statistic | 7.05 | 7.05 | 6.88 | 5.13 | | |
| $CO_2$ intensity-decile-year-dummy | Yes | Yes | Yes | Yes | Yes | Yes |
| Sales-decile-year-dummy | | Yes | Yes | Yes | Yes | Yes |
| Export share-decile-year-dummy | | | Yes | Yes | Yes | Yes |
| Sector-dummy | | | | Yes | | Yes |

*Notes:* * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$. Columns (1) to (4) show results from 2SLS estimations and columns (5) and (6) from an OLS estimation. The dependent variable is the four-year change in the log of firms' $CO_2$ emission intensity. In Panel A. the explanatory variable is the four-year change in imports from China and in Panel B. the explanatory variable is the four-year change in imports from eastern Europe; each scaled with domestic absorption in 1995 in each three-digit industry. The instrument is the four-year change of exports from China/eastern Europe to other countries in each three-digit industry. The sample period is 1995 until 2017, but 2003 - 2006 were excluded due to a break in the reporting of energy variables in 2003. Standard errors were clustered both at the firm and at the three-digit-industry-year level. The specification in columns (4) and (6) include trends within 11 broadly defined industries. For each specification, I report the Kleibergen-Paap F-statistic. Source: Research Data Centres of the Federal Statistical Office and the Statistical Offices of the Länder: AFiD-Panel Industriebetriebe, 1995-2017, own calculations.

### 4.3.2 Firm Characteristics

Table 6 examines how the effects vary based on firm characteristics. To do so, I interact the trade shock with above-median-dummies for $CO_2$ intensities, export shares and size. Additionally, I interact the trade shock with dummy variables representing single-product firms, final goods producers, and firms in sectors with high import shares in 1995. All dummy variables were determined using first-period values to prevent potential endogeneity issues with the trade shock. The choice of control variables depends on the specific interaction to avoid absorbing too much useful variation. All models are "fully interacted," meaning that all fixed effects/controls were also interacted with the above-median dummies.

Column (1) shows the effect of import penetration and its interaction with a dummy indicating whether firms' $CO_2$ intensity is above or below the median. I omit the $CO_2$ intensity-decile fixed effects since they would absorb all the variation in the interaction effect and condition on start-off period values instead. The main effect is close to zero and statistically insignificant whereas the interaction is negative and highly significant. While there exists a considerable variation in firms' emission intensity within the group of firms above the median (cf. median and p90 for emissions in Table 1), this result still suggests that the effect of import competition is quantitatively relevant for aggregate emissions. It is also not surprising that firms for which energy is not a relevant input in the production process do not consider energy efficiency a viable tool to cut costs and thus improve competitiveness.

Column (2) shows the interaction between import competition and firms' integration in the global economy, measured by firms' export share. I omit the export share decile-year fixed effect from the specification. The point estimates show a negative main effect and a small positive but insignificant interaction effect. The positive interaction effect suggests that firms' with below-median export intensity responded stronger to the increase in competition. Depending on firms' export activity, changes in import penetration might have different effects on the relative level of competition that firms face. For example, a firm that operates only on the German market might be more affected by an increase in imports than a German firm that has always sold its products globally and has therefore been exposed to tough competition in the first place.

The third column reports the interaction between import competition and firm size (measured by the number of employees). The interaction effect is negative (however insignificant), indicating that the import shock induced a larger improvement in energy efficiency among larger firms. Column (4) interacts the trade shock with a dummy for single product firms.[19] The corresponding estimate provides suggestive evidence for a larger efficiency improvement among multi-product firms. Finally, column (5) interacts the change in import exposure with a dummy for three-digit sectors with high import shares in 1995. One might expect that the competitive environment is less affected by increasing imports from the East in sectors that were already relatively open. Consistent with this idea, the main effect is negative and significant. In contrast, the interaction effect is positive, meaning that emissions reduction was centered on firms in sectors with lower import exposure in 1995.

When interpreting the heterogeneity presented above, account should be taken of the fact that part of the variation is driven by across sector differences. For instance, the most energy-efficient steel producer will still emit more $CO_2$ per unit of sales than the least efficient textile company.

[19] I am using single plant firms only here since I do not know the number of products for multi-product firms.

**Table 6:** Interaction Effects

| | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| Main Effect | -0.00049 | -0.00332*** | -0.00258*** | -0.00303*** | -0.00373*** |
| | (0.00074) | (0.00095) | (0.00084) | (0.00080) | (0.00120) |
| Interaction - $CO_2$ intensity | -0.00395*** | | | | |
| | (0.00079) | | | | |
| Interaction - Export intensity | | 0.00080 | | | |
| | | (0.00095) | | | |
| Interaction - Size | | | -0.00114 | | |
| | | | (0.00083) | | |
| Interaction - Single Prod. | | | | 0.00105 | |
| | | | | (0.00091) | |
| Interaction - High Imp. Sh. | | | | | 0.00329** |
| | | | | | (0.00151) |
| Number of Observations | 403,367 | 403,367 | 403,367 | 370,981 | 403,367 |
| Kleibergen-Paap $F$-Statistic | 56.19 | 77.07 | 116.19 | 70.60 | 70.77 |
| $CO_2$ intensity-decile-year-dummy | | Yes | Yes | Yes | Yes |
| Sales-decile-year-dummy | Yes | Yes | | Yes | Yes |
| Export share-decile-year-dummy | Yes | | Yes | Yes | Yes |

*Notes:* * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$. The table reports main and interaction effects. The dependent variable is the four-year change in the log of firms' $CO_2$ emissions scaled with firms' sales (emission intensity). The fixed effects are reported at the bottom of the table and vary depending on the interaction variable. All fixed effects were also interacted with the "above-median dummy". The dummies for the interaction effects were determined based on first-year values. The regression in column 1 further includes the start-off period values of the dependent variable. The explanatory variable is the four-year change in imports from China and Eastern Europe scaled with domestic absorption in 1995 in each three-digit industry. The instrument is the four-year change of exports from China/Eastern Europe to other countries in each three-digit industry. The sample period is 1995 until 2017, but 2003 - 2006 were excluded due to a break in the reporting of energy variables in 2003. Only single plant firms were used in column 4. Standard errors were clustered both at the firm and at the three-digit-industry-year level. Source: Research Data Centres of the Federal Statistical Office and the Statistical Offices of the Länder: AFiD-Panel Industriebetriebe, 1995-2017, own calculations.

Thus, the heterogeneity regarding emission intensity speaks more to the relevance of the effect of import competition on emissions for aggregate emissions and less to differential effects depending on firms' "$CO_2$ productivity".

To analyze heterogeneities within three-digit sectors, I split the sample into within-sector quintiles of emission intensity, export shares and size measured by number of employees. Figure A1 plots results for the baseline specification (subfigure A1(a)) and the specification that accounts for industry trends (subfigure A1(b)). Starting with the subsamples formed based on different emission intensity quintiles, one can see that the effect is relatively stable. All point estimates in subfigure A1(a) are negative and of similar magnitude; only the effect among the firms in the most emission-intensive quintile is slightly larger than the rest. Results from specifications that account for sectoral trends, as shown in subfigure A1(b) also hint at a slight increase in the effect's size for more emission-intensive firms.[20] One might have expected the largest efficiency improvements to occur among the least efficient firms, given that they have the most room

[20]These results should be interpreted cautiously as a larger effect among firms with higher intensities could also be related to mean reversion.

for improvement. When examining differences in firm size within sectors, there exists some indication for a more significant decline in emission intensities among larger firms, aligning with the results presented in Table 6. As for the export share quintiles within sectors, the point estimates are less stable, likely due to varying numbers of observations within quintiles. In particular, firms with lower export shares appear to have a lower survival rate. Results in A1 suggest that firms with higher export shares relative to other firms in their 3-digit sector respond stronger to increased import competition. In contrast, the emission intensity of firms with an above-median export intensity showed a muted response.

# 5 Additional Results

## 5.1 Leakage

An obvious concern with this analysis is ”carbon leakage”. For instance, the increase in imports from the East could be high carbon content inputs in domestic firms’ production process. If these inputs used to be produced by the domestic firms themselves and outsourced once the opening up of the East allowed firms to do so, the emission intensity of sales would decline. To (partially) address this concern, I estimate the effect of import competition on the emission intensity of value-added. In the scenario sketched above, value-added would decline. Thus, the emission intensity of value-added would remain unchanged or even increase despite a decrease in the emission intensity of sales.

The analysis of the effect of import competition on value-added is feasible only for a subsample of firms that provide information on material inputs. Therefore, the number of observations drops to approximately 75000. Panel A, B and C of Table 7 show the results for the effect of import competition on the log of emission intensity of value-added, for the share of value-added in total sales and the log of material intensity.

The baseline results indicate that a 1pp increase in the IPR induces an approximate 0.3% to 0.23% decrease in firms’ emission intensity of value added. In contrast to the main results, conditioning on industry trends leads to a statistically insignificant coefficient of -0.0008 (column 4). A note on the underlying data seems also due at this point: as explained, the cost structure survey, which forms the basis for this analysis, oversamples large firms, i.e. it includes firms with $>$ 500 employees yearly and additional firms in four-year blocks. Hence, the difference specification further distorts the sample towards large firms as only one four-year difference exists for every firm that is included on a rotating basis. Given the data structure, an empirical specification employing firm-fixed effects to control for time-invariant firm-level heterogeneities could be considered more suitable than a difference specification. Table A9 in the appendix presents estimates based on a within estimator. When comparing the results in Panel A of Table A9 with the results on the log of emission intensity of sales from the within estimator as shown in Table A4 one can see that they match closely concerning effect size. In sum, the effects of imports on the emission intensity of value-added do not suggest that the reduction of firms' emission intensity is predominantly a result of leakage.

To further investigate the role of import competition on the depth of value-added, I relate the share of value-added over total sales to the IPR. Results are shown in Panel B of Table 7. A declining share could point to the fragmentation of firms' value chains. However, the estimates in Panel B of Table 7 do not indicate that import competition from the East contributes to this since all point estimates are small and indistinguishable from zero across specifications.[21] Taken together, the results presented in Panel A and B do not support the hypothesis that the effect of import competition on the emission intensity of sales results from carbon leakage. Of course, this analysis does not imply that the imports from the East do not also include intermediate inputs. For example, imports from the East could displace imports from other countries. Also imports from the East in the three-digit sector $x$ could still be inputs in the three-digit sector $y$.

Finally, Panel C of the table reports the effect on the log of material intensity, which is closely related to the results in Panel B. Again, I do not find evidence for an increase in material intensity, which one would expect if upstream production steps were sourced out.

### 5.2 Additional Outcomes

Table A10 presents results for additional firm-level outcomes. This analysis aims to broaden the understanding of firms' adjustment to import competition. These insights allow for further speculation about the underlying mechanisms by which firms reduce emission intensity.

Panel A of Table A10 shows the effect of import competition on emissions per employee and Panel B for the number of employees. The baseline IV estimates in Panel A are negative and

[21] The dependent variable is on a scale between 0 and 100.

**Table 7:** Additional Results - Log Emissions per Value Added

| | IV Estimates | | | | OLS Estimates | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| **Panel A – Log $CO_2$ Intensity of VA** | | | | | | |
| Δ Imports | -0.0029*** | -0.0025*** | -0.0023** | -0.0008 | -0.0026*** | -0.0003 |
| | (0.0009) | (0.0009) | (0.0009) | (0.0010) | (0.0006) | (0.0006) |
| Number of Observations | 75,499 | 75,499 | 75,499 | 75,499 | 75,499 | 75,499 |
| Kleibergen-Paap $F$-Statistic | 198.96 | 201.61 | 195.06 | 144.00 | | |
| **Panel B – Share of VA** | | | | | | |
| Δ Imports | -0.0111 | -0.0182 | -0.0120 | -0.0140 | -0.0292*** | -0.0300** |
| | (0.0152) | (0.0151) | (0.0148) | (0.0163) | (0.0106) | (0.0121) |
| Number of Observations | 75,514 | 75,514 | 75,514 | 75,514 | 75,514 | 75,514 |
| Kleibergen-Paap $F$-Statistic | 198.97 | 201.62 | 195.08 | 144.00 | | |
| **Panel C – Log Material Intensity** | | | | | | |
| Δ Imports | 0.0005 | 0.0006 | 0.0005 | 0.0007 | 0.0009*** | 0.0009*** |
| | (0.0005) | (0.0005) | (0.0004) | (0.0005) | (0.0003) | (0.0004) |
| Number of Observations | 75,419 | 75,419 | 75,419 | 75,419 | 75,419 | 75,419 |
| Kleibergen-Paap $F$-Statistic | 198.91 | 201.56 | 194.98 | 143.90 | | |
| $CO_2$ intensity-decile-year-dummy | Yes | Yes | Yes | Yes | Yes | Yes |
| Sales-decile-year-dummy | | Yes | Yes | Yes | Yes | Yes |
| Export share-decile-year-dummy | | | Yes | Yes | Yes | Yes |
| Sector-dummy | | | | Yes | | Yes |

*Notes:* * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$. Columns (1) to (4) show results from 2SLS estimations and columns (4) and (5) from a OLS estimation. The dependent variable in Panel Ais the four-year-change in the log of $CO_2$ emissions per unit of value added, in Panel B the share of value-added (i.e. value-added divided by sales) and in Panel C the log of material intensity. The explanatory variable is the four-year change in imports from China and Eastern Europe scaled with domestic absorption in 1995 in each three-digit industry. The instrument is the four-year change of exports from China and eastern Europe to other countries in each three-digit industry. The sample period is 1995 until 2017, but 2003 - 2006 were excluded due to a break in the reporting of energy variables in 2003. The specification in columns (4) and (6) include trends within 11 broadly defined industries. For each specification, I report the Kleibergen-Paap F-statistic. Source: Research Data Centres of the Federal Statistical Office and the Statistical Offices of the Länder: AFiD-Panel Industriebetriebe, 1995-2017, own calculations.

significant. The coefficient from the specification that absorbs sectoral trends (column 4) is also negative but small and insignificant. Labor and energy are both inputs in the production process. A decrease in emissions per employee could indicate an improvement of energy efficiency relative to potential efficiency improvements of other inputs. This result aligns with the energy efficiency paradox.

In Panel B, I show that the number of employees decreased as competitive pressure increased, which has been documented in this specific context by Dauth et al. (2014) who analyze local labor markets. The baseline results imply that the average firm's number of employees decreased by $\approx 0.35\%$ in response to a 1pp increase in the IPR. The estimate in column (4) still indicates a significant decrease in the number of employees by 0.15%. Like energy inputs, the OLS estimates that capture the association between employees and imports show a positive bias (cf. Panel B of Table 3 with the main results).

Panel C reports the estimates with inverse hyperbolic sine (ihs) transformed investment as the dependent variable.[22] Investment to upgrade technology appears as a natural means for firms to increase their energy productivity. The results in panel C, however, do not support the hypothesis that this explains the improvement in emission intensity in this context. On the contrary, all point estimates in columns (1) to (3) are negative and significant at the 5% level. The point estimates imply a substantial reduction in investment by 1.4% in response to a 1pp increase in the IPR; however, confidence intervals are relatively wide. Again, the OLS estimates show a positive bias, e.g. firms invest more when domestic demand expands.

Finally, Panel D and E focus on the firms' product mix response. The dependent variable in Panel D is the number of products; in Panel E, the dependent variable is an indicator for single-product firms. While changes in the market environment were shown to affect firms' product mix (cf. Goldberg et al., 2010), Barrows and Ollivier (2018) highlight that emission intensity varies substantially across products within the same firm and that the emission intensity for products that account for a larger share of firms' sales is lower. Following this argument, firms concentrating their economic activity further on their core competency could contribute to a decrease in the average firms' emission intensity. Panels D and E provide some suggestive evidence in line with the above. For example, the baseline results in Panel D suggest that a 1pp increase in the IPR decreases the average firm's number of products by 0.005. and increase the chance of being a single-product firm by 0.1%. While these results provide evidence for a response of firms' product mix to changes in the competitive environment, it is hard to assess this channel's relevance for the estimated decline in the average firm's emission intensity. To study the specific mechanism described by Barrows and Ollivier (2018), I would need information about the product type, the sales shares by product and ideally, the energy consumption by product line, neither of which is available.

### 5.3 Export Opportunities

The rise of the East not only caused increased competition for the German industry; it also provided new export opportunities to German firms. Indeed, the role of export opportunities is a central aspect of the paper by Dauth et al. (2014). Subsection 4.2 discussed export opportunities as a potential confounder when import competition and export opportunities are correlated. This

[22] Investment is known to be quite lumpy; other than the log, the ihs transformation is defined for zero values.

subsection briefly analyzes the effect of export opportunities to the East on emission intensities, emissions and sales. The aim of this exercise is to complement the main analysis by providing a more comprehensive account of the consequences of the East's rise. Furthermore, it helps gain additional insight into how export opportunities can potentially confound the main analysis.

Parallel to the analysis of import competition, I relate changes in firm-level outcomes to changes in sectoral exports to the East. The OLS version of the estimation equation is expressed as follows:

$$\Delta y_{itz} = \beta_0 + \alpha \Delta EO_{z,t}^{Ger \rightarrow East} + \Delta \epsilon_{itz}$$

where $\Delta EO_{z,t}^{Ger \rightarrow East}$ is defined as the change in sectoral exports from Germany to the East scaled with domestic absorption.

$$\Delta EO_{z,t}^{Ger \rightarrow East} = \frac{\Delta Exp_{z,t}^{Ger \rightarrow East}}{DomAbs_{z,1995}}$$

Estimating the effect of export opportunities on firm-level outcomes also requires addressing endogeneity issues. For instance sectors that experience a positive productivity shock are more likely to start or increase their exports, while the same productivity shock will also affect measures such as energy/$CO_2$ intensity. Therefore simply relating changes in a firm's emission intensity to changes in the sector or firm-level export flows using OLS would produce biased results. Again, following Dauth et al. (2014) in their analysis of export opportunities, I use changes in sectoral exports of the instrument countries to the East as an instrument for the changes of sectoral exports from Germany to the East. The instrument for changes in exports by sector z, is thus defined as follows:

$$\frac{\Delta Exp_{z,t}^{Inst \rightarrow East}}{DomAbs_{z,1995}} \tag{6}$$

Table 8 reports the results. The most parsimonious specification in column (1), including only year-fixed effects, yields a negative but small and insignificant effect of changes in sectoral exports on firms' emission intensities. This result is because emissions (Panel B) and sales (Panel C) increase proportionally in response to export opportunities in this specification. After controlling for differential trends by emission intensity deciles (column 2), the positive effect of export opportunities on emissions drops and becomes insignificant (Panel B), while the positive and significant effect on sales remains unchanged and hence, emission intensity declines (Panel

A). Specifically, the point estimate in column (2) of Panel A implies that a 1pp increase in sectoral exports to the East leads to a decline in the average firm's emission intensity by approximately 0.23%. The effect remains stable when size-decile-year dummies are included (column 3) but drops by about 20% upon conditioning on trends by export intensity deciles (column 4). The OLS estimate corresponding to the IV specification in column (4) (shown in column 6) is approximately twice as large in absolute terms. An overestimation of the negative effect of exporting on emission intensities is in line with the endogeneity described above: a positive productivity shock improves energy efficiency/lowers emission intensity and increases exports. The inclusion of dummies that control for sectoral trends (column 5) leads to a qualitative change in results: the point estimate in Panel A flips its sign, indicating an increase in emission intensity due to the effect on emissions (Panel B) becoming positive and the effect on sales becoming insignificant. The corresponding OLS esimate in column (7) remains negative and significant. In sum, except for the somewhat surprising last IV result, Table 8 indicates a (small) positive effect of export opportunities on emissions and a positive effect on sales, which aligns with what one would expect. Together, the effects tend to lower the emission intensities of firms. While this result is similar to the main result of the effect of import competition on emission intensities, the mechanics are different.

**Table 8:** Export Opportunities and Firms' Emissions

| | IV Estimates | | | | | OLS Estimates | |
|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
| **Panel A – Log of $CO_2$ Emission Intensity** | | | | | | | |
| $\Delta$ Exports | -0.0005 | -0.0023** | -0.0024** | -0.0018** | 0.0026** | -0.0039*** | -0.0013** |
| | (0.0009) | (0.0010) | (0.0009) | (0.0009) | (0.0011) | (0.0005) | (0.0005) |
| Number of Observations | 403,367 | 403,367 | 403,367 | 403,367 | 403,367 | 403,367 | 403,367 |
| **Panel B – Log of $CO_2$ Emissions** | | | | | | | |
| $\Delta$ Exports | 0.0021*** | 0.0003 | 0.0009 | 0.0009 | 0.0022** | 0.0014*** | 0.0024*** |
| | (0.0007) | (0.0006) | (0.0006) | (0.0006) | (0.0009) | (0.0004) | (0.0005) |
| Number of Observations | 403,367 | 403,367 | 403,367 | 403,367 | 403,367 | 403,367 | 403,367 |
| **Panel C – Log of Sales** | | | | | | | |
| $\Delta$ Exports | 0.0025** | 0.0026** | 0.0033*** | 0.0027** | -0.0004 | 0.0054*** | 0.0037*** |
| | (0.0012) | (0.0012) | (0.0012) | (0.0011) | (0.0013) | (0.0007) | (0.0007) |
| Number of Observations | 403,576 | 403,576 | 403,576 | 403,576 | 403,576 | 403,576 | 403,576 |
| **First Stage Results** | | | | | | | |
| $\Delta$ Instrument | 0.5965*** | 0.5827*** | 0.5836*** | 0.5678*** | 0.4369*** | | |
| | (0.0385) | (0.0376) | (0.0377) | (0.0379) | (0.0447) | | |
| Kleibergen-Paap $F$-Statistic | 240.25 | 240.80 | 239.74 | 224.31 | 95.54 | | |
| Adjusted $R$-Squared | 0.44 | 0.46 | 0.46 | 0.48 | 0.63 | | |
| Number of Observations | 403,576 | 403,576 | 403,576 | 403,576 | 403,576 | | |
| Year dummy | Yes | | | | | | |
| $CO_2$ intensity-decile-year-dummy | | Yes | Yes | Yes | Yes | Yes | Yes |
| Sales-decile-year-dummy | | | Yes | Yes | Yes | Yes | Yes |
| Export share-decile-year-dummy | | | | Yes | Yes | Yes | Yes |
| Sector-dummy | | | | | Yes | | Yes |

*Notes:* * p $<$ 0.1; ** p $<$ 0.05; *** p $<$ 0.01. Columns (1) to (5) show results from 2SLS estimations and columns (6) and (7) from an OLS estimation. The dependent variable is the four-year change in the log of firms' $CO_2$ emissions scaled with firms' deflated sales (emission intensity) (Panel A.), the log of firms' $CO_2$ emissions, and the log of firms' deflated sales (Panel C.). The explanatory variable is the four-year change in sectoral exports from Germany to China and Eastern Europe scaled with domestic absorption in 1995 for each three-digit industry. The instrument is the four-year change of sectoral exports from the countries in the instrument group to China and Eastern Europe. The sample period is 1995 until 2017, but 2003 - 2006 were excluded due to a break in the reporting of energy variables in 2003. Standard errors were clustered both at the firm and at the three-digit-industry-year level. First-stage coefficients, standard errors and the Kleibergen-Paap F-statistic is reported for each specification. Source: Research Data Centres of the Federal Statistical Office and the Statistical Offices of the Länder: AFiD-Panel Industriebetriebe, 1995-2017, own calculations.

To also capture potential effects of export opportunities through reallocation, Table A11 in the appendix reports the results from the sector-level analysis, i.e. from relating changes in log sectoral emission intensity and its parts (log unweighted emission intensities and the covariance term) to changes in the measure of export opportunities. In line with the relatively weak evidence for a negative effect of export opportunities on emission intensities, the sectoral results do not show a significant decline in the unweighted average emission intensity. Still, the weighted sectoral emission intensity decreased strongly due to compositional changes captured by the covariance term. For instance, the IV estimate reported in Table A11 implies that a 1pp increase in the export opportunities measure depressed the covariance term by $\approx 0.4\%$. This finding could result from more efficient firms experiencing a disproportionate advantage from export opportunities, leading to an expansion of their market share compared to less productive ones.

## 6 Discussion and Conclusion

In this paper I analyze the effect of import competition on firm-level emission intensity. To do so, I combine comprehensive firm-level data from the German manufacturing industry with sector level trade flow. I focus on the rise of China and Eastern Europe between 1995 and 2017. Using an instrumental variable strategy, I provide evidence that increasing import competition is associated with a higher energy efficiency of production which translates into fewer $CO_2$ emissions per unit of sales. Within-firm changes drive this effect. I do not find strong indication for between-firm reallocation.

The baseline regression specification implies that firms' emission intensity of production decreases by 0.3% in response to a 1pp increase in the import penetration ratio. Between 1995 and 2017 the import penetration from the East increased by approximately 20pp. Hence the point estimate suggests that the increase in competition kept emission intensity about 6% below the level it would have had in the absence of the rise of the East.

The question about potential mechanisms naturally emerges from these results. I argue that the results align with parts of the international trade literature which tends to find positive effects of import competition on European firms' productivity (Shu and Steinwender, 2019). For Spain, Chen and Steinwender (2021) found that, in particular, family-managed firms responded to import competition by improving material use which translates into higher productivity. Firms' energy use is often regarded as particularly inefficient ("energy-efficiency-paradox"). Therefore, it seems plausible that improvements in energy efficiency appear to be a low-hanging fruit for cost cuts needed to maintain a firm's competitiveness under tougher competition.

Poor management practices are often cited as a cause for prevailing inefficiencies in energy use (cf. Bloom et al., 2010; Martin et al., 2012; De Haas et al., 2021). The lack of information on managerial quality in the data used in this paper makes it impossible to test this hypothesis. Future research could employ management quality measures to understand if they respond to changes in competition and how they contribute to improving energy efficiency. Still, management practices cannot be the ultimate reason for efficiency improvements; for instance, investments to technologically upgrade equipment appears as a plausible instrument by which a better manager could improve efficiency. Yet, my estimates regarding the impact of import competition on investment do not corroborate this hypothesis. This result is consistent with the finding by Gutiérrez and Teshima (2018), who similarly observed a decrease in energy intensity among Mexican manufacturing firms in response to import competition but reduced abatement expenditures. Barrows and Ollivier (2018) highlight the role of the firm's product mix in determining emission intensities at the firm level. They show that firms tend to be less efficient in producing products outside of their core competencies. The results shown in subsection 5.2 are indicative of an adjustment of firms' product mix consistent with Barrows and Ollivier (2018): The number of single-product firms increases slightly and the number of products decreases in response to an increase in the IPR. I also provide suggestive evidence for a larger reduction in emission intensities among multi-product firms. More generally, I find a consistent negative effect of import competition on sales, which could reflect firms concentrating on their productive core activities.

An alternative explanation relates to carbon leakage via imports of high carbon content inputs. While I cannot completely rule out that this also contributes to the decrease in emission intensity, the analysis of the effect of import competition on the emission intensity of value-added does not provide indication for leakage in that I find a similar effect of the trade shock on the emission intensity of value added. Similarly, I do not find that the share of value-added in sales declined in response to import competition. Of course, if the composition of imported intermediates changes towards more emission-intensive inputs, the share of value-added could remain unchanged despite leakage (cf. Cherniwchan, 2017). Similarly, improved access to intermediates, e.g.

because the variety increased, could also improve the productivity of downstream firms. However, recall that these alternative explanations rest on the assumption that intermediates are produced by the same economic sectors in which the German firm operates which is determined by its output. To enhance our understanding of mechanisms, future research could use more granular product-level information on the firm's output, which would allow to define the trade shock at the firm level and further isolate the effect of competition in the output market. Increasingly available information on firm-product-specific inputs (ideally also imports) could also make an in-depth analysis of changes in the composition of firms' imports feasible. However, neither of this information is available to me.

Finally, I extend the analysis in this paper to incorporate the effect of new export opportunities to the East on emission intensity, suggesting a negative effect of exporting on emission intensity through increased sales. I also find evidence for export opportunities inducing a reallocation of market shares towards more efficient firms and therefore, a further decline of sectoral emission intensities.

From a policy perspective, the key message of this paper is that pro-competitive policy can lead to environmental benefits via more efficient energy use and hence fewer emissions, a message likely to be relevant beyond trade policy.

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# Appendix A Gravity Estimation

To analyze the sensitivity of my results towards the identification strategy, I follow Autor et al. (2013) and Dauth et al. (2014), in implementing an alternative identification strategy based on gravity residuals. The idea behind this approach is to use the hypothetical increases in imports from the East, which is implied by the increase in the East's export capacity (its comparative advantage and trade costs) vis a vis Germany.

In the implementation of the gravity based approach, I follow Autor et al. (2013) closely. Consider equation 7 which relates to a standard gravity specification as in e.g. Anderson and Wincoop (2003). Variables on the left hand side are country-sector specific export flows, i.e. $X_{cz}^{East}$ are exports from the East to country $c$ in sector $z$ and accordingly $X_{cz}^{Ger}$ are German exports to country $c$ in sector $z$.

$$lnX_{cz}^{East} - lnX_{cz}^{Ger} = ln(z_z^{East}) - ln(z_z^{Ger}) - (\sigma_z - 1)[ln(\tau_{cz}^{East}) - ln(\tau_{cz}^{Ger})] \quad (7)$$

The first part on the right hand side of equation 7, $ln(z_z^{East}) - ln(z_z^{Ger})$ describes the East's export capacity in sector $z$ relative to Germany's export capacity in sector $z$, i.e. the East's comparative advantage in industry $z$; for example driven by productivity differences. The second part on the r.h.s. of equation 7 - $[ln(\tau_{cz}^{East}) - ln(\tau_{cz}^{Ger})]$ - are export destination specific cost (note subscript $c$), for example costs determined by geography. Finally, $\sigma_z$ is the elasticity of substitution for sector $z$.

To take the approach to the data, I estimate the following regression:

$$lnX_{czt}^{East} - lnX_{czt}^{Ger} = \alpha_z + \alpha_c + \epsilon_{zct} \quad (8)$$

Specifically, I project the difference between the East's exports and Germany's exports to country $c$ in sector $z$ (the East's relative exports) on sector and country/destination market fixed effects ($\alpha_z$ and $\alpha_c$). I pool trade flows over the period 1995 to 2017 and export destination markets are primarily high income EU and OECD countries.[23]

By equating the right hand sides of equations 7 and 8 and rearranging terms one gets the

[23] The list of countries includes the following: Austria, Brazil, Cyprus, Finland, Iceland, Ireland, Republic of Korea, India, Turkey, Australia, Canada, Japan, Norway, New Zealand, Sweden, Singapore, United Kingdom, Belgium, Luxemburg, Denmark, Greece, Israel, Italy, Netherland, Portugal, Spain, Switzerland, USA, France

following expression for the residual:

$$\epsilon_{zct} = \underbrace{[ln(\frac{z_{zt}^{East}}{z_{zt}^{Ger}}) - \alpha_j]}_{Comparative\ advantage} + [-(\sigma-1) \underbrace{ln(\frac{\tau_{cz}^{East}}{\tau_{cz}^{Ger}}) - \alpha_c}_{Trade\ cost\ advantage}] \quad (9)$$

The residual thus captures the East's comparative advantage in sector $z$ and year $t$ purged from structural differences due to the inclusion of the industry fixed effect $\alpha_z$ plus the trade cost advantage net of time invariant factors as the fixed effect $\alpha_c$ absorbs all such factors e.g. distance. Demand conditions in the importing country are differenced out by using the relative exports.

Hence, the four-year differences in the residual capture the change in the Easts' export capacity relative to Germany in sector $z$ and country $c$. Averaging across export destination countries provides a measure of the relative rise of the East. From this I construct the following alternative, gravity-based measure of a sector's import exposure from the East:

$$\Delta IPG_{zt}^{East} = \frac{\Delta \bar{\epsilon}_{zt} * Imp_{zt-4}^{East}}{Y_{z,1995} + Imp_{z,1995} - Exp_{z,1995}} \quad (10)$$

The hypothetical increase in imports produced by sector $z$ in the East, i.e. $\Delta IPG_{zt}^{East}$ ("Import-Penetration-Gravity") is calculated from the mean change in the residual $\bar{\epsilon}_{zt}$ multiplied with the initial imports from the East in the respective industry. The predicted change depends on the change in the East's comparative advantage and changes in trade costs. Again I scale the change in imports with domestic absorption in the first period, i.e. in 1995.

As the hypothetical change in imports is obtained from the change in the East's export capacity, unobserved domestic conditions in Germany do not contaminate it.

I can thus simply relate changes in firms' emission intensities to the hypothetical change in import penetration using OLS. Table A1 shows the results from the gravity-based approach. The explanatory variable is the change in hypothetical imports from the East relative to domestic absorption in the baseline period expressed in pp. Thus, the interpretation of the coefficient is similar to the IV approach. The baseline results without industry trends (columns 1 to 3) are quantitatively closely aligned with the IV estimates in 3. Without conditioning on year by decile of export intensity fixed effects, the point estimates imply that a 1pp increase in the gravity-based measure of import exposure leads to a reduction of emission intensity by 0.35%. The coefficient drops after adding export intensity decile fixed effects to 0.30%. However, in contrast to the IV results, the effect becomes small and insignificant once I condition on industry trends. In sum the alternative gravity-based approach results strengthen the causal interpretation of the main results with the exception of specification in column (4).

**Table A1:** Gravity Based Estimates - Log Emission Intensity

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| **Panel A – China and Eastern Europe** | | | | |
| $\Delta$ Gravity Residuals ($IPG_{zt}^{East}$) | -0.0035*** | -0.0035*** | -0.0030*** | -0.0000 |
| | (0.0007) | (0.0006) | (0.0006) | (0.0006) |
| Number of Observations | 403,508 | 403,508 | 403,508 | 403,508 |
| **Panel B – Eastern Europe** | | | | |
| $\Delta$ Gravity Residuals ($IPG_{zt}^{EE}$) | -0.0057*** | -0.0057*** | -0.0051*** | -0.0020** |
| | (0.0008) | (0.0008) | (0.0008) | (0.0008) |
| Number of Observations | 403,508 | 403,508 | 403,508 | 403,508 |
| **Panel C – China** | | | | |
| $\Delta$ Gravity Residuals ($IPG_{zt}^{China}$) | -0.0021** | -0.0021** | -0.0015** | 0.0003 |
| | (0.0008) | (0.0008) | (0.0007) | (0.0007) |
| Number of Observations | 403,508 | 403,508 | 403,508 | 403,508 |
| CO_2 intensity-decile-year-dummy | Yes | Yes | Yes | Yes |
| Sales-decile-year-dummy | | Yes | Yes | Yes |
| Export share-decile-year-dummy | | | Yes | Yes |
| Sector-dummy | | | | Yes |

*Notes:* * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$. Results are estimated by means of OLS. The dependent variable is the four-year change in the log of firms' $CO_2$ emissions intensity. The explanatory variable is the hypothetical change in imports as described by expression 10. Sample period is 1995 until 2017 but the years 2003 - 2006 were excluded due to a break in the reporting of energy variables in 2003. Standard errors were clustered both, at the firm and at the three-digit-industry-year level. Source: Research Data Centres of the Federal Statistical Office and the Statistical Offices of the Länder: AFiD-Panel Industriebetriebe, 1995-2017, own calculations.

**Table A2:** Descriptive - Trade Data

| Variable | Mean | Std. Dev | Min | Median | Max | N |
|---|---|---|---|---|---|---|
| China (1995, Mio. USD) | 354.58 | 339.79 | .44 | 276.05 | 1310.97 | 22 |
| China (2017, Mio. USD) | 4030.54 | 4028.8 | .49 | 3200.25 | 13249.88 | 22 |
| China (1995, Import Share) | .02 | .02 | 0 | .01 | .08 | 22 |
| China (2017, Import Share) | .1 | .1 | 0 | .08 | .4 | 22 |
| Eastern Europe (1995, Mio. USD) | 1413.05 | 1208.77 | 11.35 | 1246.6 | 4974 | 22 |
| Eastern Europe (2017, Mio. USD) | 8981.02 | 9528.78 | 762.47 | 5881.57 | 42817.17 | 22 |
| Eastern Europe (1995, Import Share) | .08 | .06 | .01 | .07 | .2 | 22 |
| Eastern Europe (2017, Import Share) | .23 | .12 | .08 | .2 | .51 | 22 |
| Joined Eastern (1995, Mio. USD) | 1767.63 | 1387.68 | 11.79 | 1352.5 | 5119.93 | 22 |
| Joined Eastern (2017, Mio. USD) | 13011.56 | 11366.67 | 762.95 | 9765.52 | 45000.37 | 22 |
| Joined Eastern (1995, Import Share) | .1 | .07 | .01 | .09 | .27 | 22 |
| Joined Eastern (2017, Import Share) | .33 | .14 | .11 | .33 | .58 | 22 |

*Notes:* For the years 1995 and 2017 the table reports summary statistics of sectoral imports (2. digit industries) from China and Eastern Europe and the share of sectoral imports from China and Eastern Europe in total imports in respective sectors. Source: BAKI trade data, own calculations.

**Table A3:** Correlation between the Instrument and Log Energy Prices

| | Unweighted | | | Weighted # Firms | | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| **Panel A – Δ Log(Uw. Avg. Ep)** | | | | | | |
| Δ Instrument | 0.00117** | 0.00016 | -0.00017 | 0.00305** | 0.00031 | 0.00044 |
| | (0.00053) | (0.00027) | (0.00034) | (0.00118) | (0.00040) | (0.00040) |
| Number of Observations | 1,290 | 1,290 | 1,290 | 1,290 | 1,290 | 1,290 |
| **Panel B – Δ Log(Median Ep)** | | | | | | |
| Δ Instrument | 0.00098 | -0.00004 | -0.00023 | 0.00334** | 0.00037 | 0.00060 |
| | (0.00065) | (0.00033) | (0.00034) | (0.00136) | (0.00053) | (0.00047) |
| Number of Observations | 1,290 | 1,290 | 1,290 | 1,290 | 1,290 | 1,290 |
| **Panel C – Δ Log(Ep)** | | | | | | |
| Δ Instrument | 0.00152** | 0.00048 | 0.00012 | 0.00390*** | 0.00097* | 0.00078 |
| | (0.00063) | (0.00037) | (0.00039) | (0.00142) | (0.00056) | (0.00056) |
| Number of Observations | 1,290 | 1,290 | 1,290 | 1,290 | 1,290 | 1,290 |
| Year dummy | | Yes | Yes | | Yes | Yes |
| Sector-dummy | | | Yes | | | Yes |

*Notes:* * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$. The table shows OLS regression results from a long difference regression estimated at the 3-digit sector level. The coefficients capture the correlation between changes in the instrument, i.e. sectoral trade flows from the East to the instrument countries, and changes in measures of sectoral energy prices in Germany. In Panel A the dependent variable is the four-year change in the unweighted average sectoral price, in Panel B the four-year change in the median sectoral price and Panel C the four-year change in the average sectoral price. Columns 1-3 report results for unweighted regressions and columns 4-6 for regressions weighted with the number of firms in a sector. The years 2003 - 2006 were excluded due to a break in the reporting of energy variables between 2002 and 2003. Source: Research Data Centres of the Federal Statistical Office and the Statistical Offices of the Länder: AFiD-Panel Industriebetriebe, 1995-2017, own calculations.

**Table A4:** Results from Alternative Specifications - Logs of Emission Intensity, Emissions and Sales

| | Delta 3 | | Delta 5 | | FE | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| **Panel A – Log of $CO_2$ Emission Intensity** | | | | | | |
| $\Delta$ Imports | -0.0037*** | -0.0026*** | -0.0033*** | -0.0017** | -0.0045*** | -0.0019*** |
| | (0.0008) | (0.0009) | (0.0007) | (0.0008) | (0.0006) | (0.0007) |
| Number of Observations | 476,336 | 476,336 | 338,512 | 338,512 | 736,733 | 736,733 |
| Kleibergen-Paap $F$-Statistic | 145.88 | 106.93 | 236.45 | 176.35 | 585.42 | 418.84 |
| **Panel B – Log of $CO_2$ Emissions** | | | | | | |
| $\Delta$ Imports | -0.0073*** | -0.0020** | -0.0068*** | -0.0020*** | -0.0075*** | -0.0023*** |
| | (0.0011) | (0.0008) | (0.0010) | (0.0008) | (0.0008) | (0.0007) |
| Number of Observations | 476,336 | 476,336 | 338,512 | 338,512 | 736,733 | 736,733 |
| Kleibergen-Paap $F$-Statistic | 145.88 | 106.93 | 236.45 | 176.35 | 585.42 | 418.84 |
| **Panel C – Log of Sales** | | | | | | |
| $\Delta$ Imports | -0.0036*** | 0.0006 | -0.0035*** | -0.0003 | -0.0030*** | -0.0004 |
| | (0.0013) | (0.0011) | (0.0010) | (0.0010) | (0.0007) | (0.0008) |
| Number of Observations | 476,567 | 476,567 | 338,701 | 338,701 | 736,993 | 736,993 |
| Kleibergen-Paap $F$-Statistic | 145.92 | 106.96 | 236.53 | 176.42 | 585.52 | 418.97 |
| $CO_2$ intensity-decile-year-dummy | Yes | Yes | Yes | Yes | Yes | Yes |
| Sales-decile-year-dummy | Yes | Yes | Yes | Yes | Yes | Yes |
| Export share-decile-year-dummy | Yes | Yes | Yes | Yes | Yes | Yes |
| Sector-dummy | | Yes | | Yes | | Yes |

*Notes:* * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$. The table shows 2SLS estimates from regression specifications based on three-year differences (columns 1 and 2), five-year differences (columns 3 and 4) and a within estimator (columns 5 and 6). The dependent variables are the (three-/five-year changes in the) log of firms' $CO_2$ emissions scaled with firms' deflated sales (emission intensity) (Panel A.), the log of firms' $CO_2$ emissions, and the log of firms' deflated sales (Panel C.). The explanatory variable is the (three-/five-year change in) imports from China and Eastern Europe scaled with domestic absorption in 1995 for each three-digit industry. The instrument is the (three-/five-year change of) exports from China and Eastern Europe to other countries in each three-digit industry. The sample period is 1995 until 2017, but 2003 - 2005 were excluded in columns 1 and 2 and 2003-2007 were excluded in columns 3 and 4 due to a break in the reporting of energy variables in 2003. To accommodate the break in the reporting with the within estimator, each firm received a firm-fixed before and one after the break. In the fixed effects regressions, the sector-dummy becomes a sector-year dummy. Standard errors were clustered both at the firm and at the three-digit-industry-year level. First-stage coefficients, standard errors and the Kleibergen-Paap F-statistic is reported for each specification. Source: Research Data Centres of the Federal Statistical Office and the Statistical Offices of the Länder: AFiD-Panel Industriebetriebe, 1995-2017, own calculations.

**Table A5:** Results Conditional on Changes in Export Shares - Logs of Emission Intensity, Emissions and Sales

| | IV | | OLS | |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| **Panel A – Log of $CO_2$ Emission Intensity** | | | | |
| $\Delta$ Imports | -0.0028*** | -0.0018** | -0.0030*** | -0.0006 |
| | (0.0007) | (0.0008) | (0.0005) | (0.0005) |
| $\Delta$ Export | -0.2335*** | -0.2246*** | -0.2333*** | -0.2248*** |
| | (0.0111) | (0.0110) | (0.0111) | (0.0110) |
| Number of Observations | 403,367 | 403,367 | 403,367 | 403,367 |
| Kleibergen-Paap $F$-Statistic | 186.52 | 140.26 | | |
| **Panel B – Log of $CO_2$ Emissions** | | | | |
| $\Delta$ Imports | -0.0066*** | -0.0018** | -0.0011** | 0.0012*** |
| | (0.0010) | (0.0007) | (0.0005) | (0.0004) |
| $\Delta$ Export | 0.1611*** | 0.1624*** | 0.1578*** | 0.1620*** |
| | (0.0103) | (0.0101) | (0.0102) | (0.0101) |
| Number of Observations | 403,367 | 403,367 | 403,367 | 403,367 |
| Kleibergen-Paap $F$-Statistic | 186.52 | 140.26 | | |
| **Panel C – Log of Sales** | | | | |
| $\Delta$ Imports | -0.0038*** | 0.0000 | 0.0019*** | 0.0019*** |
| | (0.0011) | (0.0010) | (0.0006) | (0.0006) |
| $\Delta$ Export | 0.3944*** | 0.3869*** | 0.3910*** | 0.3867*** |
| | (0.0135) | (0.0134) | (0.0135) | (0.0134) |
| Number of Observations | 403,576 | 403,576 | 403,576 | 403,576 |
| Kleibergen-Paap $F$-Statistic | 186.57 | 140.30 | | |
| $CO_2$ intensity-decile-year-dummy | Yes | Yes | Yes | Yes |
| Sales-decile-year-dummy | Yes | Yes | Yes | Yes |
| Export share-decile-year-dummy | Yes | Yes | Yes | Yes |
| Sector-dummy | | Yes | | Yes |

*Notes: Notes:* * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$. Columns (1) and (2) show 2SLS estimations and columns (3) and (4) the corresponding OLS results. The dependent variable is the four-year change in the log of firms' $CO_2$ emissions scaled with firms' deflated sales (emission intensity) (Panel A), the log of firms' $CO_2$ emissions (Panel B), and the log of firms' deflated sales (Panel C). The explanatory variable of interest is the four-year change in imports from China and Eastern Europe scaled with domestic absorption in 1995 for each three-digit industry. The instrument is the four-year change of exports from China and Eastern Europe to other countries in each three-digit industry. Changes in firm-level export shares (on a 0-1 scale) were included as a control. The table reports the corresponding coefficient. The sample period is 1995 until 2017, but 2003 - 2006 were excluded due to a break in the reporting of energy variables in 2003. Standard errors were clustered both at the firm and at the three-digit-industry-year level. First-stage coefficients, standard errors and the Kleibergen-Paap F-statistic is reported for each specification. Source: Research Data Centres of the Federal Statistical Office and the Statistical Offices of the Länder: AFiD-Panel Industriebetriebe, 1995-2017, own calculations.

**Table A6:** Results Conditional on E-Prices - Logs of Emission Intensity

| | IV | | OLS | |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| **Panel A – Log of $CO_2$ Emission Intensity** | | | | |
| $\Delta$ Imports | -0.0028*** | -0.0017** | -0.0031*** | -0.0005 |
| | (0.0007) | (0.0008) | (0.0005) | (0.0005) |
| $\Delta$ Energy Price | -0.0716** | -0.0818*** | -0.0707** | -0.0867*** |
| | (0.0296) | (0.0255) | (0.0295) | (0.0251) |
| Number of Observations | 403,367 | 403,367 | 403,367 | 403,367 |
| Kleibergen-Paap $F$-Statistic | 185.28 | 138.51 | | |
| $CO_2$ intensity-decile-year-dummy | Yes | Yes | Yes | Yes |
| Sales-decile-year-dummy | Yes | Yes | Yes | Yes |
| Export share-decile-year-dummy | Yes | Yes | Yes | Yes |
| Sector-dummy | | Yes | | Yes |

*Notes:* * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$. Columns (1) and (2) show 2SLS estimations and columns (3) and (4) the corresponding OLS results. The dependent variable is the four-year change in the log of firms' $CO_2$ emissions scaled with deflated sales (emission intensity). The explanatory variable of interest is the four-year change in imports from China and Eastern Europe scaled with domestic absorption in 1995 for each three-digit industry. The instrument is the four-year change of exports from China and Eastern Europe to other countries in each three-digit industry. The regression controls for changes in the log of average energy prices at the three-digit sector level. The table reports the corresponding coefficient. The sample period is 1995 until 2017, but 2003 - 2006 were excluded due to a break in the reporting of energy variables in 2003. Standard errors were clustered both at the firm and at the three-digit-industry-year level. First-stage coefficients, standard errors and the Kleibergen-Paap F-statistic is reported for each specification. Source: Research Data Centres of the Federal Statistical Office and the Statistical Offices of the Länder: AFiD-Panel Industriebetriebe, 1995-2017, own calculations.

**Table A7:** East and China Separately: Log of $CO_2$ Emissions

| | IV Estimates | | | | OLS Estimates | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| **Panel A – Imports from China** | | | | | | |
| $\Delta$ Imports | -0.0089*** | -0.0090*** | -0.0098*** | -0.0026*** | -0.0032*** | -0.0004 |
| | (0.0015) | (0.0015) | (0.0015) | (0.0009) | (0.0008) | (0.0005) |
| Number of Observations | 403,367 | 403,367 | 403,367 | 403,367 | 403,367 | 403,367 |
| Kleibergen-Paap $F$-Statistic | 212.66 | 214.05 | 205.98 | 182.10 | | |
| **Panel B – Imports from Eastern Europe** | | | | | | |
| $\Delta$ Imports | -0.0044 | -0.0041 | -0.0046 | -0.0002 | 0.0009 | 0.0038*** |
| | (0.0038) | (0.0038) | (0.0040) | (0.0046) | (0.0008) | (0.0007) |
| Number of Observations | 403,367 | 403,367 | 403,367 | 403,367 | 403,367 | 403,367 |
| Kleibergen-Paap $F$-Statistic | 7.05 | 7.05 | 6.88 | 5.13 | | |
| CO_2 intensity-decile-year-dummy | Yes | Yes | Yes | Yes | Yes | Yes |
| Sales-decile-year-dummy | | Yes | Yes | Yes | Yes | Yes |
| Export share-decile-year-dummy | | | Yes | Yes | Yes | Yes |
| Sector-dummy | | | | Yes | | Yes |

*Notes:* * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$. Columns (1) to (4) show results from 2SLS estimations and columns (5) and (6) from an OLS estimation. The dependent variable is the four-year change in the log of firms' $CO_2$ emissions. In Panel A. the explanatory variable is the four-year change in imports from China and in Panel B. the explanatory variable is the four-year change in imports from eastern Europe; each scaled with domestic absorption in 1995 in each three-digit industry. The instrument is the four-year change of exports from China/eastern Europe to other countries in each three-digit industry. The sample period is 1995 until 2017, but 2003 - 2006 were excluded due to a break in the reporting of energy variables in 2003. Standard errors were clustered both at the firm and at the three-digit-industry-year level. The specification in columns (4) and (6) include trends within 11 broadly defined industries. For each specification, I report the Kleibergen-Paap F-statistic. Source: Research Data Centres of the Federal Statistical Office and the Statistical Offices of the Länder: AFiD-Panel Industriebetriebe, 1995-2017, own calculations.

**Table A8:** East and China Separately: Log of Sales

| | IV Estimates | | | | OLS Estimates | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| **Panel A – Imports from China** | | | | | | |
| $\Delta$ Imports | -0.0040*** | -0.0042*** | -0.0061*** | -0.0008 | -0.0013 | -0.0005 |
| | (0.0015) | (0.0015) | (0.0015) | (0.0013) | (0.0009) | (0.0010) |
| Number of Observations | 403,576 | 403,576 | 403,576 | 403,576 | 403,576 | 403,576 |
| Kleibergen-Paap $F$-Statistic | 212.71 | 214.10 | 206.02 | 182.13 | | |
| **Panel B – Imports from Eastern Europe** | | | | | | |
| $\Delta$ Imports | 0.0030 | 0.0031 | 0.0015 | 0.0085* | 0.0065*** | 0.0057*** |
| | (0.0045) | (0.0045) | (0.0049) | (0.0049) | (0.0011) | (0.0011) |
| Number of Observations | 403,576 | 403,576 | 403,576 | 403,576 | 403,576 | 403,576 |
| Kleibergen-Paap $F$-Statistic | 7.05 | 7.06 | 6.88 | 5.13 | | |
| $CO_2$ intensity-decile-year-dummy | Yes | Yes | Yes | Yes | Yes | Yes |
| Sales-decile-year-dummy | | Yes | Yes | Yes | Yes | Yes |
| Export share-decile-year-dummy | | | Yes | Yes | Yes | Yes |
| Sector-dummy | | | | Yes | | Yes |

*Notes:* * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$. Columns (1) to (4) show results from 2SLS estimations and columns (5) and (6) from an OLS estimation. The dependent variable is the four-year change in the log of firms' sales. In Panel A. the explanatory variable is the four-year change in imports from China and in Panel B. the explanatory variable is the four-year change in imports from eastern Europe; each scaled with domestic absorption in 1995 in each three-digit industry. The instrument is the four-year change of exports from China/eastern Europe to other countries in each three-digit industry. The sample period is 1995 until 2017, but 2003 - 2006 were excluded due to a break in the reporting of energy variables in 2003. Standard errors were clustered both at the firm and at the three-digit-industry-year level. The specification in columns (4) and (6) include trends within 11 broadly defined industries. For each specification, I report the Kleibergen-Paap F-statistic. Source: Research Data Centres of the Federal Statistical Office and the Statistical Offices of the Länder: AFiD-Panel Industriebetriebe, 1995-2017, own calculations.

**Table A9:** Additional Results - Log Emissions per Value Added - Within Estimator

| | IV Estimates | | | | OLS Estimates | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| **Panel A – Log $CO_2$ Intensity of VA** | | | | | | |
| $\Delta$ Imports | -0.0041$^{***}$ | -0.0039$^{***}$ | -0.0037$^{***}$ | -0.0018$^{**}$ | -0.0034$^{***}$ | -0.0002 |
| | (0.0007) | (0.0007) | (0.0007) | (0.0008) | (0.0005) | (0.0005) |
| Number of Observations | 285,581 | 285,581 | 285,581 | 285,581 | 285,581 | 285,581 |
| Kleibergen-Paap $F$-Statistic | 584.38 | 582.36 | 568.95 | 418.24 | | |
| **Panel B – Share of VA** | | | | | | |
| $\Delta$ Imports | 0.0007 | -0.0041 | 0.0054 | 0.0075 | -0.0222$^{**}$ | -0.0211$^{*}$ |
| | (0.0122) | (0.0122) | (0.0125) | (0.0154) | (0.0092) | (0.0110) |
| Number of Observations | 285,581 | 285,581 | 285,581 | 285,581 | 285,581 | 285,581 |
| Kleibergen-Paap $F$-Statistic | 584.38 | 582.36 | 568.95 | 418.24 | | |
| **Panel C – Log Material Intensity** | | | | | | |
| $\Delta$ Imports | 0.0001 | 0.0002 | -0.0001 | -0.0001 | 0.0007$^{**}$ | 0.0007$^{*}$ |
| | (0.0004) | (0.0004) | (0.0004) | (0.0005) | (0.0003) | (0.0004) |
| Number of Observations | 285,360 | 285,360 | 285,360 | 285,360 | 285,360 | 285,360 |
| Kleibergen-Paap $F$-Statistic | 584.33 | 582.33 | 568.97 | 418.02 | | |
| $CO_2$ intensity-decile-year-dummy | Yes | Yes | Yes | Yes | Yes | Yes |
| Sales-decile-year-dummy | | Yes | Yes | Yes | Yes | Yes |
| Export share-decile-year-dummy | | | Yes | Yes | Yes | Yes |
| Sector-dummy | | | | Yes | | Yes |

*Notes:* * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$. Columns (1) to (4) show results from 2SLS estimations and columns (4) and (5) from a OLS estimation. The dependent variable in Panel A is the log of $CO_2$ emissions per unit of value-added, in Panel B the share of value-added (i.e. value-added divided by sales) and in Panel C the log of material intensity. The explanatory variable is the import penetration ratio from China and Eastern Europe in each three-digit industry. The instrument is the import penetration ratio from China and Eastern Europe to other countries in each three-digit industry. The sample period is 1995 until 2017. Each firm received a separate fixed effect for 1995-2002 and 2003-2017 to accommodate the break in the reporting of energy variables. The specifications in columns (4) and (6) include year-industry fixed effects (11 broadly defined industries). For each specification, I report the Kleibergen-Paap F-statistic. Source: Research Data Centres of the Federal Statistical Office and the Statistical Offices of the Länder: AFiD-Panel Industriebetriebe, 1995-2017, own calculations.

**Table A10:** Additional Outcomes

| | IV Estimates | | | | OLS Estimates | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| **Panel A – Log Emissions per Employee** | | | | | | |
| $\Delta$ Imports | -0.0023*** | -0.0023*** | -0.0023*** | -0.0003 | -0.0012*** | 0.0005* |
| | (0.0005) | (0.0005) | (0.0005) | (0.0005) | (0.0003) | (0.0003) |
| Number of Observations | 403,367 | 403,367 | 403,367 | 403,367 | 403,367 | 403,367 |
| Kleibergen-Paap $F$-Statistic | 194.93 | 195.37 | 186.56 | 140.27 | | |
| **Panel B – Log # of Employees** | | | | | | |
| $\Delta$ Imports | -0.0035*** | -0.0035*** | -0.0042*** | -0.0015*** | 0.0002 | 0.0008** |
| | (0.0008) | (0.0008) | (0.0008) | (0.0006) | (0.0003) | (0.0003) |
| Number of Observations | 403,576 | 403,576 | 403,576 | 403,576 | 403,576 | 403,576 |
| Kleibergen-Paap $F$-Statistic | 194.99 | 195.43 | 186.61 | 140.31 | | |
| **Panel C – ihs(Investment)** | | | | | | |
| $\Delta$ Imports | -0.0149** | -0.0140** | -0.0163*** | 0.0046 | 0.0012 | 0.0036 |
| | (0.0064) | (0.0062) | (0.0062) | (0.0062) | (0.0032) | (0.0036) |
| Number of Observations | 403,576 | 403,576 | 403,576 | 403,576 | 403,576 | 403,576 |
| Kleibergen-Paap $F$-Statistic | 194.99 | 195.43 | 186.61 | 140.31 | | |
| **Panel D – # of Products** | | | | | | |
| $\Delta$ Imports | -0.0048** | -0.0048** | -0.0046** | 0.0003 | -0.0013 | 0.0009 |
| | (0.0019) | (0.0019) | (0.0019) | (0.0020) | (0.0008) | (0.0009) |
| Number of Observations | 360,989 | 360,989 | 360,989 | 360,989 | 360,989 | 360,989 |
| Kleibergen-Paap $F$-Statistic | 183.34 | 183.74 | 175.52 | 130.31 | | |
| **Panel E –Single Product Dummy** | | | | | | |
| $\Delta$ Imports | 0.0008*** | 0.0008*** | 0.0010*** | 0.0003 | 0.0005*** | 0.0003 |
| | (0.0003) | (0.0003) | (0.0003) | (0.0003) | (0.0002) | (0.0002) |
| Number of Observations | 360,989 | 360,989 | 360,989 | 360,989 | 360,989 | 360,989 |
| Kleibergen-Paap $F$-Statistic | 183.34 | 183.74 | 175.52 | 130.31 | | |
| $CO_2$ intensity-decile-year-dummy | Yes | Yes | Yes | Yes | Yes | Yes |
| Sales-decile-year-dummy | | Yes | Yes | Yes | Yes | Yes |
| Export share-decile-year-dummy | | | Yes | Yes | Yes | Yes |
| Sector-dummy | | | | Yes | | Yes |

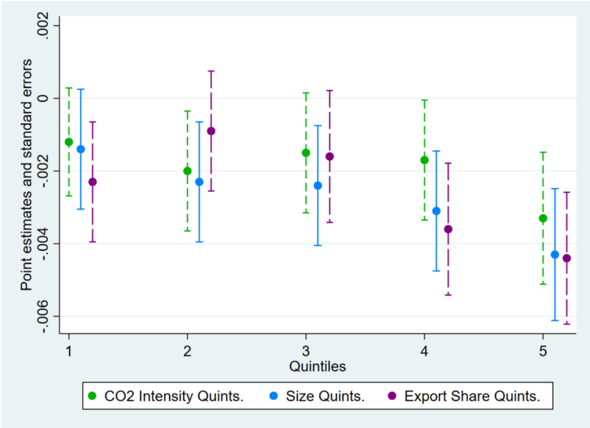
*Notes:* * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$. Columns (1) to (4) of the table show results from 2SLS estimations and columns (5) and (6) from an OLS estimation. The dependent variables are the four-year changes in the log of firms' $CO_2$ emissions per employee (Panel A), the log of the number of employees (Panel B), the inverse hyperbolic since transformed investment, the number of products and an indicator for single product firms. The explanatory variable is the four-year change in imports from China and Eastern Europe scaled with domestic absorption in 1995 in each three-digit industry. The instrument is the four-year change of exports from China and Eastern Europe to other countries in each three-digit industry. The sample period is 1995 until 2017 but the years 2003 - 2006 were excluded due to a break in the reporting of energy variables in 2003. Standard errors were clustered at the firm and the three-digit-industry-year level. Source: Research Data Centres of the Federal Statistical Office and the Statistical Offices of the Länder: AFiD-Panel Industriebetriebe, 1995-2017, own calculations.

**Table A11:** Export Opportunities and Log $CO_2$ Intensity - Sectoral Effects

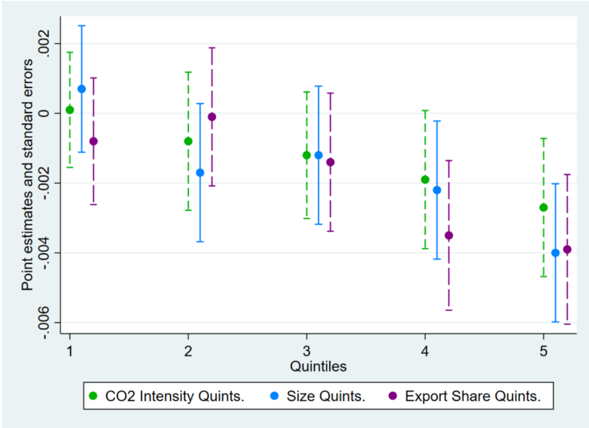
| | Weighted Mean | | Unweighted Mean | | Covariance | |
|---|---|---|---|---|---|---|
| | (IV) | (OLS) | (IV) | (OLS) | (IV) | (OLS) |
| **Panel A – 3. Digit Sector Level** | | | | | | |
| $\Delta$ Exports | -0.0046*** | -0.0056*** | -0.0004 | -0.0025*** | -0.0042*** | -0.0031*** |
| | (0.0016) | (0.0013) | (0.0012) | (0.0008) | (0.0009) | (0.0009) |
| Number of Observations | 1,290 | 1,290 | 1,290 | 1,290 | 1,290 | 1,290 |
| Kleibergen-Paap $F$-Statistic | 50.84 | | 50.84 | | 50.84 | |
| Year dummy | Yes | Yes | Yes | Yes | Yes | Yes |

*Notes:* * p < 0.1; ** p < 0.05; *** p < 0.01. The table shows IV and OLS regression results from a long difference regression estimated at the 3-digit sector level for three dependent variables (given at the top). The dependent variables are the corresponding four-year changes. "Weighted mean" is total emissions divided by total sales in sector z. "Unweighted Mean" is the average firm's $CO_2$ intensity in sector z. "Covariance" is the covariance between a firm's market share and a firm's $CO_2$ intensity. The years 2003 - 2006 were excluded due to a break in the reporting of energy variables between 2002 and 2003. The explanatory variable is the four-year change in sectoral exports of Germany to China and Eastern Europe scaled with domestic absorption in 1995. The instrument is the four-year change of exports from the instrument countries to China and Eastern Europe in each three-digit industry. Source: Research Data Centres of the Federal Statistical Office and the Statistical Offices of the Länder: AFiD-Panel Industriebetriebe, 1995-2017, own calculations.

**Figure A1:** Effect Heterogeneity: Splits by within Sector Quintiles




(a) Baseline




(b) Sectoral Trends

Notes:The dependent variable is emission intensity in log. All specifications include year-by-decile fixed effects for emission intensity, sales and export shares. Subfigure (a) corresponds to the baseline specification and subfigure (b) to the specification that accounts for sectoral trends. The thin lines demarcate 95% confidence intervals. Firms are assigned to a quintile based on the first observation available for each firm. Standard errors were clustered both at the firm and at the three-digit-industry-year level. Source: Research Data Centres of the Federal Statistical Office and the Statistical Offices of the Länder: AFiD-Panel Industriebetriebe, 1995-2017, own calculations.