Import competition and firm-level CO_2 emissions: Evidence from the German manufacturing industry

Jakob Lehr
University of Mannheim

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 1 pp increase in the import penetration ratio caused a reduction of the average firm's emission intensity by approximately 0.3%. This result implies that the rise of the joint East between 1995 and 2017 kept the average firm's 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 emissions, with a small, if any, negative effect on emission intensities.

Résumé. Concurrence des importations et émissions de CO_2 des entreprises : l'exemple de l'industrie manufacturière allemande. En utilisant le recensement allemand de l'industrie manufacturière, j'analyse l'incidence de la concurrence des importations sur les émissions de carbone par unité de ventes en termes réels (intensité des émissions). Je combine des données précises sur les émissions de CO_2 des entreprises avec les flux des échanges commerciaux sectoriels. En examinant la période allant de 1995 à 2017, je me concentre sur l'effet de la montée en puissance de l'Europe de l'Est et de la Chine tout en tenant compte de l'endogénéité des flux commerciaux à l'aide de la méthode des variables instrumentales. Les résultats de base suggèrent qu'une augmentation d'un point du taux de pénétration des importations entraîne une réduction de l'intensité des émissions de l'entreprise moyenne d'environ 0,3 %. Ce résultat indique que la montée en puissance des pays de l'Est entre 1995 et 2017 a maintenu l'intensité des émissions de l'entreprise moyenne 6 % en dessous du niveau qu'elle aurait atteint en l'absence de celle-ci. Je ne constate pas d'indication forte d'une redistribution de la production vers des entreprises plus efficaces. Enfin, je complète l'analyse en examinant l'effet des possibilités d'exportation dues à la montée en puissance de l'Est. Les résultats indiquent que les exportations vers l'Est ont augmenté les ventes et les émissions, avec un effet négatif faible, voire nul, sur l'intensité des émissions.

JEL classification: F18, Q54, L60, D22

Corresponding author: Jakob Lehr, jakob.lehr@uni-mannheim.de

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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 (see Copeland and Taylor 2004, Cherniwchan et al. 2017). While older studies have mostly focused on country or sector-level effects (see 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 (see Cherniwchan 2017, Barrows and Ollivier 2018, Gutiérrez and Teshima 2018, 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 (see Holmes and Schmitz 2001, Bloom et al. 2015, Shu and Steinwender 2019, Chen and Steinwender 2021). Because the environmental and energy economics literature has identified energy use as particularly inefficient ("energy efficiency paradox"; see 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 span the period from 1995 until 2017, cover the universe of manufacturing plants with more than 20 employees (approximately 40,000 plants annually) and provide, among other things, detailed information on plant-level fuel use. This information allows calculating CO_2 emissions based on fuel-specific conversion factors.[1] To identify the effect of import competition on emission intensity, I exploit the rise of China and Eastern Europe (which I will jointly refer to as "the East") as major actors in the world economy. A rising share of imported manufacturing goods in Germany originating from these regions is one manifestation of this process.[2]

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).

The paper relates to several strands of literature. First, it contributes to the literature on trade, globalization and the effects on the environment.[3] By examining the effect of

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 labour 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.

2 For example, between 1995 and 2017, the share of German imports from the East rose from 10% to almost 30% (see table A6 in the online appendix).

3 See Cherniwchan (2017) and Copeland et al. (2021) for recent literature reviews.

import competition on CO_2 emission intensity in Germany, it closely relates to Gutiérrez and Teshima (2018), who found that intensified import competition due to tariff cuts improved energy efficiency among firms in Mexico. It also complements recent work by Leisner et al. (2023), who document that import competition from China lowered emissions and sales among Danish manufacturing firms but did not reduce emission intensities except in the most emission-intensive quartile. My paper extends this literature by focusing on manufacturing in Germany—Europe's largest economy, its largest emitter and a country with a relatively energy-intensive industrial structure.[4] Leisner et al. (2023) also analyze the effects of offshoring, i.e., importing intermediate inputs. Similar to Akerman et al. (2021) and Dussaux et al. (2023), who examine Swedish and French manufacturing firms, respectively, they find that offshoring leads to lower emission intensities by increasing sales more than emissions.[5] In related work on the effects of trade liberalization through NAFTA, Cherniwchan (2017) attributes reduced emissions of local pollutants from US manufacturing plants to the increased availability of emission-intensive intermediate inputs and new export opportunities for American manufacturers. The relation between exporting and firms' CO_2 emission intensity has been studied by Richter and Schiersch (2017) and Barrows and Ollivier (2021) for Germany and India, while Kong et al. (2022) and Bombardini and Li (2020) examine the impact of exporting on local pollutants in China.

The paper further relates to the literature on the determinants of energy efficiency and the so-called "energy efficiency paradox" (see DeCanio 1993, Jaffe and Stavins 1994, Gerarden et al. 2017), which refers to seemingly suboptimal energy use by firms. The literature has identified several potential explanations for inefficient energy use, such as managerial inability (see Bloom et al. 2010, Martin et al. 2012), capital constraints (see 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.[6] For instance, Bloom et al. (2015) document "trade induced technical change," i.e., technological upgrading, more patenting and higher total factor productivity (TFP) revenue among European firms that operate in sectors more exposed to Chinese imports. Chen and Steinwender (2021) also find positive effects of import competition on productivity among initially unproductive family-owned firms in Spain.[7] In contrast, Autor

4 For example, during the first three trading periods of the EU–ETS (2005–2020) approximately 20% of verified emissions from industrial installations came from Germany (see European Environmental Agency 2023).

5 While this is an arguably important channel through which trade integration can affect German firms, I cannot study offshoring because I lack relevant information on imports.

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

7 They provide evidence that competition forces unproductive firms to improve material usage and eliminate what they call "X-inefficiencies," which describes suboptimal firm behaviour regarding the objective to maximize monetary profits.

et al. (2020) estimate a negative effect of increasing import competition from China on R&D expenditure and patenting among US manufacturing firms. 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."

I start the analysis with a decomposition of the three-digit sector-level emission intensity (see Olley and Pakes 1996), showing that total sector-level emission intensity is negatively related to imports from the East, driven by within-firm changes. Reallocation of market shares towards more productive firms, if at all, played only a minor role.

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% to 0.4% in response to a 1 pp increase in the share of imports from the East relative to baseline absorption (import penetration ratio). By examining firms' CO_2 emissions and sales separately, I show that both decline due to increased import competition, with a stronger response in emissions, resulting in a fall in emission intensity. The effect is centred 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 and to "controlling" for changes in sectoral exports to the East, for which I constructed an instrument analogous to the one for imports. Respective estimates suggest that new export opportunities lead to a nearly proportional increase in emissions and sales. I further analyze the effect of import competition on emissions per unit of value added, which can be calculated for a subsample of firms yielding quantitatively similar estimates. The baseline results are also robust to an alternative identification strategy based on gravity residuals presented in the paper's online appendix.

The remainder of the paper is structured as follows. In section 2, I outline the empirical approach. 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 α 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 (see Autor et al. 2020). Concretely, the "import penetration ratio" (IPR) is defined as follows:

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

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

$$\Delta y_{itz} = \beta_0 + \alpha \Delta IPR_{zt}^{East} + \Delta\epsilon_{itz}. \tag{2}$$

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.[8]

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' behaviour simultaneously.[9] I address the endogeneity similar to Autor et al. (2013) and Dauth et al. (2014) by instrumenting the changes in German imports from the East's industry z with changes in trade flows from the same industry z in the East to a set of other countries:

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

The idea is that part of the variation of German imports from the East 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 (endogenous) part of the variation is due to domestic conditions in Germany and needs to be separated out. The instrument succeeds in separating the exogenous component of trade flows to Germany from the endogenous under the assumption that conditions in Germany are orthogonal to those in the chosen set of other countries. The exclusion restriction further demands that trade flows between the set of other countries and the East have no direct effect on German firms. These considerations 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 borders Germany nor is any of them a member of the European Monetary Union (EMU). Dauth et al. (2014) argue that demand conditions among neighbouring 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.[10] Finally, for the instrument to work, it needs to be relevant, which, however, can be tested and is indeed confirmed by the first-stage results reported in section 4.

8 Ideally, I would like to use lagged absorption from the period before the rise of the East in the denominator of the instrument. However, due to data limitations this was not possible. 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.

9 Suppose the demand for some goods, e.g., heat pumps and solar panels, suddenly increases in Germany. That will simultaneously affect the imports of respective goods and domestic producers of those goods. For example, domestic producers' production might increase, and hence, they require more energy inputs. Moreover, their energy intensity might also increase because expanding production beyond the efficient level will still be profitable given that high demand drives up prices.

10 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 A8 in the online 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), which 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).

The industrial plants module contains economic variables such as sales, sales abroad, number of employees and investment. To deflate these monetary values, I use the four-digit sector-specific producer price indices published by the German statistical office.[11] The energy use module details plant-level 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 (see Petrick et al. 2011, Richter and Schiersch 2017).[12] 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 (see 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 are both 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.[13] The final dataset is an unbalanced panel aggregated at the firm level, covering 1995 until 2017.

I supplement the main data with the "cost structure survey," an unbalanced panel at the firm level that typically includes firms for four consecutive years.[14] The cost structure survey provides—among other things—information on intermediate input expenditures, allowing for an estimation of the effect of import competition on the emission intensity of value added. Unfortunately, more granular information on intermediate inputs, such as by product and origin, is unavailable, making it impossible to study offshoring.

I rely on the BACI 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 six-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 three-digit economic sector level using the classification

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11 See "Statistisches Bundesamt, Index der Erzeugerpreise gewerblicher Produkte (Inlandsabsatz) – Lange Reihen der Fachserie 17 Reihe 2."

12 For the conversion of energy from primary sources, I draw upon the emission factors provided by the Umweltbundesamt (a federal agency). A table with the relevant information is available at www.umweltbundesamt.de/themen/klima-energie/treibhausgas-emissionen, last retrieved November 18, 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.

13 In the main specification that uses four-year differences, this implies the omission of the years 2003–2006. For further background on the energy use module as well as the change in reporting, see Petrick et al. (2011).

14 This sampling procedure also dictates the choice of differencing, making it infeasible to take differences longer than four years. Only firms with more than 500 employees are included annually in the cost structure survey.

from 1993 (equivalent to NACE industry codes).[15] I fix firms' economic sector to the sector from the first year in which the firm appears in AFiD.

The final data set 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 1st percentile or above the 99th 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" (WZ 32). 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 indices in these sectors are outliers making a comparison of deflated sales as measures of physical output over time difficult.[16] 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 to 116 employees and generates approximately 23 million euros in annual turnover, of which—on average—18% are exported. Additional information on value added from the cost structure survey is available for about 40% of the observations. 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.

TABLE 1

Descriptive statistics – Firm-level information

Variable	Mean	Std. dev.	p10	p50 (median)	p90	N
Number of employees	116	188	24	54	255	744,062
Sales	22,923.2	53,710.3	1,729.5	6,705.33	51,559.5	744,062
Export share	0.18	0.24	0	.07	0.56	744,062
Value added	23,726.5	56,173	1,668.8	7,398.2	58,492.91	297,241
Value added share	0.60	0.17	0.37	0.61	0.82	297,241
Total energy (in MWh)	11,048.7	103,877.5	155.8	933.5	12,400	744,062
Total CO_2 emissions (in t)	3,722.4	31,634.2	65.9	381.7	4,823.46	744,062
Total electricity (in MWh)	3,619.55	29,104.7	64.4	423.3	5,351.5	744,062
Import penetration ratio	8.85	9.94	1.04	5.26	20.44	744,062

NOTES: The table shows the average of respective variables from the period 1995–2017. Deflated sales and value added are in 1,000 euro, energy use (total and electricity) is in MWh and CO_2 emissions in tons.
SOURCES: Research data centres of the Federal Statistical Office and the Statistical Offices of the Länder: AFiD-Panel Industriebetriebe, 1995–2017; own calculations.

15 To be precise, I first convert the product-level information from HS92 to SITC3 (conversion table was downloaded from https://unstats.un.org/unsd/trade/classifications/correspondence-tables.asp) and then I map from SITC3 to the three-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 because the economic sector based on the classification from 1993 is unknown for these firms.

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

In addition to presenting economic performance indicators, table 1 summarizes total energy use, electricity use and CO_2 emissions. For instance, the table shows that mean energy use amounts to 11,048 MWh annually, resulting in 3,722 tons of CO_2 emissions per firm. Finally, the last row of the table shows the average firm's import penetration ratio from the East at approximately 9 pp. This average masks strong dynamics over time and differences across sectors as can be seen from table A6 in the online appendix, which reports summary statistics for imports (shares) from China and Eastern Europe from 22 two-digit industries for 1995 and 2017. In the initially least-exposed sector (Manufacture of tobacco products, NACE Rev.1 16), imports from the East accounted for merely 1.4% in 1995 but for 27% in the most exposed sector (Manufacture of wearing apparel; dressing and dyeing of fur, NACE Rev.1 18). Twenty-two years later, import shares ranged from 11% (manufacture of chemicals and chemical products, NACE Rev. 1 24) to 58% (manufacturing of office machinery and computers, NACE Rev.1 30).[17] China's accession to the WTO and the EU's eastward enlargement played an important role in the increase in import shares, which indeed increased in all 22 sectors during the time window under consideration.

3.3. Motivating exercise: Sectoral decomposition of emission intensity

Before turning to the firm-level analysis, 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:

$$\underbrace{W_{zt} = \sum_{i \in Z} s_{it} lnE_{it}}_{\text{Weighted CO}_2\text{ Intensity in Sector Z}} = \underbrace{\overline{lnE_{zt}}}_{\text{Unweighted avg. Intensity}} + \underbrace{\sum_{i \in Z} (s_{it} - \overline{s_t})(lnE_{it} - \overline{lnE_t})}_{\text{Covariance}}, \quad (3)$$

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 reflect changes within firms.

Figure 1 shows the evolution of the weighted average, the unweighted average and the covariance term averaged across three-digit economic sectors. One can see that the weighted average decreased by approximately 40% between 1995 and 2017 as indicated by the solid

17 Aggregated across the sectors, imports from China amounted to approximately US$8 billion (approximately 22*350 MIO USD) in 1995, corresponding to an import share of 2%. Until 2017, this share rose to 10% (imports worth US$89 billion and approximately US$4 billion from the average two-digit sector). Similarly, imports from Eastern Europe rose from US$32 billion (approximately 8% of total imports) in 1995 to US$200 billion in 2017, corresponding to an import share of nearly 20%.

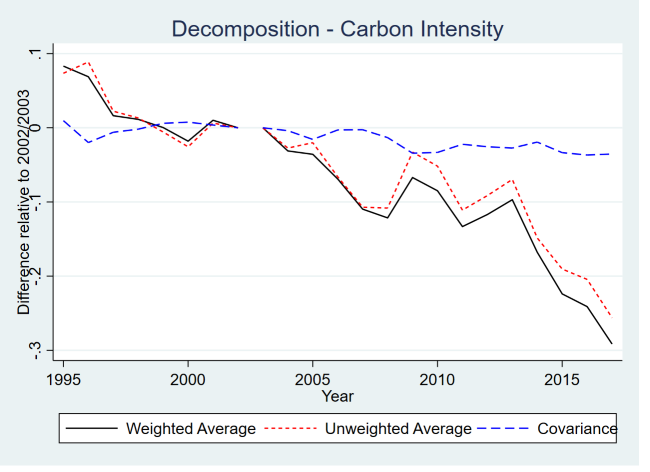

FIGURE 1 Decomposition of sectoral emission intensity
NOTE: The figure shows the average across three-digit sectors from a decomposition of total emissions (weighted average) in the unweighted average and the covariance between market share and CO_2 intensity.
SOURCES: Research Data Centres of the Federal Statistical Office and the Statistical Offices of the Länder: AFiD-Panel and BAKI trade data, 1995–2017

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 4 pp, 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 on changes in sector-specific IPRs from the East to gauge the carbon efficiency-import competition link. The estimating equation is given below:

$$\Delta y_{zt} = \beta_0 + \beta_1 \Delta IPR_{zt}^{East} + \tau_t + \Delta\epsilon_{zt}. \tag{4}$$

Each regression includes year dummies (τ_t) as controls. Table 2 shows results from an OLS estimation and the IV approach introduced in section 2.

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 1 pp increase in the IPR from the East.[18] 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 decrease 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

18 Note that the Kleibergen–Paap F-statistic provided at the bottom of the table indicates a strong first stage.

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)
Three-digit sector level						
Δ 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 estimated at the three-digit sector level. The dependent variables are the four-year changes of the "weighted mean" (total sectoral emissions divided by total sales), the "unweighted mean" (the average firm's CO_2 intensity in sector z) and the "covariance," i.e., the covariance between a firm's market share and a firm's CO_2 intensity. The explanatory variable is the four-year change in the sectoral IPR from the East. The instrument is the respective four-year change of exports from the East to other countries. Regressions are weighted by the number of firms in a sector.
SOURCES: Research Data Centres of the Federal Statistical Office and the Statistical Offices of the Länder: AFiD-Panel Industriebetriebe, 1995−2017; own calculations.

mean. Hence, respective IV and OLS estimates are negative but small and statistically insignificant. For example, the IV estimate implies that a 1 pp 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.

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 logarithms of firms' CO_2 emissions and firms' sales as dependent variables. The explanatory variable is the corresponding change in the IPR from the East. 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 decile, sales decile and export-share decile dummies and years. First-year values determine the assignment of firms to respective deciles.[19] Columns (5) and (7) show the most demanding specification which controls for trends within 12 broadly defined industries (see Autor et al. 2014 and Autor et al. 2020). Standard errors were clustered at the firm level to account for within-firm autocorrelation and at the year−three-digit sector level (two-way clustering). In a robustness check, I show results with standard errors clustered at the three-digit sector level only. At the bottom of the table, I report first-stage results (coefficient, standard errors and Kleibergen−Paap F-statistic).

19 For emission intensities, I updated the deciles in 2003 because 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							
Δ 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							
Δ 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							
Δ 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							
Δ 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 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 is the four-year change in the IPR from the East for each three-digit industry. The instrument is the respective four-year change of sectoral exports from the East to other countries. 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 are reported for each specification.
SOURCES: 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 relevance of the instrument. 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 1 pp 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 fixed effects 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 1 pp increase in the IPR, but the effect remains highly significant.

Finally, column (5) includes trends for 12 broadly defined industries. In the aggregation of industries, I closely follow Autor et al. (2014) and Autor et al. (2020), 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.[20] Controlling for industry trends also absorbs useful variation to identify the effect. Losing this variation 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 1 pp 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 the same set of fixed effects as the IV estimations in columns (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, panels 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 for only year

20 Table A7 in the online appendix shows how two-digit industries were aggregated into the 12 groups.

fixed effects yields a point estimate of −0.0033, implying that a 1 pp 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 1 pp increase in the IPR. As before, including sectoral trends cuts the point estimate to −0.0018 (see column (5)), but the effect remains significant at the 95% confidence level. The OLS result in column (6) of panel B is much smaller than the corresponding IV estimate 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 panels A and B, specifically from the fact that point estimates in panel A were smaller than those 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, domestic demand is likely to act as an omitted variable which increases both. Note from panels 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

4.2.1. Alternative samples and specifications

The main results on import competition's effect on emission intensity are subjected to various robustness and sensitivity checks shown in table A1 of the online appendix. First, I estimate the main effect on alternative estimation samples, e.g., I rely on the full sample, including NACE1 sectors 30 and 32, subsamples of single plant firms only, firms that never generate their own electricity and data from post-2002, i.e., after the break in the reporting of energy variables. Second, I check the sensitivity of results towards alternative specifications, e.g., I use non-overlapping intervals of data, an alternative instrument group and alternative clustering of standard errors. Section A1 of the online appendix shows and describes the results and the rationale for each robustness check in detail. Overall, the estimates turn out to be very robust: they remain almost unchanged when focusing on single plant firms, "never generators" or using the alternative instrument group which excludes Sweden and the UK. The estimates are substantially larger when using the full sample and a bit smaller when using data from post-2002 only. Clustering at the sector-level increases the standard errors by more than 50%. Therefore, the baseline specification is significant at the 5% level and the specification that controls for sectoral trends is significant at the 10% level only.

To check robustness towards alternative specifications, table A2 in section A1 of the online appendix provides estimates based on three and five-year differences, as well as from a fixed effects/within estimator. If anything, the point estimates in table A2 are slightly larger than those in table 3. Finally, section A2 in the online appendix presents results from an alternative identification strategy based on gravity residuals (see Autor et al. 2013, Dauth et al. 2014 and Dippel et al. 2021), which yields estimates in line with the main results.

4.2.2. Export opportunities as potential confounder

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.[21] Because new export opportunities lead to an expansion of market size, they could be expected to decrease emission intensity (see Richter and Schiersch 2017, Forslid et al. 2018). 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 and gain insight into the effect of export opportunities on emission intensities itself, I add changes in sectoral exports from Germany to the East as an additional explanatory variable to the baseline specification. The OLS version of the estimating equation now reads as follows:

$$\Delta y_{itz} = \beta_0 + \alpha^{Imp} \Delta IPR_{zt}^{East} + \alpha^{Exp} \Delta EO_{zt}^{Ger \rightarrow East} + \Delta \epsilon_{itz}, \tag{5}$$

where $\Delta EO_{zt}^{Ger \rightarrow East}$ is defined as the change in sectoral exports from Germany to the East scaled with domestic absorption at baseline:

$$\Delta EO_{zt}^{Ger \rightarrow East} \equiv \frac{\Delta Exp_{zt}^{Ger \rightarrow East}}{Y_{z,1995} + Imp_{z,1995} - Exp_{z,1995}}.$$

The measure of export opportunities is also prone to 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. Again, I follow Dauth et al. (2014) and construct the following instrument for changes in German exports by sector z to the East:

$$\frac{\Delta Exp_{zt}^{Inst \rightarrow East}}{Y_{z,1995} + Imp_{z,1995} - Exp_{z,1995}},$$

that is, I use changes in sectoral exports of the instrument countries to the East to instrument the changes of sectoral exports from Germany to the East.

Table 4 reports corresponding IV and OLS estimates for the baseline specification and the specification that includes sectoral trends. The coefficient that captures the effect of import competition on emission intensity in column (1), remains almost unchanged compared to the corresponding estimate in table 3 (see panel A, column (4)). The point estimate measuring the effect of export opportunities on emission intensity is also negative but quantitatively small and statistically insignificant. Reassuringly, the effects of intensifying import competition and export opportunities on the logs of emissions and sales (panels B and C) align with expectations: as in table 3, import competition negatively impacts both outcomes. In contrast, export opportunities lead firms to scale up, moving output and emissions almost in lockstep. Therefore, the effect of export opportunities on intensities is relatively small. Overall, these results do not suggest that export opportunities drive the main findings, especially because the decline in emission intensity in the main analysis occurs because emissions decrease more sharply than output, whereas new export opportunities have a positive effect on these outcomes. Upon adding sector dummies (column (2) of table 4), the main coefficient, capturing the effect of import competition, becomes more negative compared to the corresponding estimate in table 3. This is driven by a stronger decrease in

21 Indeed, in their analysis, positive labour market effects resulting from the rise of the East dominate the adverse effects of import competition.

TABLE 4
Effects of import competition and export opportunities

	IV		OLS	
	(1)	(2)	(3)	(4)
Panel A. Log of CO_2 emission intensity				
Δ imports	−0.0026***	−0.0029***	−0.0012***	−0.0001
	(0.0007)	(0.0009)	(0.0005)	(0.0005)
Δ exports	−0.0008	0.0037***	−0.0034***	−0.0013**
	(0.0010)	(0.0012)	(0.0005)	(0.0005)
Number of observations	403,367	403,367	403,367	403,367
Kleibergen−Paap F-statistic	106.78	60.91		
Panel B. Log of CO_2 emissions				
Δ imports	−0.0079***	−0.0027***	−0.0024***	0.0004
	(0.0012)	(0.0008)	(0.0005)	(0.0004)
Δ exports	0.0041***	0.0033***	0.0024***	0.0022***
	(0.0009)	(0.0010)	(0.0005)	(0.0005)
Number of observations	403,367	403,367	403,367	403,367
Kleibergen−Paap F-statistic	106.78	60.91		
Panel C. Log of gross output				
Δ imports	−0.0053***	0.0001	−0.0011	0.0005
	(0.0013)	(0.0011)	(0.0007)	(0.0007)
Δ exports	0.0049***	−0.0004	0.0058***	0.0035***
	(0.0013)	(0.0014)	(0.0007)	(0.0007)
Number of observations	403,576	403,576	403,576	403,576
Kleibergen−Paap F-statistic	106.68	60.90		
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 results from 2SLS estimations and columns (3) and (4) from an OLS estimation. The dependent variable is the four-year change in the log of firms' CO_2 emission intensity (panel A), the log of firms' CO_2 emissions (panel B) and the log of firms' deflated sales (panel C). The explanatory variables are the four-year changes in the sectoral IPR from the East and changes in sectoral exports from Germany to the East scaled with domestic absorption in 1995. The instruments are the four-year changes of exports from the East to other countries (to instrument changes in German imports) and the sectoral change in exports from other countries to the East (to instrument the German exports). Standard errors were clustered both at the firm and at the three-digit industry−year level.
SOURCES: Research Data Centres of the Federal Statistical Office and the Statistical Offices of the Länder: AFiD-Panel Industriebetriebe, 1995−2017, own calculations.

emissions (panel B). Surprisingly, the point estimate for the effect of export opportunities on emission intensity is positive due to a positive effect on emissions but a null effect of export opportunities on output (panel C).[22]

In addition to the main goal of the analysis presented here—to control for export opportunities as a potential confounder—the findings about the impact of export opportunities on firm-level emissions are of significance by themselves. Section A3 in the online appendix

22 An alternative is to simply control for firms export shares in the baseline IV estimation, with the caveat that this does not lend to a causal interpretation of the export share coefficient. From table A9 in the online appendix, one can see that a 1 pp increase in firms' export share is associated with a reduction in emission intensity by 0.23%, driven by an increase in sales and a less-than-proportional increase in emissions. The main effect on the effect of import competition on emission intensity remains unchanged.

expands on this analysis and further analyzes the effect of export opportunities on emission intensity.

4.2.3. Energy prices as potential confounder

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 the East's sector z 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 A10 in the online 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.

4.3. Heterogeneity

The subsequent paragraphs shed light on heterogeneities. First, I distinguish between imports from Eastern Europe and imports from China. Second, I analyze heterogeneities depending on firm characteristics, e.g., firms' emission intensity, export share or size.

4.3.1. Eastern Europe vs. China

Table 5 reports separately the effects of changes in the IPR from China (columns (1) and (2)) and Eastern Europe (columns (3) and (4)). As in the main results table, the dependent variables are the logs of emission intensity (panel A), emissions (panel B) and sales (panel C).

One can see that the effect of imports from China closely resembles the main effect reported in table 3. The coefficient in column (1) indicates a decrease in emission intensity by 0.37% due to a 1 pp increase in the IPR. This effect drops to 0.18% after accounting for sectoral trends (column (2)). Panels B and C show that the effect on CO_2 emissions is negative and significant in both specifications, while the effect on sales is negative and significant in column (1) but becomes insignificant in column (2).

For Eastern European imports, I find a large and highly significant negative effect on emission intensities in both specifications. However, these effects must be qualified: first, the first stages are weak, with F-statistics below 10. Second, when examining the effect on sales in panel C, I find positive point estimates, which become larger after conditioning on industry trends.[23] Dauth et al. (2014) emphasize the role of intra-industry trade between Germany and Eastern Europe and the correlation between industry-level imports from and German exports to Eastern Europe. Therefore, the positive effect on sales, which reduces emission intensity, might partly result from correlated German exports. The integration of Eastern European economies into German firms' value chains, for example, through FDI from Germany, further challenges the identification. For instance, productivity improvements

23 Specifically, the point estimate without industry trends is 0.0015 with a standard error of 0.0049. After conditioning on industry trends, the point estimate is 0.0085 with a corresponding standard error of 0.0049, making it marginally significant. The point estimate with CO_2 emissions as the dependent variable is −0.0046 without and −0.0002 with industry trends.

TABLE 5
Eastern Europe and China separately

	China		Eastern Europe	
	(1)	(2)	(3)	(4)
Panel A. Log of CO_2 emission intensity				
Δ imports	−0.0037***	−0.0018*	−0.0062***	−0.0088**
	(0.0010)	(0.0011)	(0.0024)	(0.0040)
Number of observations	403,367	403,367	403,367	403,367
Kleibergen−Paap F-statistic	205.98	182.10	6.88	5.13
Panel B. Log of CO_2 emissions				
Δ imports	−0.0098***	−0.0026**	−0.0046	−0.0002
	(0.0015)	(0.0009)	(0.0040)	(0.0046)
Number of observations	403,367	403,367	403,367	403,367
Kleibergen−Paap F-statistic	205.98	182.10	6.88	5.13
Panel C. Log of sales				
Δ imports	−0.0061***	−0.0008	0.0015	0.0085*
	(0.0015)	(0.0013)	(0.0049)	(0.0049)
Number of observations	403,576	403,576	403,576	403,576
Kleibergen−Paap F-statistic	206.02	182.13	6.88	5.13
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: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. The table show results from 2SLS estimations. The explanatory variable is the four-year change in the IPR from China (columns (1) and (2)) and Eastern Europe (columns (3) and (4)) at the three-digit industry level. The instruments are the respective four-year changes of exports from China/Eastern Europe to other countries. The dependent variables are the four-year changes in the logs of firms' CO_2 emission intensity (panel A), CO_2 emissions (panel B) and sales (panel C). Standard errors were clustered both at the firm and at the three-digit industry−year level. For each specification, I report the Kleibergen−Paap F-statistic.
SOURCES: Research Data Centres of the Federal Statistical Office and the Statistical Offices of the Länder: AFiD-Panel Industriebetriebe, 1995−2017; own calculations.

in Germany might increase exports from German foreign affiliates in Eastern Europe. Given the weak first stage in the IV specification for Eastern Europe and the limitations mentioned above, the magnitude of the effect of imports from Eastern Europe should be interpreted with caution.

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 and firms in sectors with high import shares in 1995.[24]

Column (1) reports heterogeneities by emission intensity, showing a statistically insignificant main effect and a negative and highly significant interaction effect.[25] Despite

24 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.

25 I omit the CO_2 intensity−decile fixed effects because they would absorb all the variation in the interaction effect and condition on start-off period values instead.

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 product				0.00105	
				(0.00091)	
Interaction – High import shares					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 from 2SLS estimations. The dependent variable is the four-year change in the log of firms' CO_2 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 value of the dependent variable. The explanatory variable is the four-year change in the sectoral IPR from the East instrumented with the respective four-year change of exports from the East to other countries. 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.
SOURCES: Research Data Centres of the Federal Statistical Office and the Statistical Offices of the Länder: AFiD-Panel Industriebetriebe, 1995–2017; own calculations.

considerable variation in firms' emission intensity above the median (see table 1), this result still suggests that the effect of import competition is quantitatively relevant for aggregate emissions. Column (2) shows the interaction between import competition and firms' integration in the global economy, measured by their export shares. The estimated main effect is negative, and the interaction effect is positive but small and insignificant. For a German firm selling primarily domestically, an increase in IPR might be more consequential compared to one selling in the competitive world market, providing a plausible rationale for the stronger response of firms with below-median export shares. The third column reports the interaction effect between import competition and firm size (measured by the number of employees), indicating a larger effect among larger firms. Column (4) interacts the trade shock with a dummy for single product firms.[26] 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, while the interaction effect is positive. This implies that the reduction in emissions was concentrated among firms in sectors with lower import exposure in 1995.

26 I am using single plant firms only here because I do not know the number of products for multi-product firms.

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. 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. Figure A1 in the online appendix plots results for the baseline specification (left subfigure) and the specification that accounts for industry trends (right subfigure). Starting with the subsamples formed based on different emission intensity quintiles, one can see that the effect is relatively stable. All point estimates in the left Subfigure 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 also hint at a slight increase in the effect's size for more emission-intensive firms—the ones that presumably have the most room for improvement.[27]

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, possibly due to varying numbers of observations within quintiles, e.g., firms with lower export shares appear to have a lower survival rate. Results in figure A1 suggest that firms with higher export shares relative to other firms in their three-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 (see table 6).

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 described above, value added would decline, so the emission intensity of value added would remain unchanged or even increase despite a decrease in the emission intensity of sales. Recall that this analysis is feasible only for firms included in the cost structure survey, which oversamples large firms (i.e., it includes firms with > 500 employees yearly and additional firms in four-year blocks). Because the difference specification further distorts the sample towards large firms, table 7 includes estimates from a specification that controls for time-invariant firm-level unobservables through firm fixed effects (similar to columns (5) and (6) in table A2 in the online appendix), in addition to results from the baseline difference specifications.

The baseline results in panel A of table 7 indicate that a 1 pp 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

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

TABLE 7
Additional results – Value added

	IV				IV–FE		OLS		OLS–FE	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Panel A. CO_2 intensity of value added										
Δ imports	−0.0029***	−0.0025***	−0.0023**	−0.0008	−0.0037***	−0.0018**	−0.0026***	−0.0003	−0.0034***	−0.0002
	(0.0009)	(0.0009)	(0.0009)	(0.0010)	(0.0007)	(0.0008)	(0.0006)	(0.0006)	(0.0005)	(0.0005)
Number of observations	75,499	75,499	75,499	75,499	285,581	285,581	75,499	75,499	285,581	285,581
Kleibergen–Paap F-statistic	198.96	201.61	195.03	144.00	568.76	418.40				
Panel B. Share of value added										
Δ imports	−0.0111	−0.0182	−0.0120	−0.0140	0.0054	0.0075	−0.0292***	−0.0300**	−0.0222**	−0.0211*
	(0.0152)	(0.0151)	(0.0148)	(0.0163)	(0.0125)	(0.0154)	(0.0106)	(0.0121)	(0.0092)	(0.0110)
Number of observations	75,514	75,514	75,514	75,514	285,581	285,581	75,514	75,514	285,581	285,581
Kleibergen–Paap F-statistic	198.97	201.62	195.08	144.00	568.95	418.24				
Panel C. Log material intensity										
Δ imports	0.0005	0.0006	0.0005	0.0007	−0.0001	−0.0001	0.0009***	0.0009***	0.0007**	0.0007*
	(0.0005)	(0.0005)	(0.0004)	(0.0005)	(0.0004)	(0.0005)	(0.0003)	(0.0004)	(0.0003)	(0.0004)
Number of observations	75,419	75,419	75,419	75,419	285,360	285,360	75,419	75,419	285,360	285,360
Kleibergen–Paap F-statistic	198.91	201.56	194.98	143.90	568.97	418.02				
CO_2 intensity–decile–year dummy	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sales–decile–year dummy		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Export share–decile–year dummy			Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sector dummy				Yes		Yes		Yes		Yes

NOTES: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Columns (1) to (6) show results from 2SLS estimations and columns (7) to (10) from an OLS estimation. Columns (1) to (4) and (7) and (8) report estimates from the four-year difference specification, while columns (5), (6), (9) and (10) show results from a fixed effects estimation in which each firm received a separate fixed effect for 1995 to 2002 and 2003 to 2017 to accommodate the break in the reporting of energy variables. The dependent variable in panel A is the log of CO_2 emissions per unit of deflated 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 IPR from the East in each three-digit industry instrumented with respective exports from the East to other countries. For each specification, I report the Kleibergen–Paap F-statistic. Standard errors were clustered both at the firm and at the three-digit industry–year level.
SOURCES: Research Data Centres of the Federal Statistical Office and the Statistical Offices of the Länder: AFiD-Panel Industriebetriebe, 1995–2017; own calculations.

insignificant coefficient of −0.0008 (column (4)). The estimates in columns (5) and (6) based on the within estimator yield somewhat larger point estimates and match the main results closely concerning effect size. Not only are these estimates based on a larger f but also the sample is also arguably less distorted towards large firms. 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 a 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 because all point estimates are small and indistinguishable from zero across specifications.[28] Taken together, the results presented in panels 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 A11 in the online appendix shows results for additional outcomes such as emissions per worker, number of employees, investment and measures of firms' product choice. This analysis aims to understand better how companies adjust to import competition. Based on this, speculations can also be made about the mechanisms underlying the main results on emission intensity.

First, and in line with Dauth et al. (2014), I document a negative effect of increasing competitive pressure on the number of employees, e.g., the baseline estimate implies that the average firm's number of employees decreased by approximately 0.35% in response to a 1 pp increase in the IPR. Like energy inputs, the OLS estimates that capture the association between the number of employees and imports show a positive bias. Despite a negative effect on both production inputs—labour and energy—I find that emissions per employee fall significantly in the baseline specification (see panel B), which provides suggestive evidence for an improvement of energy efficiency relative to potential efficiency improvements in the use of other inputs.

Panel C reports the estimates with inverse hyperbolic sine transformed investment as the dependent variable.[29] On the one hand, investment to upgrade technology appears as a natural means for firms to increase their energy productivity. On the other hand, in an environment in which competition is becoming more intense and market shares are falling, a general decline in investments would be expected. The point estimates in panel C rather align with the second hypothesis, suggesting a substantial reduction in investment by 1.4% in response to a 1 pp increase in the IPR (relatively imprecisely estimated though). Again, the OLS estimates show a positive bias, e.g., firms invest more when their products are in high demand.

Finally, panels D and E focus on firms' product mix responses. The dependent variables are the number of products (panel D) and an indicator for single-product firms (panel E).

28 The dependent variable is on a scale between 0 and 100.

29 Investment is quite lumpy; other than the log, the inverse hyperbolic sine transformation is defined for zero values.

While changes in the market environment have been shown to affect firms' product mix (see Goldberg et al. 2010), Barrows and Ollivier (2018) highlight the product mix's role as a determinant of firm-level emission intensity. For example, when firms concentrate their economic activity further on their core competency, this could decrease the firms' emission intensity. Panels D and E provide some suggestive evidence in line with this idea: The baseline results in panel D suggest that a 1 pp increase in the IPR decreases the average firm's number of products by 0.005 and increases the chance of being a single-product firm by 0.1%.

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 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 1 pp increase in the import penetration ratio. Between 1995 and 2017 the import penetration from the East increased by approximately 20 pp. 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 results are robust to examining emission intensity of value added and accounting for new export opportunities to the East. The latter analysis indicates that new export opportunities increased sales and emissions, i.e., firms scaled up, with only a small effect on emission intensity.

The main results align with parts of the international trade literature, which tends to find positive effects of import competition on European firms' productivity (see Shu and Steinwender 2019 and Chen and Steinwender 2021). Given that energy consumption is often viewed inefficient ("energy-efficiency paradox"), it appears plausible that improving energy efficiency is an easy cost-cutting measure to stay competitive under tougher conditions.

The results further align with findings by Gutiérrez and Teshima (2018), who show that Mexican manufacturing firms' energy intensity decreased in response to intensifying import competition. More recently, Leisner et al. (2023) find evidence for a negative impact of import competition from China on emissions intensities among Danish firms, but only among the most emission intensive ones. This result fits my heterogeneity analysis, which also showed that the more emissions-intensive companies drive the effect. Against the background of a comparatively emissions-intensive industry in Germany, different average effects can be well explained.

The question about potential mechanisms naturally emerges from my results. Throughout the analysis, I find consistent evidence for a negative effect of import competition on sales and employment. Moreover, Subsection 5.2 provides suggestive evidence for firms adjusting their product mix, e.g., a slight increase in the number of single-product firms and a decrease in the number of products in response to an increase in the IPR. These adjustments could reflect firms concentrating on their productive core activities—a plausible explanation for the efficiency improvements (see Barrows and Ollivier 2018).

While the estimates on the effect of the trade shock on the emission intensity of value added and the value added share do not support the hypothesis that carbon leakage drives the results, future work using more granular input data could examine this potential channel more closely. Similarly, improved access to intermediates could enhance the overall productivity of downstream firms. Indeed, a small number of recent papers (see Akerman et al. 2021, Dussaux et al. 2023, Leisner et al. 2023) have examined the effect of improved access to intermediate inputs on emission intensities and found consistent evidence for a negative effect due to a disproportionate increase in output.

From a policy perspective, one 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.

Supporting information

Supplementary material accompanies this article. The data and code that support the findings of this study are available in the Canadian Journal of Economics Dataverse at https://doi.org/10.5683/SP3/TAJMH0.

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