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Carbon Footprints of European Manufacturing Jobs: Stylized Facts and Implications for Climate Policy*

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Abstract

This paper presents first results from a new European-wide research network for evidence-based climate policy. Using administrative data on industrial firms in Denmark, Finland, France, Germany, Lithuania, Norway, and Sweden, we construct harmonized measures of carbon dioxide emissions per job. We characterize the distribution of this measure and explore how it varies across countries, two-digit industries, and over time. We relate those changes to participation in the EU Emissions Trading System – Europe's flagship climate policy instrument since 2005.

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1 Introduction

Curbing greenhouse gas (GHG) emissions from the manufacturing sector has been, and continues to be, a key objective of climate policy. The importance of manufacturing derives from a variety of reasons. First, manufacturing is the backbone of both newly developed and emerging economies around the world. It also continues to be an important engine of economic growth in many post-industrial economies. Second, some of the most emissions-intensive activities in the economy occur within the manufacturing sector, and do not necessarily derive from the combustion of fossil fuels. Third, the fact that existing policies to regulate GHG emissions are very incomplete could lead to carbon leakage – the shifting of carbon dioxide (CO_2) emissions from regulated to unregulated jurisdictions. Carbon leakage is more likely to occur in manufacturing than in other economic sectors because production is highly integrated at the global scale: manufacturing firms routinely ship products around the globe as they compete in international product markets and source intermediate inputs via global supply chains. Moreover, multi-plant manufacturing firms can easily shift production from one plant to another, or relocate plants from one country to another.

Therefore, as unilateral climate policies become more stringent, their effects on both the scale and the geographic distribution of industrial production worldwide are bound to become more severe. For example, if CO_2 prices invert existing patterns of comparative advantage, this may not only drive carbon leakage but also change the geographic distribution of manufacturing jobs in the world. Concerns about both carbon leakage and adverse competitiveness impacts has been a perennial source of opposition towards climate policies for the manufacturing sector –

even though there is no conclusive empirical evidence to support such fears.

In light of this unresolved trade-off, and against the political background of a European Green Deal (EC, 2019), we have built a new data infrastructure by forming a pan-European network of researchers who have access to administrative micro data on emissions and economic performance data at the level of the industrial plant or firm. The purpose of this network is to consolidate access to relevant administrative data sources across Europe, to harmonize the concepts for measuring key variables of interest, and to develop consistent econometric frameworks for estimating the impact of climate policy on treated firms across multiple countries and datasets. Our ultimate goal is to provide policy makers with evidence-based advice on these important issues, in a way that is both more comprehensive and more consistent than research conducted for a single country.

This paper presents first results from the network by comparing the carbon footprint of manufacturing jobs across seven European countries and 28 industries. We define the carbon footprint as the amount of CO_2 emitted per full-time worker. Exploring patterns of heterogeneity in this variable can uncover inefficiencies and untapped abatement potential both within industries and across countries. We document high dispersion in the carbon footprint within industries and countries. We also show that both the carbon footprint and its dispersion have declined over time.

An important source of such heterogeneity is regulation. We shed light on this aspect by studying a group of countries that have adopted different sets of national policies while also adhering to overlapping, European-wide regulation of GHG emissions. We pay particular attention to the role of the European Union Emissions Trading System (EU ETS) for explaining differences in CO_2 emissions per worker between firms and over time.

Related literature Our paper ties in with other efforts to use administrative microdata in multi-country comparisons. Based on the seminal contributions by Melitz (2003) and Syverson (2011), this literature has focused on measuring and explaining within-sector heterogeneity in productivity. For instance, Bartelsman et al. (2013) empirically analyze the within-industry covariance between size and productivity in the manufacturing sector across eight OECD countries. Berlingieri et al. (2018) gather firm-level data from 17 OECD countries to analyze the correlation between the size, the wages paid, and the productivity of firms. They find evidence that larger firms are both more productive and pay higher wages, particularly in the manufacturing sector. ISGEP (2008) analyze the relationship between exports and productivity using confidential micro data from 14 countries. Their analysis applies a harmonized approach in order to obtain comparable results for each country. In a second step, a meta-analysis is conducted in order to explain cross-country differences in the results.

None of these cross-country analyses has looked at energy outcomes or CO_2 emissions, as we do in this paper. Studies conducted at the national level, however, have documented that the dispersion in these outcomes can be large. For example, Lyubich et al. (2018) find substantial within-industry heterogeneity in energy and CO_2 productivity in U.S. manufacturing plants across 375 industries. A plant at the 90^{th} percentile of the (within-industry) distribution of CO_2 productivity produces 870 percent more output per ton of CO_2 emitted than a plant at the 10^{th} percentile. The same metrics for energy productivity leads to a difference of 580 percent within industries. Using German microdata, Petrick (2013) documents substantial heterogeneity in CO_2 emission per output and shows that improvements in that measure are driven mainly by new entrants. Also for Germany, von Graevenitz and Rottner (2020) show that energy intensity in the manufacturing sector has not decreased substantially between 2003 and 2014, although carbon intensity has fallen slightly over this period.

A third strand of the literature relevant to this paper uses microdata on firms or plants to analyze the impact of climate policies such as the EU ETS (Martin et al., 2016). For instance, Calel and Dechezleprêtre (2016) estimate that the EU ETS has caused applications for low-carbon innovation filed by regulated firms in Europe to increase by up to 10 percent. Finally, members of our research network for this study have used administrative firm data from individual countries to estimate the impact of the EU ETS on emissions and economic performance (Jaraite and Di Maria, 2016; Klemetsen et al., 2020; Gerster et al., 2020; Colmer et al., 2020; Hintermann et al., 2020).

2 Data

2.1 Sources

Collectively, the members of our network have approved-researcher status to access to administrative plant-level or firm-level data in seven countries: Denmark, Finland, France, Germany, Lithuania, Norway, and Sweden. These datasets comprise rich information obtained through the official census of production or similar surveys carried out in these countries. Unlike balance sheet data that is commercially available, our datasets also include detailed information on CO_2 emissions.

2.2 Outcome variables

The choice of outcome variables is guided by our goal to construct a measure of CO_2 per worker that is harmonized across countries and industries. Constraints arise because the raw data for this measure are obtained from six different national statistics offices, all of which impose strict data-access restrictions to honor the statistical secret. This leads us to a parsimonious choice of outcome variables for this first pan-European study. Specifically, we define the carbon footprint of a job as the ratio of *direct* CO_2 emissions (in tons) and the number of employees (in full-time equivalent).

Direct CO_2 emissions are those that are produced by the firm itself, as opposed to emissions generated by power plants that supply electricity to the firm. Direct emissions are either provided directly by the statistical authority, or computed by us. In the latter case, the firm's annual consumption of fossil fuels is converted into CO_2 emissions using national emissions factors and then aggregated across fuels.

The number of employees refers to full-time equivalent workers. We divide the firms' annual CO_2 emissions by the number of employees to obtain our variable of interest.

Our sample includes firms with 20 employees or more. Further details on the sampling frame and variables definition for each country are reported in Appendix Table B.1.

2.3 Aggregation

We obtain data from the statistical offices of Denmark, Finland, France, Germany, Lithuania, Norway, and Sweden. The data comprises all deciles of the distribution of CO_2 emissions per worker for every two-digit sector, using the NACE rev.2 classification.[1] We obtain these deciles for the years 2004, 2007, and 2012. In Denmark, Finland and Lithuania data were not available for the years 2004, 2004 and 2012, respectively.[2] Furthermore, we obtain the number of firms in each two-digit sector, as well as the number of firms regulated under the EU ETS. Overall, our dataset comprises information from a population of 48,627 firms in 2004 (51,396 firms in 2007 and 47,529 firms in 2012). In 2004, 939 of these firms were regulated under the EU ETS (1,027 in 2007 and 1,006 in 2012).[3]

To determine the aggregate cumulative distribution of CO_2 emissions per worker for these countries, we proceed as follows. For every two-digit sector and year, we approximate the cumulative distribution function by a step function. We assign every decile of the distribution to 10% of the firms in that sector and year. As information on firms with extremely low or high carbon emissions per worker cannot be retrieved by the statistical offices for reasons of confidentiality, we treat the top and bottom 5% of observations within every sector and year as missing.[4]

[1]For Lithuania, we obtain data based on NACE rev. 1.1 and convert it to NACE rev.2.

[2]Due to privacy rules, percentiles for Denmark are calculated based on a simple average of five observations: the actual percentile, as well as two values below and two above.

[3]In 2007, for instance, the underlying data comprises 2,053 firms (36 regulated under the EU ETS) in Denmark, 826 firms (64 regulated) in Finland, 7,466 firms (250 regulated) in France, 35,812 firms (523 regulated) in Germany, 1,057 (26 regulated) in Lithuania, 164 (26 regulated) in Norway, and 4,018 (99) in Sweden.

[4]Effectively, we set their carbon footprint above the largest and below the smallest decile in our dataset, respectively, which implies that they will not influence any of the deciles in the aggregate distribution.

3 Stylized Facts about Carbon Dioxide Emissions per Worker

We conduct a simple comparative analysis that produces average CO_2 emissions per employee at each decile of the distribution within a sector and for a given year (2004, 2007, and 2012). The analysis is conducted at the two-digit sector level.

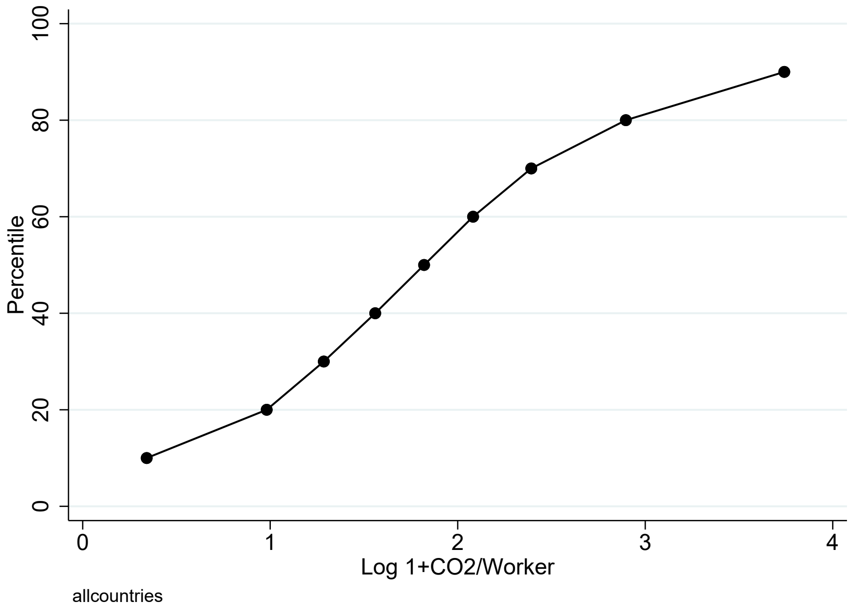
3.1 Aggregate level

Figure 1 displays the empirical cumulative distribution function of CO_2 emissions per worker for all countries in the sample, based on observations from the year 2007. We note three stylized facts. First, more than 80% of the firms in our sample have direct CO_2 emissions. Second, the distribution of logarithm of this variable is approximately S-shaped. Third, the distribution has a long tail. Even on the logarithmic scale, going from the bottom fifth to the median is associated with a much smaller change in emissions per worker than going from the median to the top fifth of firms in the sample.

3.2 Cross-sector comparison

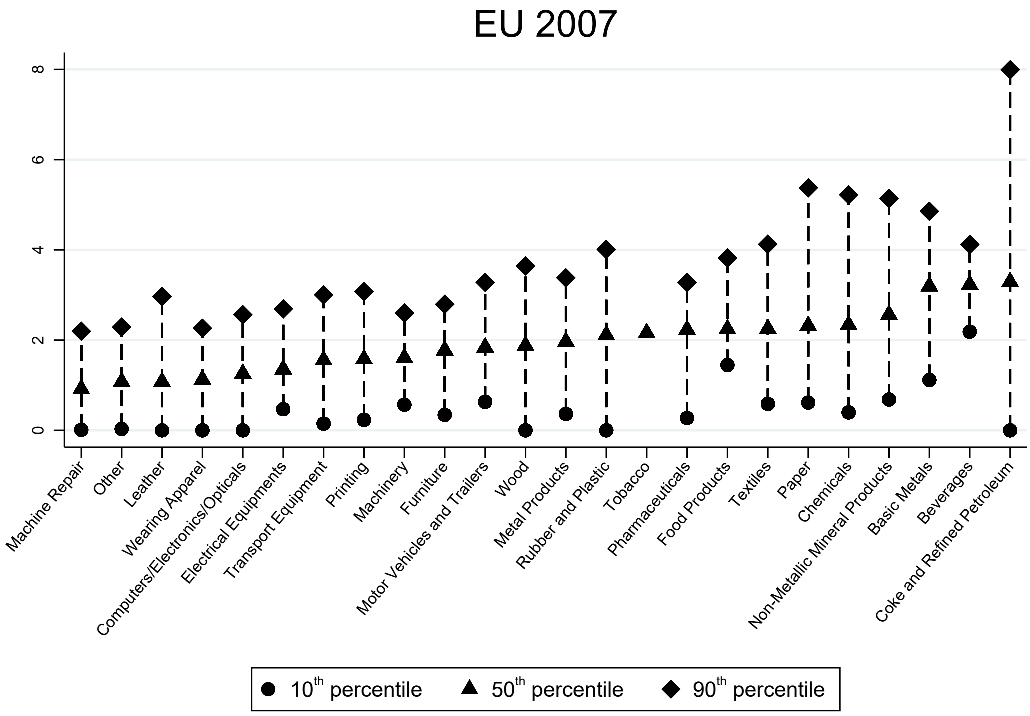
Next, we explore the distribution of carbon intensity across two-digit industries. Figure 2 plots the median of log CO_2 emissions per worker, along with the interdecile range, i.e. the range between the top and bottom decile of this variable. The plot is based on pooled observations for all countries in the year 2007. We observe that there is substantial variation across industries, both in terms of the median carbon intensity as well as in terms of the interdecile range. The long right

Figure 1: Distribution of Log CO_2 Per Worker in the Full Sample



Notes: The figure plots the cumulative distribution function of carbon emissions per worker on a log scale for all countries and sectors in our sample. The points indicate the value of $\log(1+CO_2/L)$ at each decile of the distribution, excluding the top and bottom. Data are based on observations for the year 2007.

Figure 2: Log CO_2 Per Worker Across Two-Digit Industries



Notes: The figure displays the median and interdecile range of CO_2 emissions per worker across two-digit NACE sectors. For each sector, we report the 1^{st}, 5^{th}, and 9^{th} decile of $\log(1+CO_2/L)$, based on observations for the year 2007 and the full set of countries in our sample. The interdecile range for Tobacco is omitted for confidentiality reasons.

tail observed in the aggregate distribution is found in most sectors.

3.3 Cross-country comparison

Next, we break down the distribution of CO_2 emissions per worker at the country level. This allows us to compare the carbon footprint of manufacturing jobs across countries. It also provides insights into the heterogeneity of the carbon footprint between countries as well as between firms within a country. Among the driving forces of this heterogeneity are factors like the historically-grown industry structure

Table 1: Carbon tax rates by country and sector

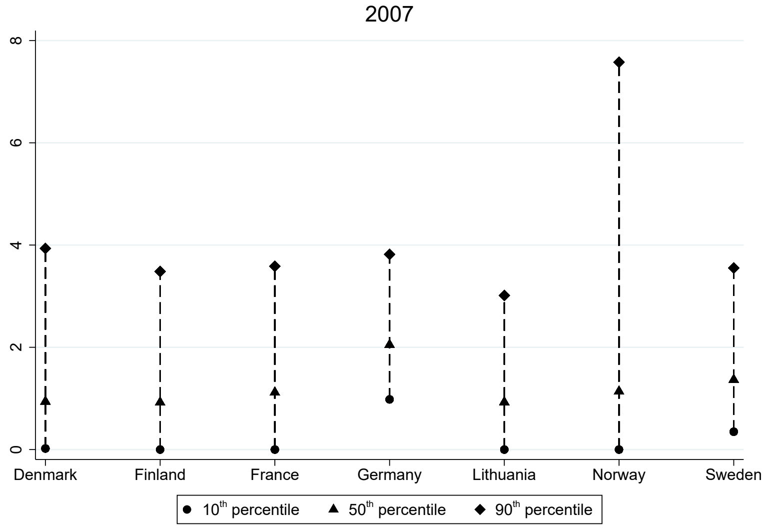
Country	Industry	Sectors Electricity	Total
Denmark	15.0	78.4	81.7
Finland	30.4	38.6	60.2
France	5.5	11.4	61.1
Germany	7.6	27.7	58.3
Norway	14.1	548.3	93.3
Sweden	9.8	165.5	78.6

Notes: Carbon taxes in Euros per tonne of CO_2 obtained from (OECD, 2013). Effective tax rates based on energy consumption data from 2009 and statutory tax rates as of 1 April 2012. Rates are based on total consumption of oil products, coal, peat, natural gas, biofuels, and waste. Total includes CO_2 taxes levied on industrial energy transformation, electricity, transportation, as well as on residential and commercial energy use.

of a country, technical and managerial efficiency, the taxation of production factors, and not least the mix of national policies that govern energy supply and pollution emissions. For instance, cheap electricity supply or high taxes on fossil fuels in a country may have boosted electrification rates for industrial processes where this is possible. Carbon taxes have been in place in Denmark, Finland, Sweden and Norway since the 1990s, but not in all countries in our sample, and rates differ.

Table 1 summarizes the average effective tax rates on CO_2 in different uses reported by the OECD (2013). Total rates vary between 58 Euros (per ton of CO_2) in Germany and 93 Euros in Norway. Carbon tax rates are generally higher in Scandinavia, where explicit carbon taxes exist. A common finding across countries is that carbon emissions from industrial energy use are taxed at lower rates than carbon emissions from electricity usage. Overall, we can see that carbon taxes vary

Figure 3: Log CO_2 Per Worker Across Countries



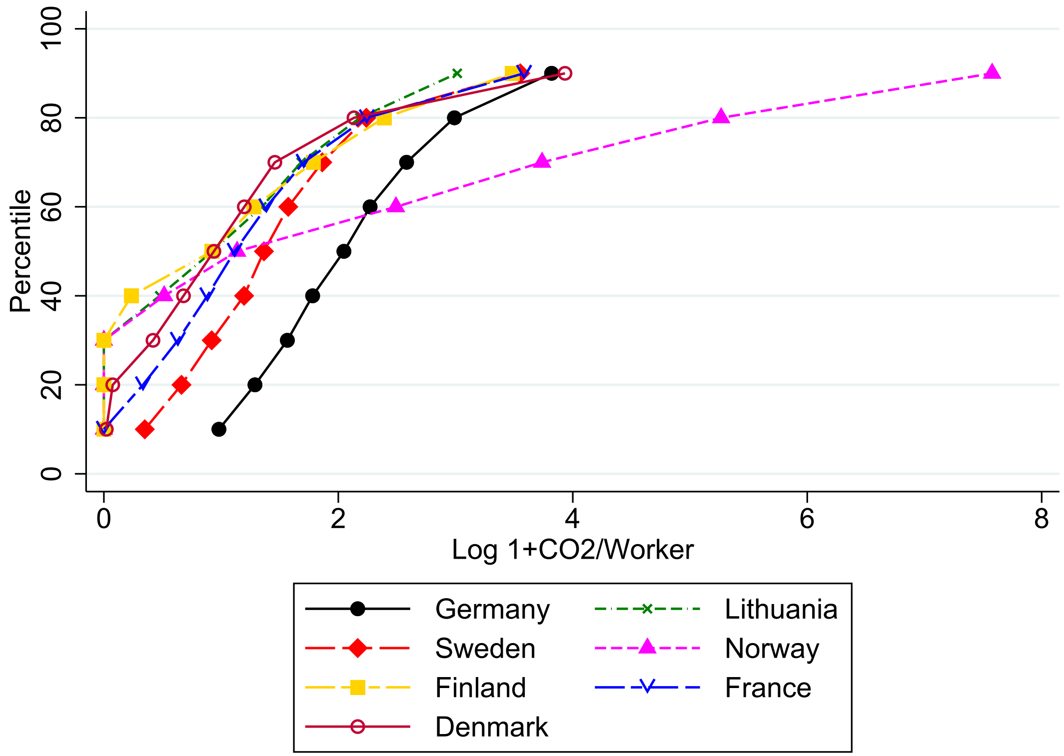
Notes: The figure displays the median and interdecile range of CO_2 emissions per worker across countries. For each country, we report the 1^{st}, 5^{th}, and 9^{th} decile of $\log(1 + CO_2/L)$, based on observations for the year 2007.

substantially cross countries and usage types. It bears noting, that the reported tax rates are effective rates based on actual usage in the country and thus do not reflect marginal incentives for CO_2 abatement.

Figure 3 displays the median and the interdecile range of CO_2 emissions per worker for each country in our sample. While there is some variation in the median, the most pronounced differences arise in the interdecile range. With the exception of Norway, which has some extremely carbon intensive jobs, the spread between the first and ninth decile is relatively similar across countries. Therefore, the heterogeneity in emissions per worker is larger *within* countries than between them – notwithstanding the differences in national policies, preferences and industrial structures.

Figure 4 plots the cumulative distribution functions of emissions per worker for each country in a single chart, which allows for cross-country comparisons over the entire support. Two stylized facts emerge. First, some countries have lower CO_2 emissions per worker across the entire range, e.g. Sweden vs. Germany or Lithuania vs. France. That is, the distribution for the latter countries stochastically dominates that of the former. Second, the graph corroborates – at each decile of the distribution – the above-mentioned finding that the dispersion between countries is smaller (with the exception of Norway) than the overall dispersion within countries.

Figure 4: Distribution of Log CO_2 Per Worker Across Countries



Notes: The figure plots the cumulative distribution functions of $\log(1 + CO_2/L)$ for each country based on observations for the year 2007.

3.4 Carbon intensity over time

An investigation of the evolution of emissions per worker over time reveals whether the manufacturing sector has started to move into the direction of achieving the ambitious decarbonization targets that the countries in our sample have adopted under the Paris Agreement and as part of their national climate change mitigation strategies. Moreover, it might provide a first clue as to whether climate policy instruments in Europe implemented since 2005 have been effective at reducing the carbon footprint in manufacturing.

To begin, we look at the cumulative distribution functions for the years 2004, 2007 and 2012, which are depicted in Figure 5. We observe that the distribution shifts to the left in the direction of a lower carbon footprint between 2007 and 2012, a time period that closely corresponds to the second trading phase of the EU ETS. However, the graph is not proof that the lower carbon footprint of manufacturing jobs can be attributed to a particular climate policy because we do not control for confounding factors, such as the great recession that occurred during this time period. Section 4 below revisits this issue in more detail.

Figures A.1-A.7 in Appendix A display distribution function plots analogous to Figure 5 for each country and two-digit industry. These plots show that the decline in the carbon footprint occurred in many industries. When aggregating across sectors and comparing countries in Appendix Figure A.8, the most pronounced inward shift in the distribution of CO_2 emissions per worker occurred in Sweden, the country with the highest carbon tax.

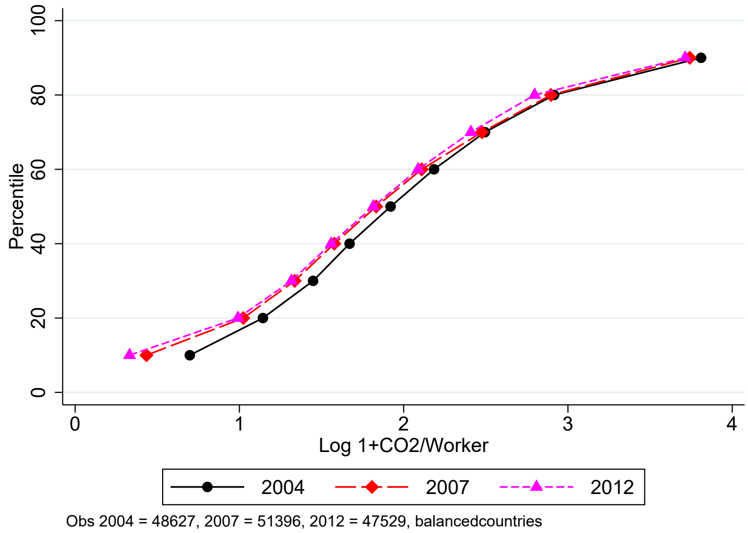
Figure 5 is based on a balanced data sample in order to abstract from sample composition effects. In regression analysis we can use all observations while

Table 2: Time Trends In CO_2 Emissions Per Worker: Deciles And Ranges

	$\hat{\beta}$	Std.Err.	p-value	N observations	N Country-sector
A. Percentiles					
p10	-0.338	0.351	0.337	394	150
p20	-0.402	0.348	0.250	397	151
p30	-0.463	0.350	0.187	397	151
p40	-0.536	0.352	0.130	397	151
p50	-0.700	0.428	0.104	397	151
p60	-0.297	0.781	0.704	397	151
p70	-0.800	0.707	0.260	397	151
p80	-2.110	1.618	0.194	397	151
p90	-3.695	2.079	0.078	394	150
B. Interpercentile ranges					
idr	-3.357	2.033	0.101	394	150
iqr	-1.708	1.549	0.272	397	151

Notes: The table gives the result from regressing the sector-level deciles $p10, p20, \ldots, p90$, as well as the interdecile range (IDR) and the interquintile range (IQR), on a linear time trend, as well as on sector-by-country fixed effects. Standard errors are clustered at the sector-by-country level.

Figure 5: Cumulative Distribution of Log CO_2 Per Worker Over Time



Notes: The figure plots the cumulative distribution functions for $\log(1 + CO_2/L)$ for 2004, 2007 and 2012. The graph is based on observations from a subset of countries (France, Germany, Norway and Sweden) for which data are available in all three years.

controlling for sample composition. To do so, we specify the regression equation as

$$\left(\frac{CO_2}{L}\right)^q_{c,s,t} = \alpha + \beta_q t + \lambda_{c,s} + \epsilon^q_{c,s,t} \tag{1}$$

where q indicates the quantile of the distribution, c is the country, s is the sector, t denotes the linear time trend and $\lambda_{c,s}$ denotes sector-by-country fixed-effects. We estimate this equation separately for each decile and report the estimated β coefficients in panel A of Table 2. To assess how the dispersion in the carbon footprint of jobs evolves over time, we estimate versions of equation (1) where the dependent variable is, alternatively, the interdecile ($p90 - p10$) or interquintile ($p80 - p20$) range of CO_2 emissions per worker. The results are reported in panel B of Table 2.

We estimate negative time trends for all deciles. While individual point estimates are not statistically significant at the 5% level, an F-test indicates joint significance with $p = 0.008$. The change is larger at the top of the distribution. The point estimate for the 9^{th} decile implies that firms reduced CO_2 emissions per worker by 3.7 tons of CO_2. Likewise, we estimate reductions in the interquartile and interdecile ranges over time, but they are not statistically significant at the conventional levels.

Next we estimate the pooled regression

$$\left(\frac{CO_2}{L}\right)_{q,c,s,t} = \alpha + \sum_c \beta_c\, t \times D_c + \lambda_{c,s} + \eta_q + \epsilon_{q,c,s,t}, \tag{2}$$

where η_q denotes decile-fixed-effects, D_c is a dummy variable for country c, and β_c is the time trend of this country. The results are reported in Table 3. We find that improvements in the carbon footprint of manufacturing jobs were driven by Norway and Sweden where CO_2 emissions per worker fell by 4.1 and 1.9 tons per year, respectively, over the sample period. Morevoer, small but significant reductions were achieved in France with reductions on the order of 0.3 tons per year.

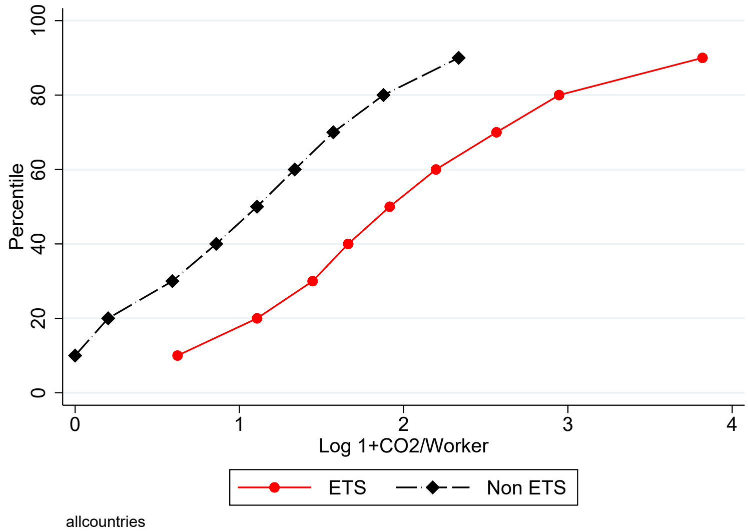
Given that the time window of our analysis overlaps with the introduction and the first two trading phases of the EU Emissions Trading System, one might have expected to see stronger reductions in the carbon footprint over time and across countries. The next section examines this issue in greater detail.

Table 3: Time Trend In CO_2 Per Worker By Country

	(1)	(2)
t	-1.036**	
	(0.494)	
$t \times$ Denmark		-0.236
		(0.252)
$t \times$ Finland		1.452
		(1.185)
$t \times$ France		-0.258***
		(0.074)
$t \times$ Germany		0.826
		(0.874)
$t \times$ Lithuania		-5.580
		(5.676)
$t \times$ Norway		-4.065**
		(2.056)
$t \times$ Sweden		-1.882**
		(0.751)
R^2	0.5094	0.5102
Number of obs.	3,567	3,567
Number of country-sector pairs	151	151

Notes: The table gives the result from regressing all sector-level deciles (pooled) on a linear time trend, as well as on decile and sector-by-country fixed effects. Standard errors clustered at the sector-by-country level. In the second column, we also include an interaction between the time trend and indicator variables for every country in our dataset.

Figure 6: Distribution Of Log CO_2 Per Worker: ETS vs. Non-ETS



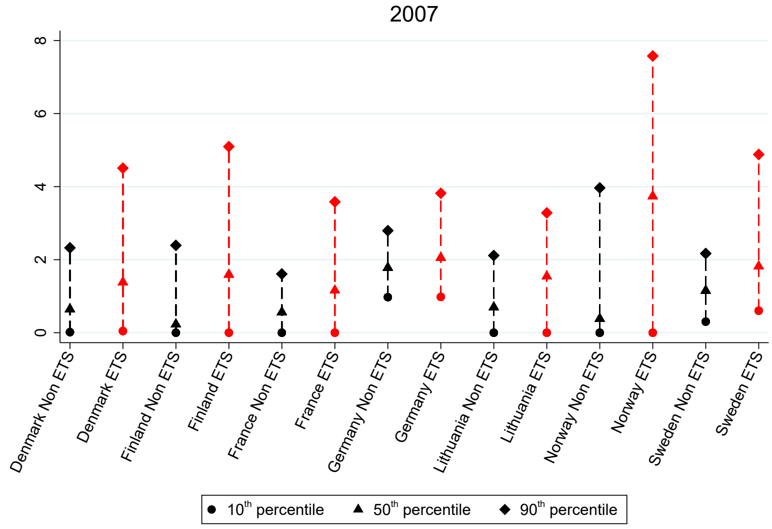
Notes: The figure reports the cumulative distribution function for $\log(1 + CO_2/L)$ by regulation status. Data is based on observations for the year 2007. We denote a sector as (ETS) regulated if at least one firm in the sector is regulated by the EU ETS.

4 The EU Emissions Trading System

The EU ETS was introduced in 2005 as a cap-and-trade system for CO_2 emissions of more than 12,000 stationary emitters. In terms of regulated emissions under the cap, manufacturing is second only to the power sector. However, not all manufacturing emissions are regulated under the EU ETS. This is because (i) not all energy-intensive processes are regulated by the EU trading directive and (ii) mandatory participation of regulated processes is subject to capacity thresholds. As a consequence, the heterogeneity in the carbon footprint across manufacturing jobs could be driven by differences in CO_2 prices faced by firms that participate in the EU ETS and those that do not.

To shed light on this, this section characterizes the CO_2 footprint of manufac-

Figure 7: Log CO_2 Per Worker By Country And ETS Status

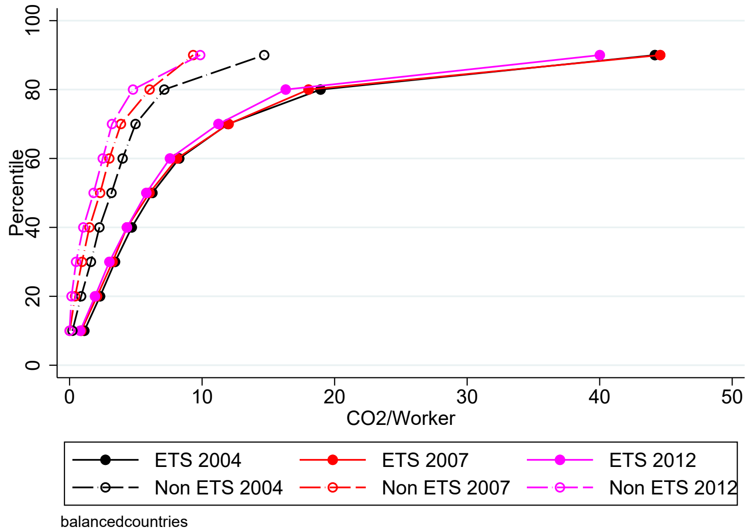


Notes: The figure displays the median and interdecile range of CO_2 emissions per worker across countries. For each country, we report the 1^{st}, 5^{th}, and 9^{th} decile of $\log(1 + CO_2/L)$, by ETS regulatory status, based on observations for the year 2007.

turing jobs both within and outside of the EU ETS. We begin with a comparison of the distribution of this variable across regulated (ETS) and unregulated (non-ETS) sectors. We denote a sector as regulated if at least one firm in this sector is regulated. Figure 6 plots the cumulative distribution function separately for ETS and non-ETS sectors. As expected, the carbon footprint of workers in regulated sectors is higher than in unregulated sectors. This holds in a stochastic dominance sense.

In Figure 7, the comparison is broken down to the country level. We note two stylized facts. First, the median carbon footprint is higher for jobs in ETS sectors than in non-ETS sectors, and the same is true for the interdecile range. Second, the differences in means are not necessarily large, particularly in large economies such as Germany and France, and there is substantial overlap in the distributions,

Figure 8: Distribution Of CO_2 Per Worker By Year And ETS Status



Notes: The figure plots cumulative distribution functions of CO_2/L by ETS regulatory status for each year in the sample. The plots are based on observations from a balanced set of countries (France, Germany, Norway, and Sweden).

particularly in the left tail. This reflects the fact that regulatory coverage of the EU ETS is far from complete among carbon intensive firms in Europe. Incomplete regulation leads to an inefficient allocation of CO_2 emissions to jobs by driving a wedge between the marginal cost of emitting CO_2 at regulated and unregulated sectors.

To investigate the evolution over time, we plot the cumulative distribution functions by year and regulatory status in Figure 8. This exercise corroborates that the decline in carbon emissions per worker, established in Figure 5 above, has occurred in both ETS and non-ETS sectors. Perhaps surprisingly, the graph shows that improvements in the carbon footprint are at least as pronounced in jobs at unregulated sectors as they are among regulated sectors.

We investigate the association between ETS participation and improvements in

Table 4: Trend In CO_2 Per Worker: ETS vs. Non-ETS Firms

	(1)	(2)
t	-1.036**	-0.159
	(0.494)	(0.452)
$ETS_{c,s,t}$		1,229.305**
		(541.301)
t x $ETS_{c,s,t}$		-0.611**
		(0.269)
R^2	0.5094	0.5184
Number of obs.	3,567	3,567
Number of country-sector pairs	151	151

Notes: The table gives the result from regressing all sector-level deciles (pooled) on a linear time trend, as well as on decile and sector-by-country fixed effects. Standard errors clustered at the sector-by-country level. In the second column, we also include an interaction between the time trend and $ETS_{c,s,t}$, which gives the percentage of regulated firms within a sector. We set $ETS_{c,s,t}$ to zero in 2004 and fix it at 2007 levels for the years 2007 and 2012.

the carbon footprint of jobs more rigorously using a regression framework. Based on equation (2) above we specify pooled regression model

$$\left(\frac{CO_2}{L}\right)_{q,c,s,t} = \alpha + \beta t + \gamma ETS_{c,s,t} + \delta\, t \times ETS_{c,s,t} + \lambda_{c,s} + \eta_q + \epsilon_{q,c,s,t}, \qquad (3)$$

where the time trend t is interacted with $ETS_{c,s,t}$, the percentage share of firms that are regulated under the EU ETS in country c, sector s, and year t. This is akin to a difference-in-differences estimation where the coefficient of interest δ measures the differential effect of the ETS on the distribution of CO_2 per worker in an industry as the share of regulated firms increases by one percentage point.

Table 4 reports the results. The first column replicates the coefficient for the linear time trend in the pooled regression equation (2). Across deciles of the distribution, the carbon footprint improved by 1.0 ton of CO_2 per year. The second column reports the coefficients obtained by OLS estimation of equation (3). The coefficient on the ETS share is positive and statistically significant, which is consistent with the stochastic dominance of ETS firms documented in Figures 6 and 8 above. The coefficient on the interaction term is negative and statistically significant, implying that the improvement in the carbon footprint was stronger in ETS regulated industries. This constitutes suggestive evidence that the ETS contributed to the decline in the carbon footprint of manufacturing jobs. As the share of ETS regulated firms in an industry increases by one percentage point, the CO_2 emissions per worker fall by an additional 0.6 tons each year.

In order to interpret this effect as the causal impact of the EU ETS, we would have to rule out that the change in this variable was driven by confounding shocks at two-digit industry level that are correlated with the share of ETS firms. Controlling for such confounders would require us to use firm-level variation in regulatory status in the regression – something that is currently not possible given the protocols for data protection put in place by our data providers.

5 Discussion and Conclusion

We have conducted the first cross-country comparison of the CO_2 intensity of production using administrative firm-level data from seven European countries. Using a consistent measure of the carbon footprint of a job, calculated as the ratio of a firm's direct CO_2 emissions and the number of full-time workers, we have derived a number of stylized facts that have implications for climate policy.

First, more than 80% of the firms in our sample have direct CO_2 emissions, and there is a long right tail in the distribution. This highlights the large potential for CO_2 abatement in the manufacturing sector, particularly among firms with above-median CO_2 emissions per worker.

Second, we have established that the variability in the carbon footprint of jobs *within* two-digit NACE industries exceeds the variability across both industries and countries – despite differences in production technologies, industrial structure and policies. One can think of two aspects driving within-sector heterogeneity which call for policy interventions. First, the gap between the bottom and the top deciles of firms in a given industry might arise from genuine productivity differences. In this case, policy intervention could target capital upgrades that bring the bottom decile closer to the efficiency frontier. Or else it could target market frictions that prevent firms from undertaking such upgrades even when they would be profitable (energy efficiency paradox). Second, the gap might arise from the many exemptions that both the EU ETS and national policies grant from carbon pricing. In this case, the implication for policy is to ensure that there is a level playing field for firms within broadly defined two-digit industries.

Third, cross-country differences in the carbon footprint of jobs – while being smaller than intra-industry differences – are non-negligible and sometimes hold even in a stochastic-dominance sense. For instance, CO_2 emissions per worker are higher in Germany than in Sweden or Finland at every decile of the distribution. This is consistent with the fact that the latter two countries, unlike Germany, have been taxing CO_2 since the 1990s. Related work by members of our team has shown that pricing CO_2 reduces the energy and carbon intensities of manufacturing production in Europe (Martin et al., 2014; Jaraite and Di Maria, 2016; Colmer et al., 2020). Although we are unable to provide such proof here, our findings are consistent with the notion that carbon taxes can reduce the carbon footprint over the entire cross-firm distribution of the carbon footprint of jobs.

Fourth, with respect to the common climate policy instrument adopted across countries in our sample, the EU ETS, we show that there is a substantial overlap in the carbon footprint of a job between regulated and unregulated firms. This means that the policy fails to cover many carbon intensive firms. It also suggests that there is substantial scope for efficiency improvements by expanding the EU ETS to cover those firms. Our comparison of time trends in the carbon footprint across sectors with different levels of ETS penetration is suggestive, but not conclusive, evidence that cap-and-trade is a suitable policy instrument for reducing the carbon footprint of manufacturing. Putting this hypothesis to a rigorous empirical test is beyond the scope of this paper. By forming a pan-European research network with access to high-quality microdata, we have nonetheless overcome an important hurdle on the path towards conducting data-driven ex-post analysis for supporting evidence-based climate policy in Europe and elsewhere.

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A Additional Figures

Figure A.1: Carbon Intensity by Sector: Denmark

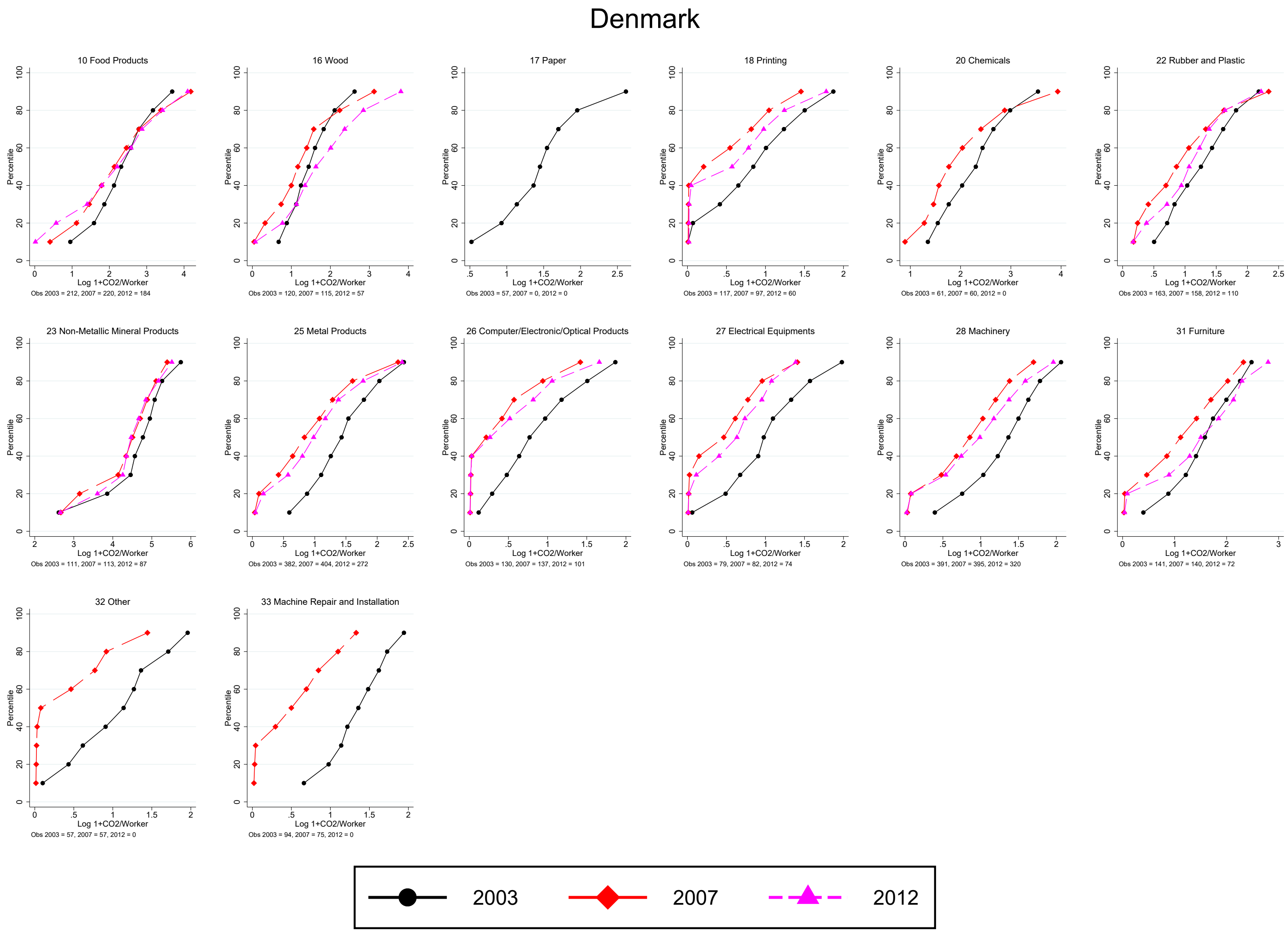


Figure A.2: Carbon Intensity by Sector: Finland

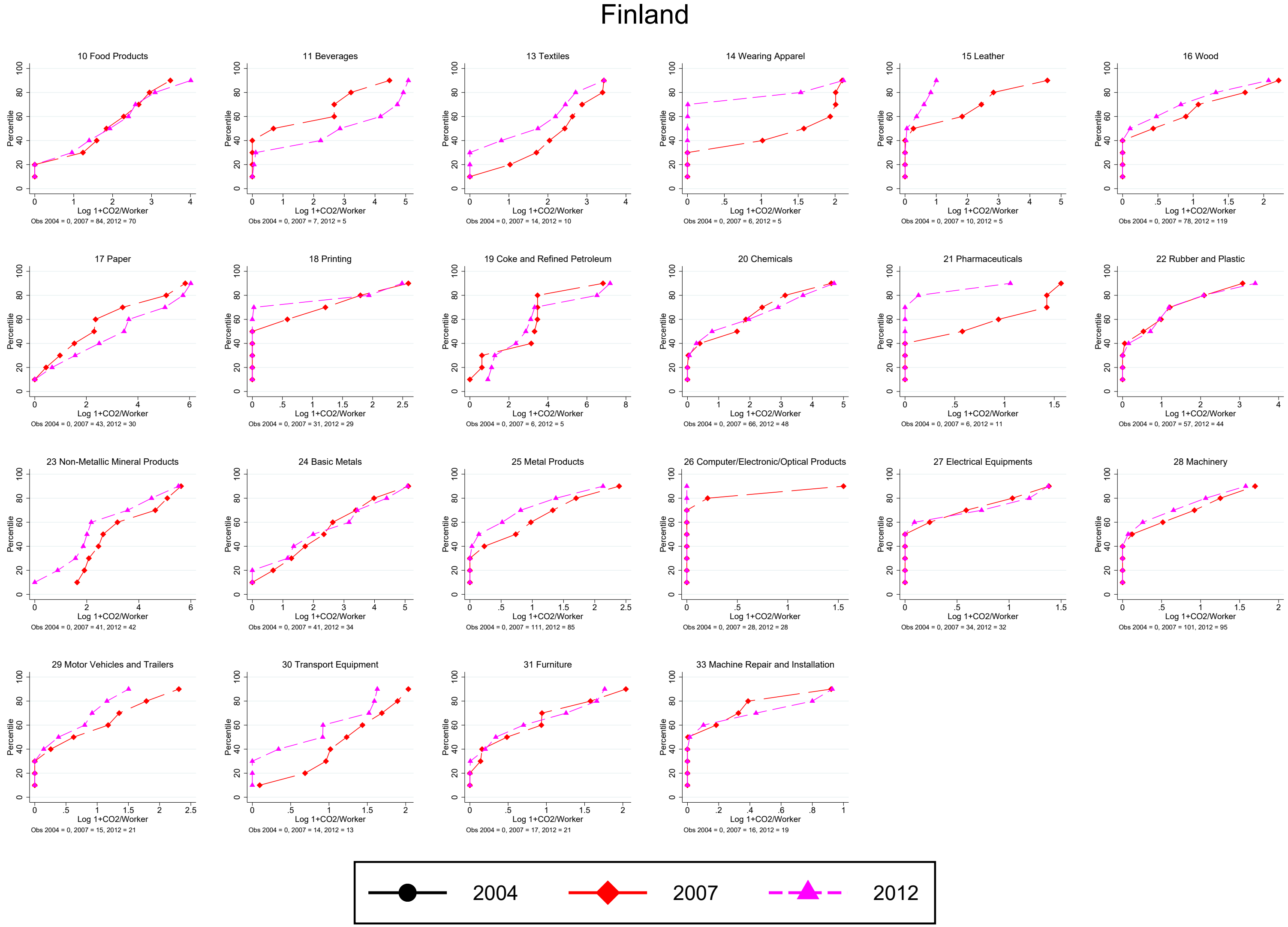


Figure A.3: Carbon Intensity by Sector: France

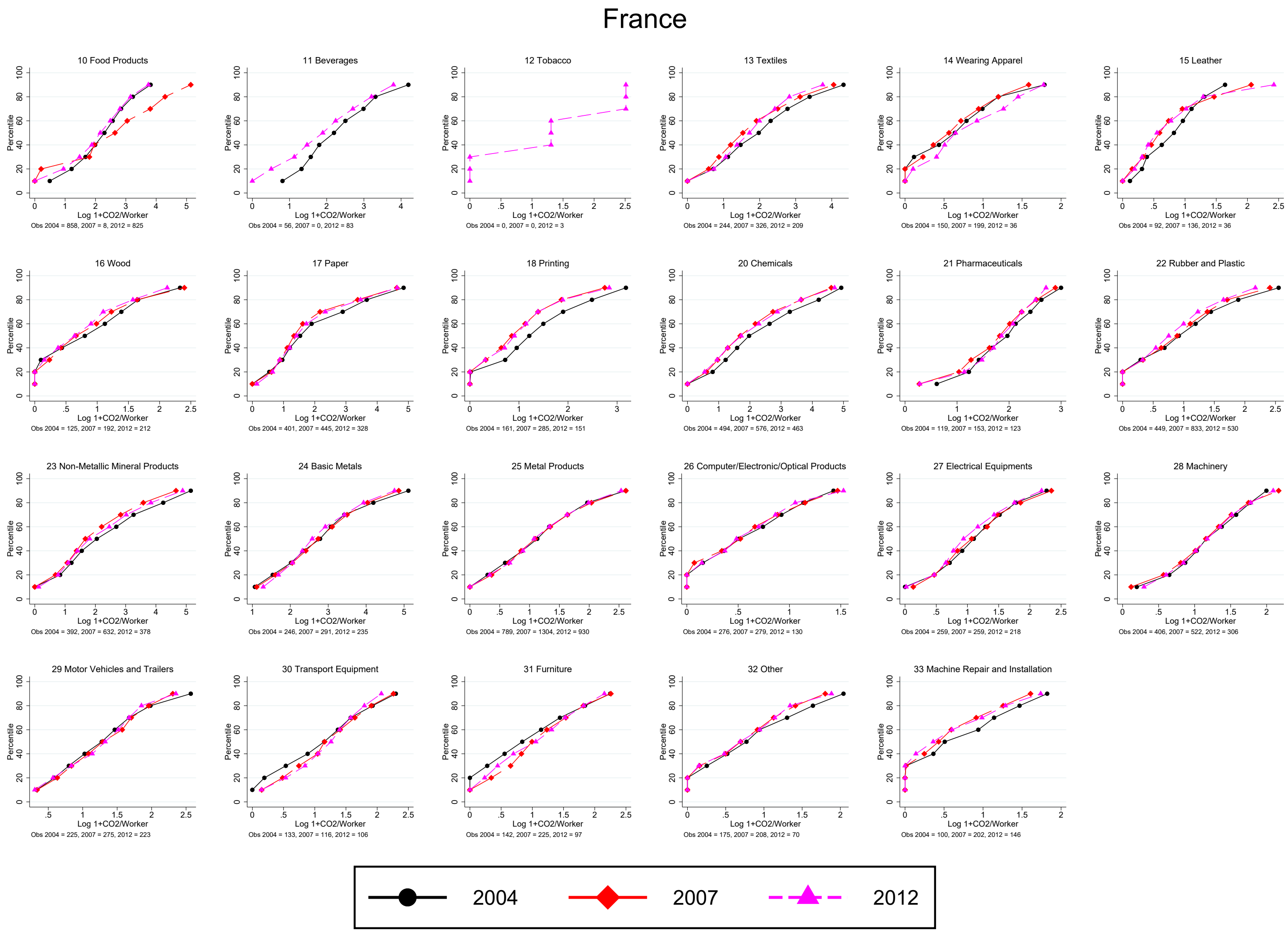


Figure A.4: Carbon Intensity by Sector: Germany

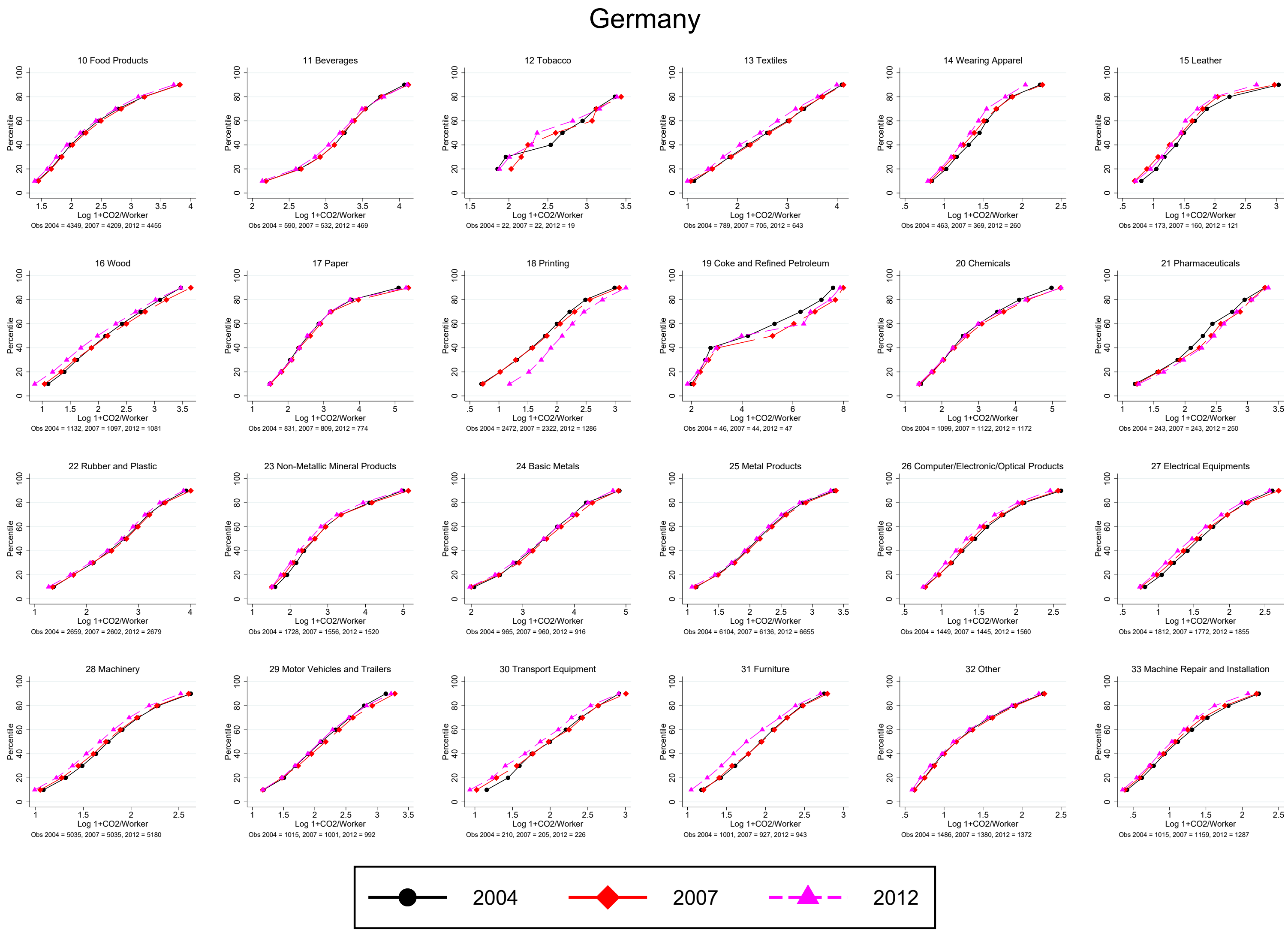


Figure A.5: Carbon Intensity by Sector: Lithuania

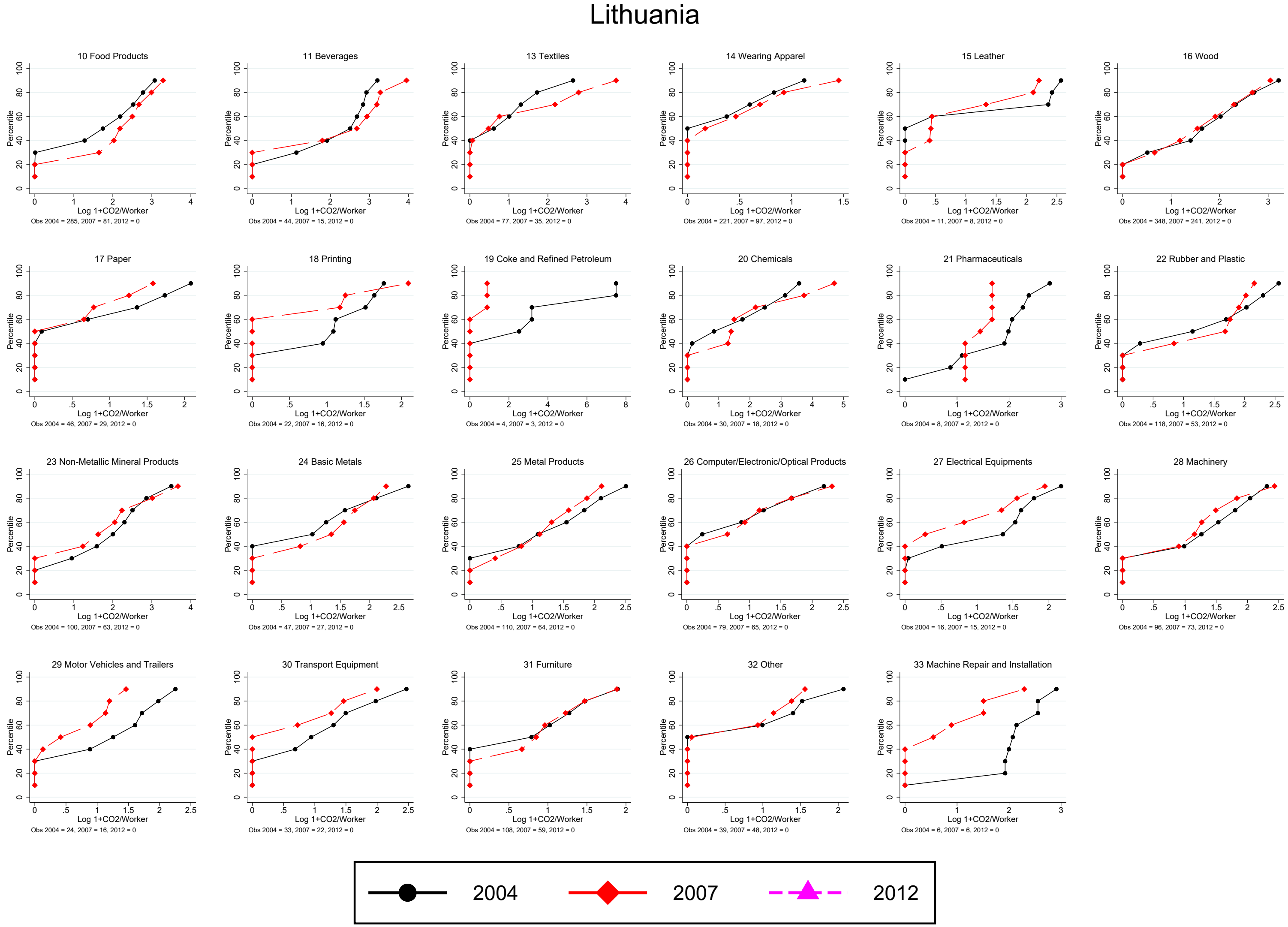


Figure A.6: Carbon Intensity by Sector: Norway

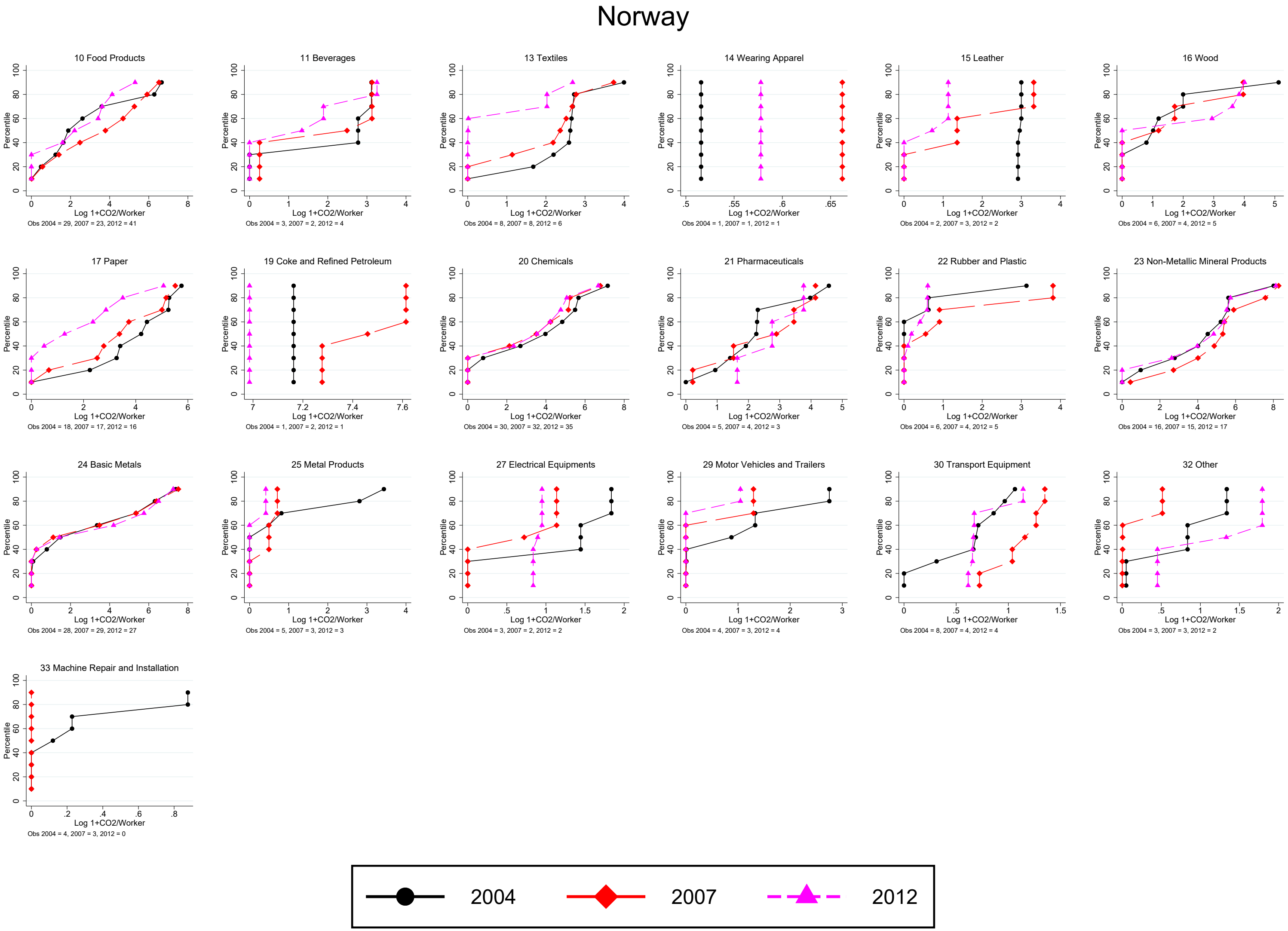


Figure A.7: Carbon Intensity by Sector: Sweden

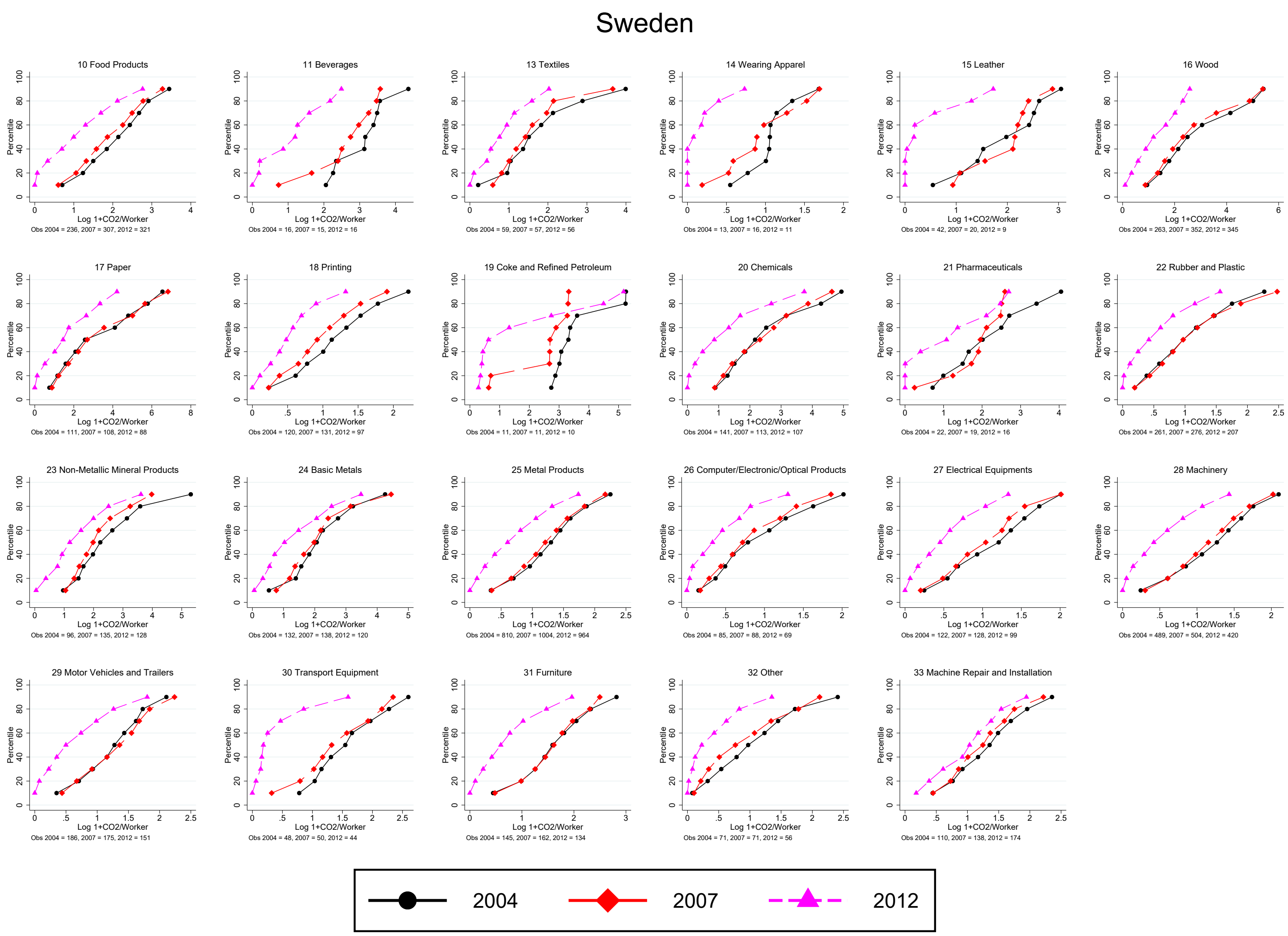
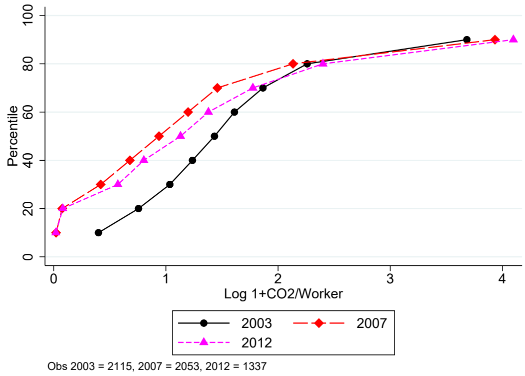
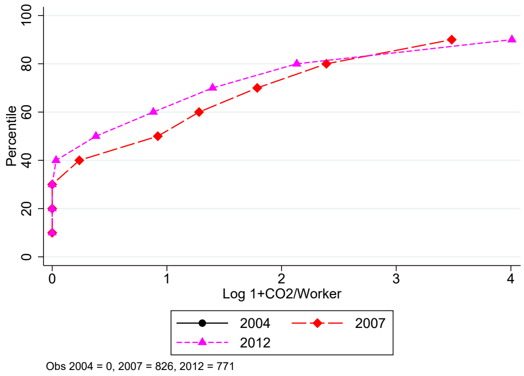


Figure A.8: Carbon Intensity over Time by Country

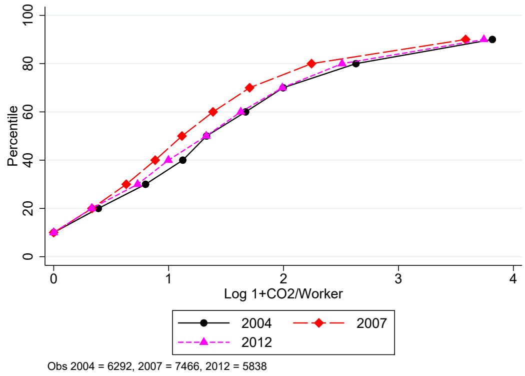
(a) Denmark



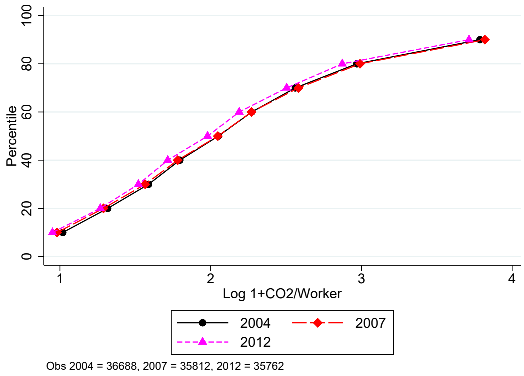
(b) Finland



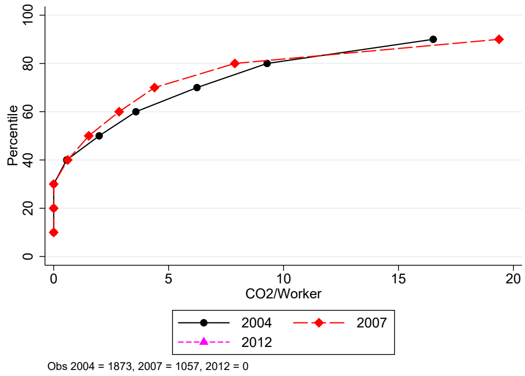
(c) France



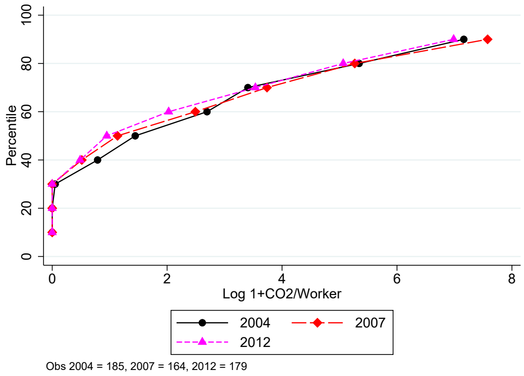
(d) Germany



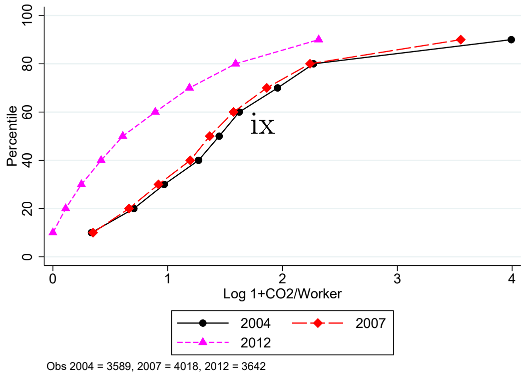
(e) Lithuania



(f) Norway



(g) Sweden



B Data Collection

Table B.1: Data Collection, by Country

Country	Years	NACE	Sampling Frame	Definition of Employment	Definition of Carbon Emissions
Denmark	2003 2007 2012	Rev. 2 (for 2003, 2007, 2012)	All manufacturing plants with 20+ employees (for 2007, 2012)	Av. number of employees within a year (full time equivalent, for 2003, 2007, 2012)	Calculated based on av. carbon emissions for: natural gas, coal, oil, waste, liquid gas, petroleum products, coke, other mineral products using av. carbon emissions from each energy use. Process emissions at industry level are allocated to firms using sale shares. Combined with ETS and PRTR.
Finland	2007 2012	Rev. 2 (for 2007, 2012)	All manufacturing plants with 20+ employees (for 2007, 2012)	Av. number of employees within a year (for 2007, 2012)	Calculated based on average carbon emissions from Statistics Finland for the following energy uses: coke, hard coal, lignite, lignite briquets, other coal products, natural gas, liquid gas, other gas products, fuel light, fuel heavy, other minearal products, peat (for 2007, 2012).
France	2004 2007 2012	Rev. 2 (for 2004, 2007, 2012)	Manufacturing plants with 10+ employees. Stratified and restricted sample through matching. (for 2004, 2007, 2012)	Av. number of employees within a year (for 2004, 2007, 2012)	Calculated based on average carbon emissions for: natural gas, other types of gas available on the network, coal, lignite, coke, butane, propane, heavy fuel oil, heating oil, other petroleum products, the black liquor (for 2004, 2007, 2012).
Germany	2004 2007 2012	Rev. 2 (for 2004, 2007, 2012)	All manufacturing plants with 20+ employees (for 2004, 2007, 2012)	Av. number of employees within a year (for 2004, 2007, 2012)	Calculated based on average carbon emissions for the following energy uses: coke, hard coal, lignite, lignite briquets, other coal products, natural gas, liquid gas, other gas products, fuel light, fuel heavy, other mineral products (for 2004, 2007, 2012).
Lithuania	2004 2007	Rev. 1.1 (for 2004 and 2007)	A representative sample manufacturing firms (for 2004 and 2007)	Av. number of employees within a year (for 2004 and 2007)	Calculated based on average carbon emissions for the following energy uses: coal, petroleum products and natural gas (for 2004 and 2007).
Norway	2004 2007 2012	Rev. 2 (for 2004, 2007, 2012)	All manufacturing plants with emission permits from the Norwegian Environment Agency (2004, 2007, 2012)	Av. number of employees within a year (for 2004, 2007, 2012)	Plant-specific carbon emissions retrieved directly from the Norwegian Environment Agency
Sweden	2004 2007 2012	Rev. 2 (for 2004, 2007, 2012)	All manufacturing plants with 50+ employees (for 2007 and 2012); with 20+ employees (for 2004)	Av. number of employees within a year (full-time equivalent, for 2004, 2007, 2012)	Calculated based on average carbon emissions from Svensk Miljöemissionsdata for the following energy uses: coke, hard coal, other coal products, natural gas, liquid gas, other gas products, fuel light, other minearal products (for 2004, 2007, 2012).