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The Impact of Carbon Trading on Industry: Evidence from German Manufacturing Firms

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joint work with
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Motivation

- Manmade climate change is real and will cause severe economic damage
(Assessment Report V by IPCC, 2013)
- Principal cause: CO₂ emissions from combustion
- Mitigating climate change thus requires major policy interventions across all economic sectors
- Market-based regulation in the EU:
Stationary sources of CO₂ engage in 'Carbon trading' under the EU Emissions Trading Scheme (EU ETS)

The EU ETS is the world's...

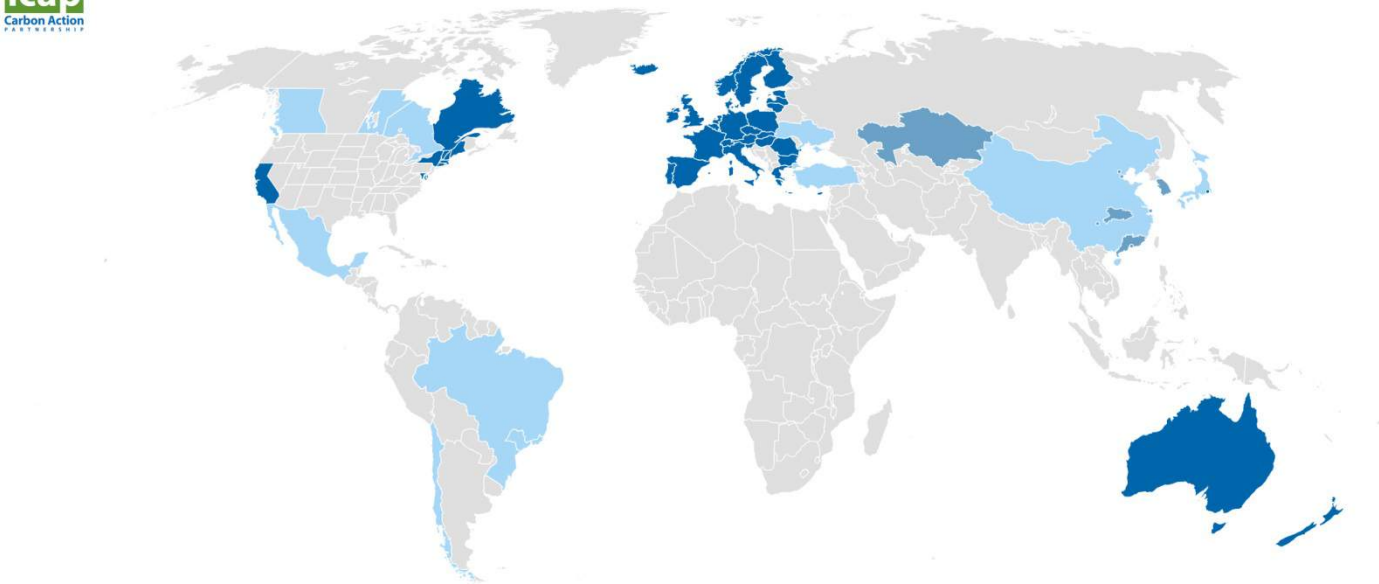





- ... largest carbon market
- ... largest carbon pricing experiment
- ... first mandatory carbon trading scheme
- ... first trans-boundary cap-and-trade system

EU ETS serves as a blueprint for other trading schemes around the globe



Updated on: 7 December 2012



-  ETS in force
-  ETS implementation scheduled
-  ETS under consideration

www.icapcarbonaction.com

Developed in cooperation with **ECOFYS**

A recent view on carbon trading

The Administration is developing a comprehensive energy and climate change plan to (...) address the global climate crisis, and create new American jobs that cannot be outsourced. (...) This program will be implemented through a cap-and-trade system (...).

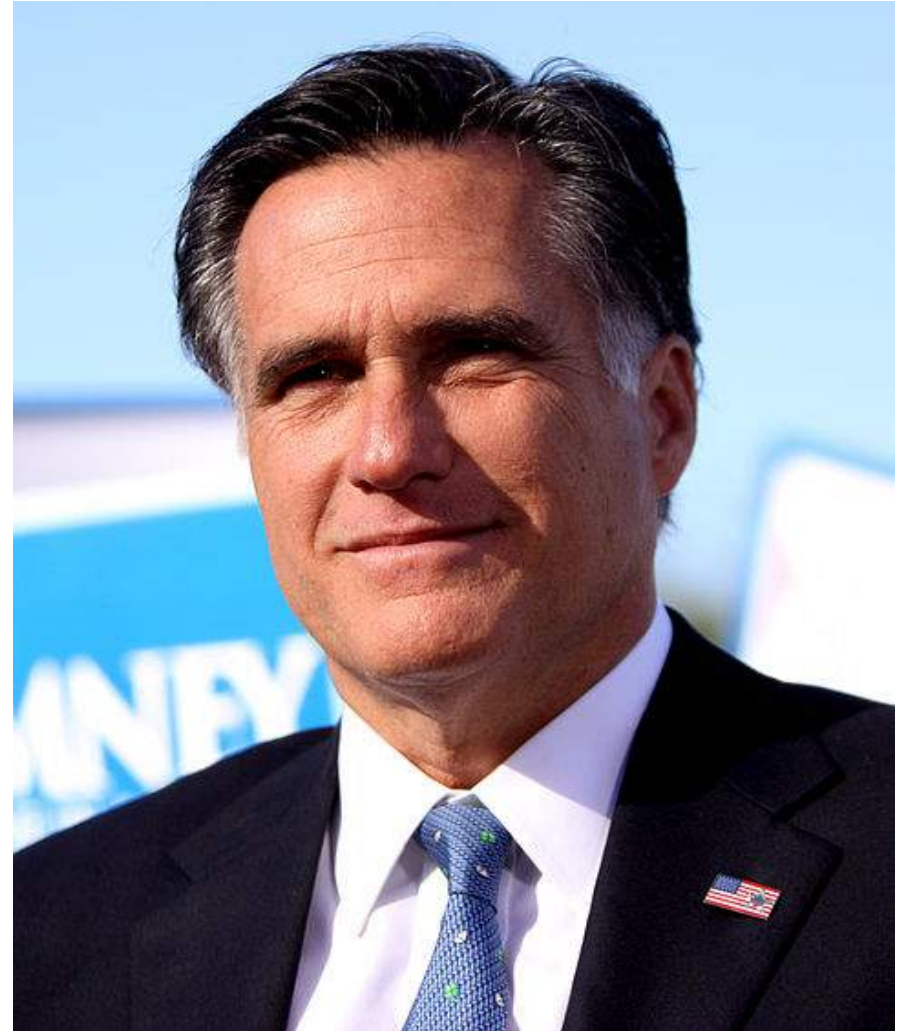
Executive Budget Office of the President,
Budget 2009.



Another view on Carbon Trading

“I do not believe in a cap-and-trade program. (...) It loses jobs for Americans, and ultimately it won't be successful, because industries that are energy-intensive will just get up and go somewhere else.”

Mitt Romney,
Former GOP Presidential Candidate,
October 2011, Pittsburgh



So far, lack of empirical evidence on the consequences of carbon trading

- Policy makers should adopt evidence-based policies when
 - Improving carbon trading in Europe
 - Implementing new carbon trading schemes elsewhere
- Goal: Provide sound empirical evidence on the impact of carbon trading on industry

Why focus on Germany?

- Largest carbon market share (>20%) of all participants
- Largest EU economy
- Export oriented manufacturing sector, highly competitive
- Access to administrative data of excellent quality

Research questions

Did the EU ETS...

- ...reduce carbon emissions? **YES**
- ...cost jobs or revenue? **NO**
- ...damage international competitiveness? **NO**

Outline

1. Motivation
- 2. Background and Literature**
3. Data and Empirical Strategy
4. Main Results and Robustness Checks
5. How did firms reduce emissions?
6. Conclusions

A cap-and-trade system for industrial carbon dioxide (CO₂) emissions



- Three trading phases:
 - 2005-2007: Trial phase
 - 2008-2012: Phase II
 - 2013-2020: Phase III
Now covers >11,000 stationary installations in 31 countries and >2 bn. tons of CO₂
- The EU ETS regulates two types of stationary sources of CO₂
 1. All combustion installations >20 MW thermal rated input
 2. Installations with capacity > specific threshold established for specific industrial processes: refineries, coke ovens, cement clinker, glass, ceramic bricks, pulp & paper, iron & steel

Evaluation literature

- **Emissions:**
 - No firm-level evaluation study so far for lack of emissions data
 - Studies use aggregate emissions and construct counterfactual emissions trajectory by extrapolating past trends (Ellerman & Buchner 2007,2008; Ellerman & Feilhauer 2009; Ellerman et al. 2010; Anderson & DiMaria 2009)
 - Treatment effect: -2.4% to -6.4% . Confounded by aggregate shocks?
- **Performance and competitiveness:**
 - Evaluation studies at firm level: Anger & Oberndorfer 2008; Abrell et al. 2011; Chan et al. 2013, Commins et al. 2011; Bushnell et al. 2012.
 - Mixed results for revenue, profits, employment
- **Matching** estimator of choice for evaluation of cap & trade
 - Abrell et al. (2011): performance impact of ETS
 - Calel & Dechezlepretre (201x *ReStat*): impact of ETS on clean patents
 - Fowlie et al. (2012 *AER*): impact of RECLAIM on NOx emissions

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Causal Inference with Matching

- Parameter of interest:

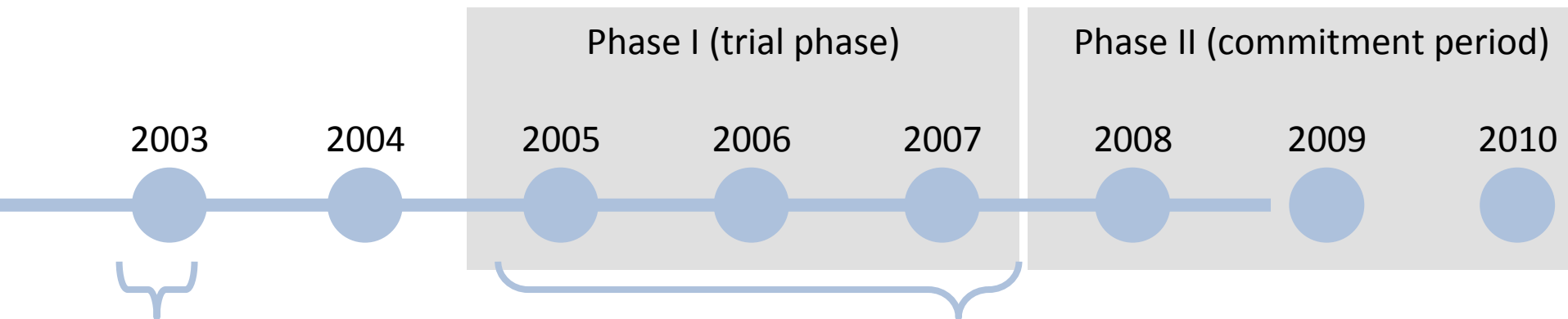
$$\alpha_{ATT} = E(Y_{it}(1) - Y_{it}(0) | X, D = 1)$$

- Identification problem: $Y_{it}(0)$ unobserved for treated firms and treatment not randomly assigned.
- Focus on DiD to purge estimate from persistent confounders and build counterfactual using semiparametric matching (Heckman et al. 1997, 1998)

$$\hat{\alpha} = \frac{1}{N_1} \sum_{i \in I_1} \left\{ (Y_{it}(1) - Y_{i0}(0)) - \sum_{k \in I_0} W_{N_0, N_1}(i, k) \cdot (Y_{kt}(0) - Y_{k0}(0)) \right\}$$

Administrative data on German firms

- AFiD panel “Industrial Establishments” (destatis)
 - ~ 48 000 plants per year, all plants with more than 20 employees
 - Yearly data for 16 years (1995-2010)
 - Easily aggregated up to the firm level
- Information on production and energy characteristics
 - Purchases, use, supply, stock of 15 different fuels (from 2003)
 - Detailed information on electricity generation and trading (from 2003)
 - Allows for very precise calculation of CO₂ emissions
- Match in information on treatment status from trading registry
 1. Identify 1,879 facilities potentially in the manufacturing sector.
 2. Of these we could match 1,658 (88%) account holders to our data.
 - Highly unlikely that unmatched installations end up in the control group. Rather, they are too small or not manufacturing.
 3. Treatment variable equals 1 if firm has at least one plant in the ETS
- Great data, but stringent access restrictions to preserve confidentiality



Estimate propensity score of treatment:

- CO₂ emissions
- gross output
- employment
- export share
- average wage rate
- squares of these
- 29 sector dummies
- 16 regional dummies

DiD (treated vs. non-treated) in outcomes

- CO₂ emissions
- carbon intensity
- gross output
- employment
- export measures

Pairing of treated and non-treated firms using nearest-neighbor matching algorithms based on propensity scores within two strata:

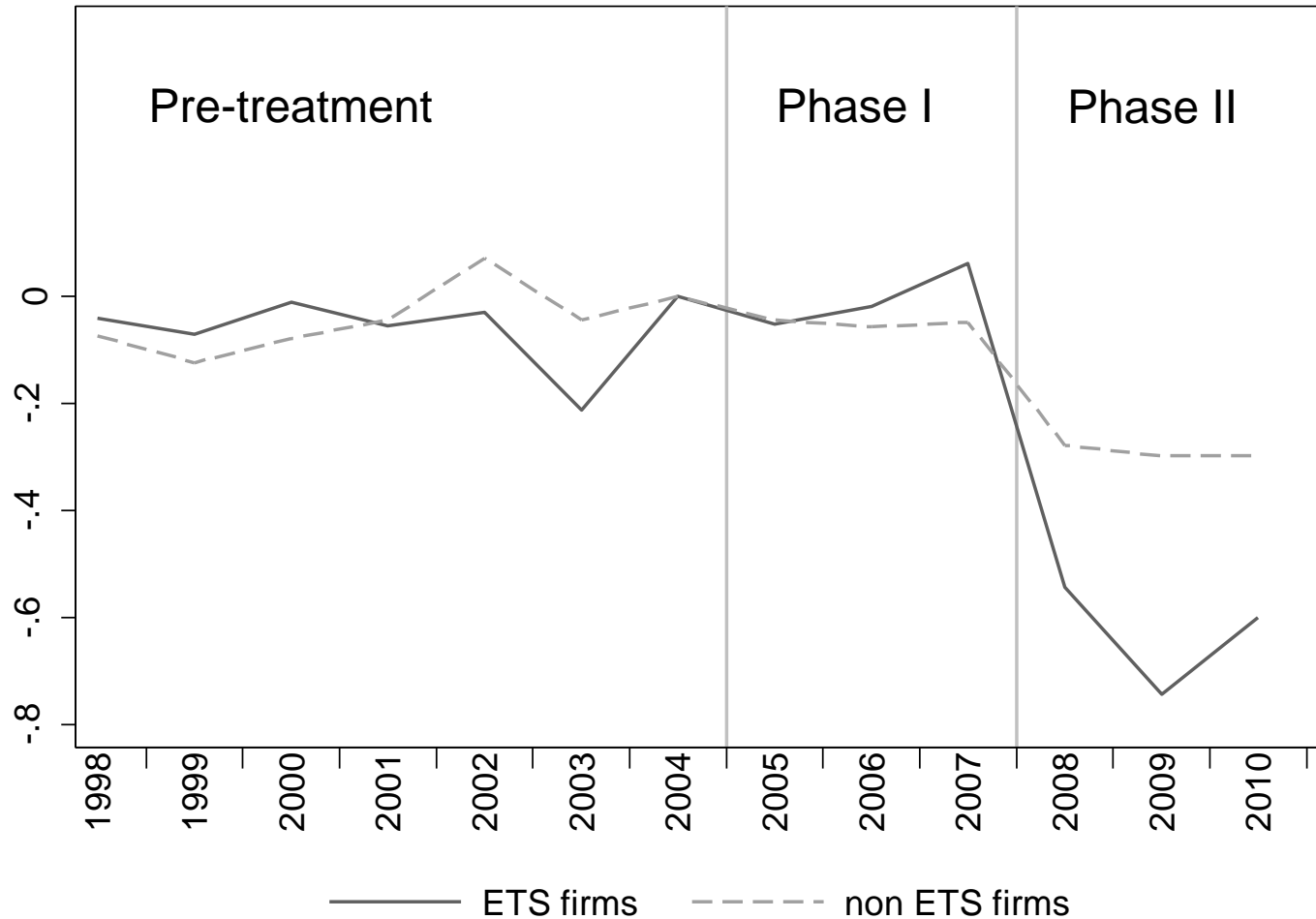
- (i) process-regulated sectors and
- (ii) all other sectors.

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CO₂ EMISSIONS

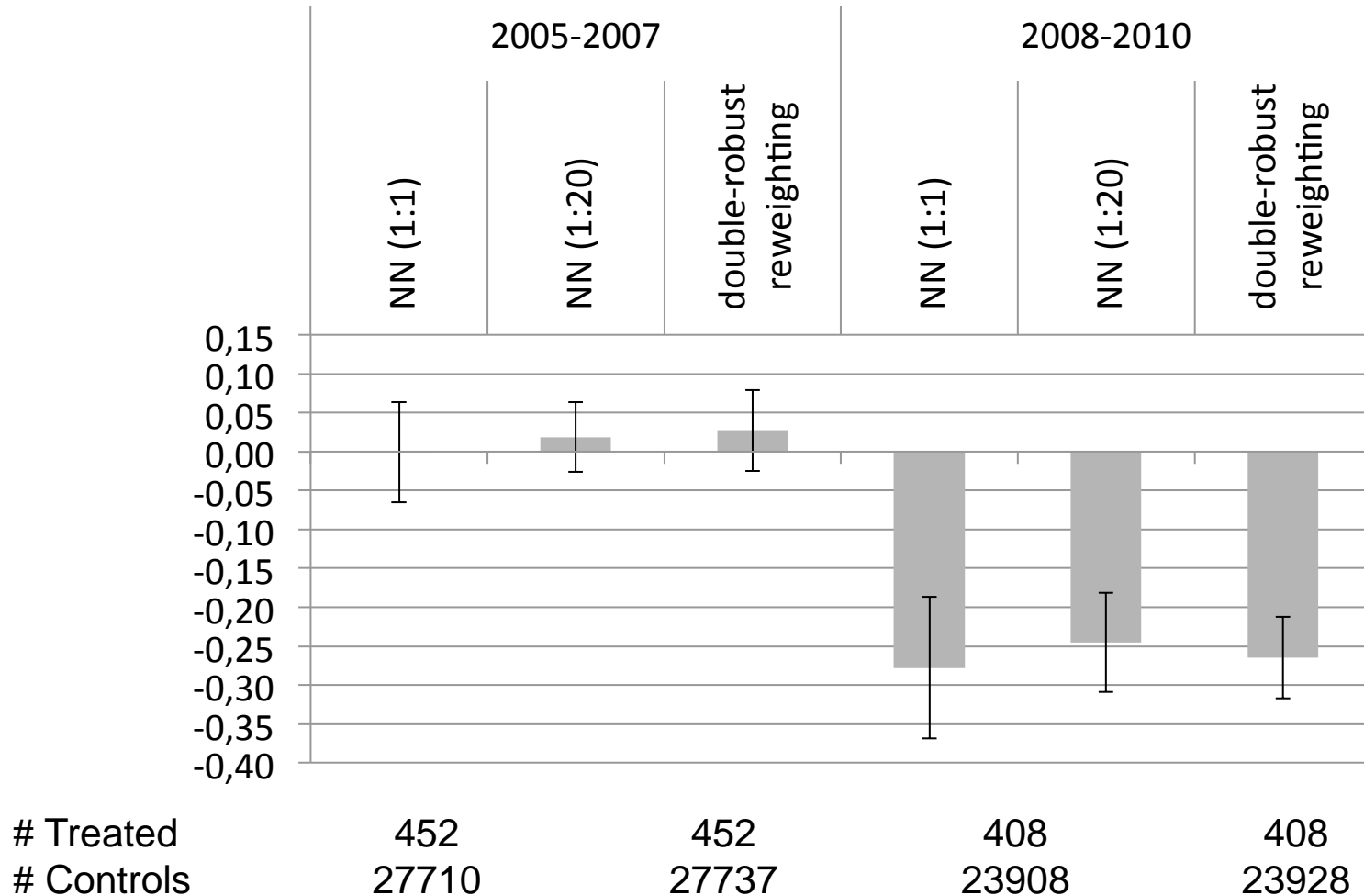
Log-changes in emissions against 2004, by treatment status



Note: Balanced sample of ETS firms and matched control firms

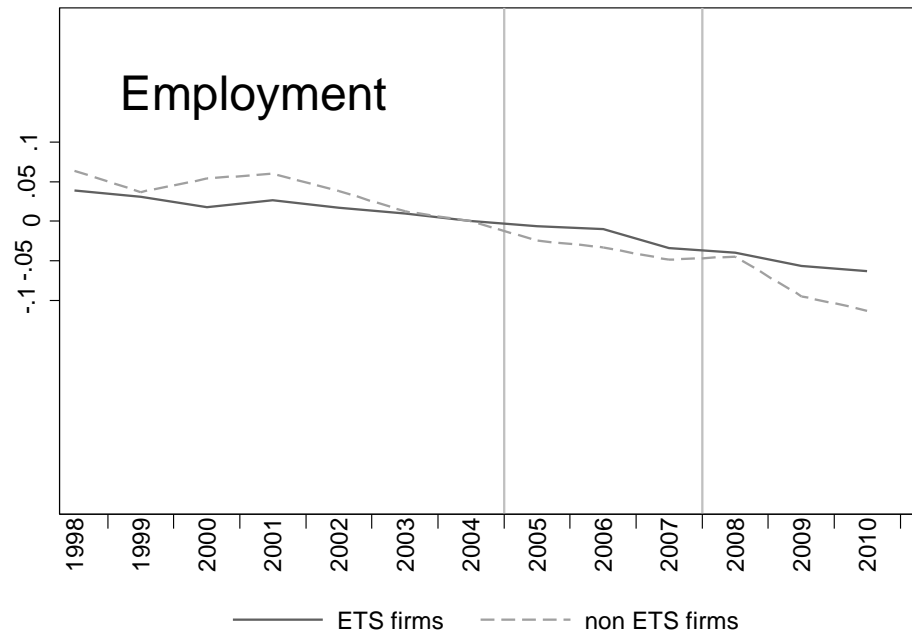
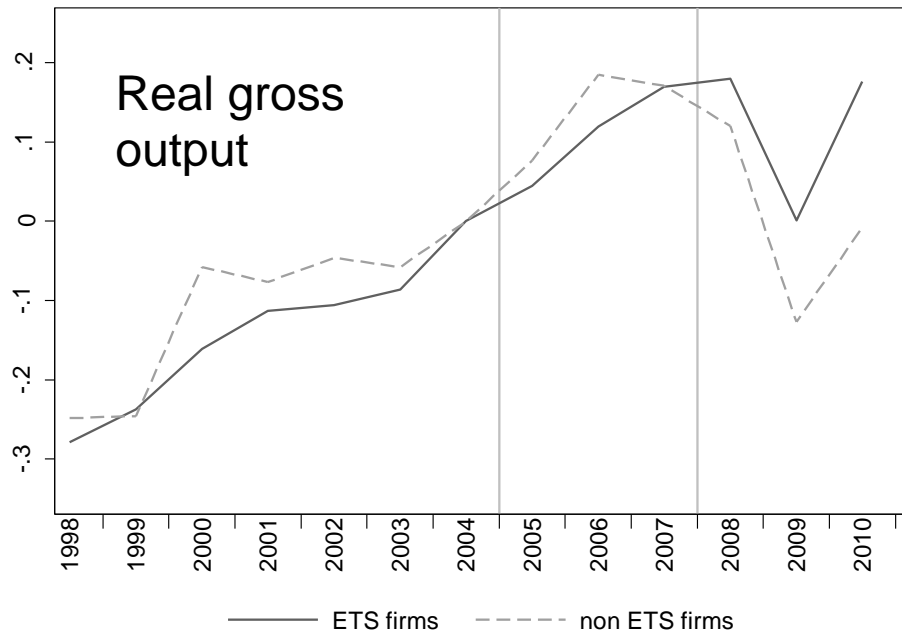
Emissions fall in Phase II

ATTs: Log CO₂ emissions



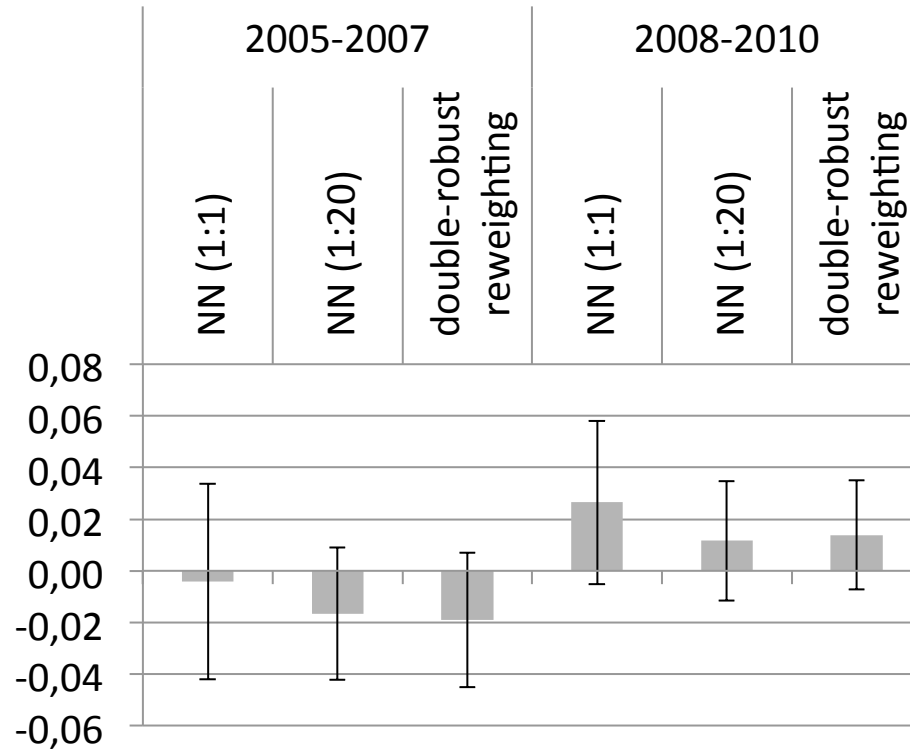
ECONOMIC PERFORMANCE

Log-changes against 2004, by treatment status



Note: Balanced sample of ETS firms and matched control firms

No significant impact on employment

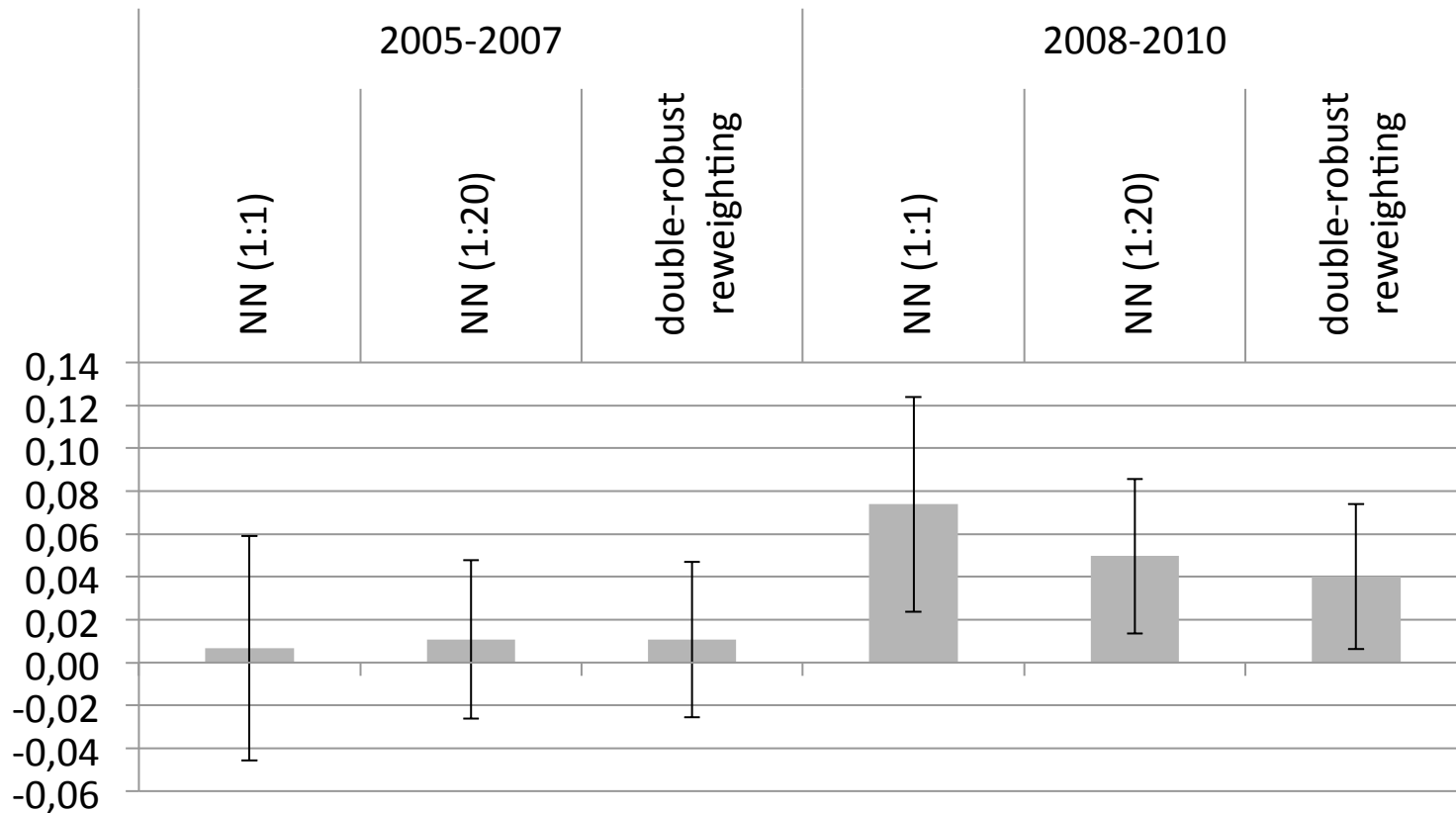


NN:
Treated
Controls

454
28396

433
24237

Positive impact on gross output in phase II



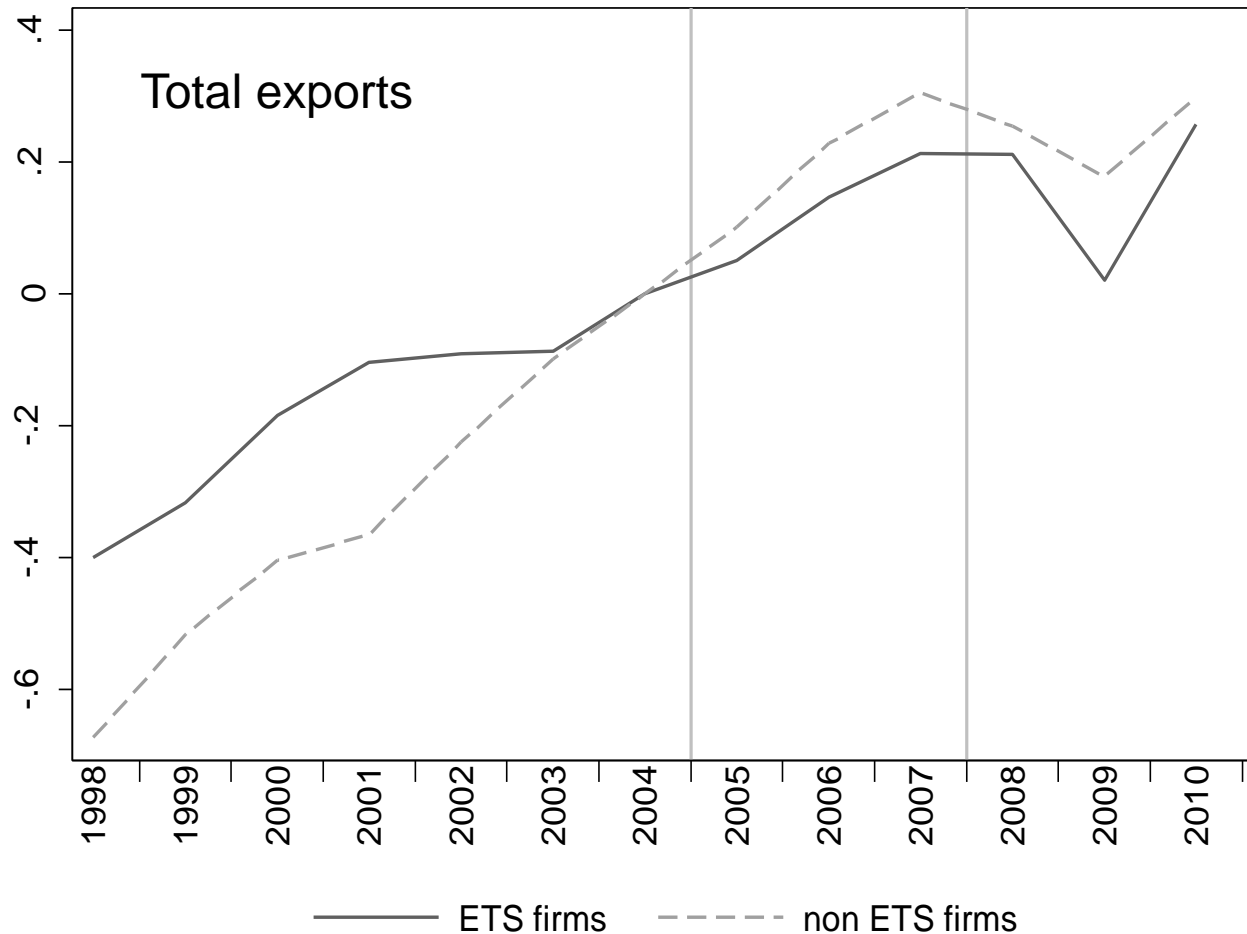
NN:

Treated 449
Controls 28465

430
24240

INTERNATIONAL COMPETITIVENESS

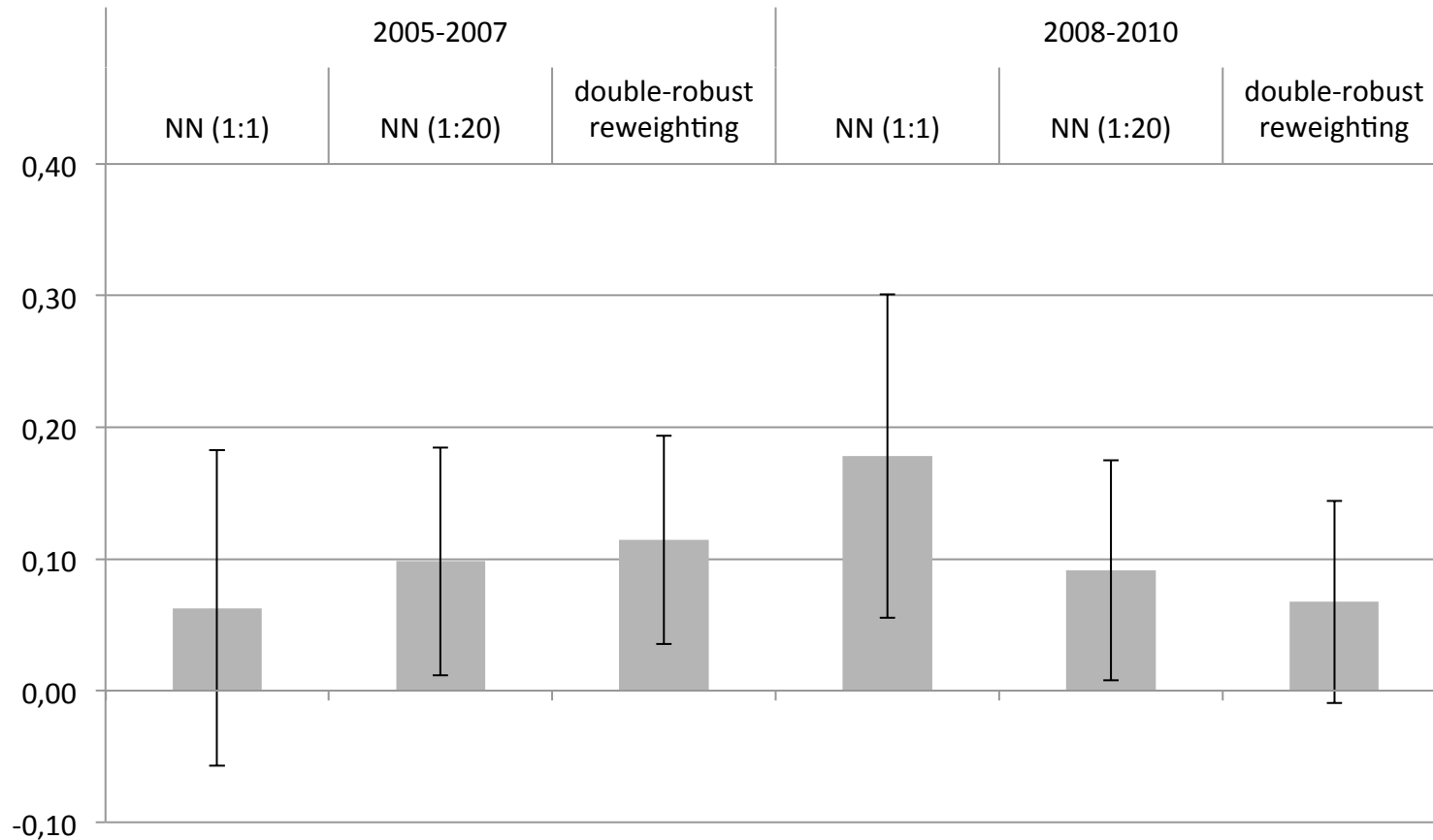
(log-changes against 2004)



Note: Balanced sample of ETS firms and matched control firms

ATTs exporting activity

Log Exports



Exports:	2005-2007	2008-2010
# Treated	371	348
# Controls	17864	15463

Robustness

- Look at alternative specifications (NN 1:20, OLS with reweighting)
- Unconfoundedness assumption
 - Pre-treatment trends parallel? yes
 - Exact matching on 2-dig. sectors: All goes through but output effect (+) becomes insignificant
 - Match on pre-treatment trends in outcomes: All goes through but export effect (+) becomes insignificant
- Pre-treatment dynamics:
 - Announcement effect
 - Effect of the great recession

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How did firms abate emissions?

$$CO_2 = \underbrace{\sum f_i (CO_2 / kWh)_i}_{\text{carbon intensity}} \cdot \underbrace{E_i / E}_{\text{energy use}} \cdot \underbrace{E / Y \cdot Y}_{\text{energy use}}$$

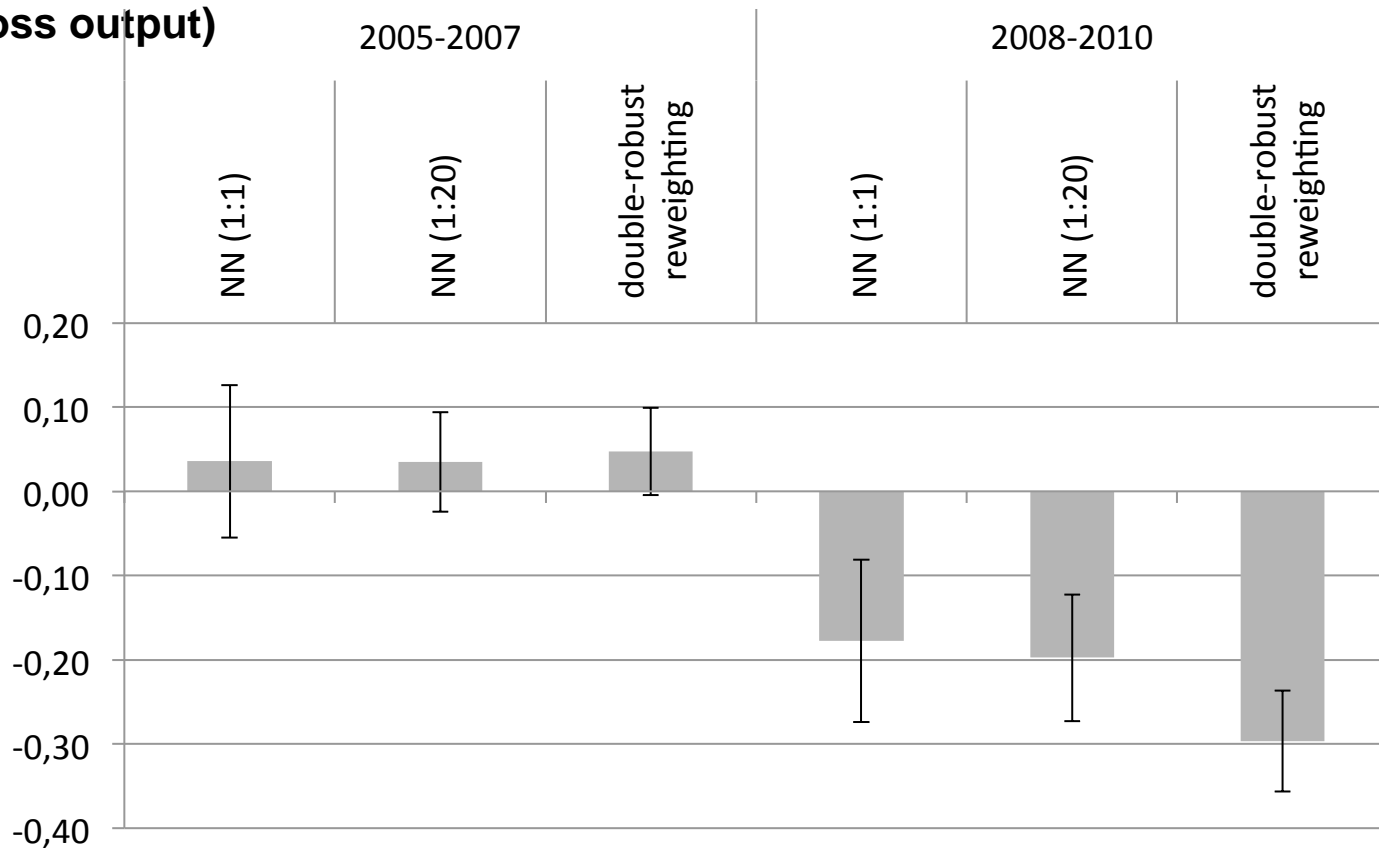
Investigate two possibilities:

- Reduce energy use (for given carbon intensity)
- Reduce carbon intensity for given energy use

and shed light on the underlying mechanism

Impact through intensity, not scale

Log Carbon Intensity log
(CO₂/Gross output)



NN:

Treated

451

412

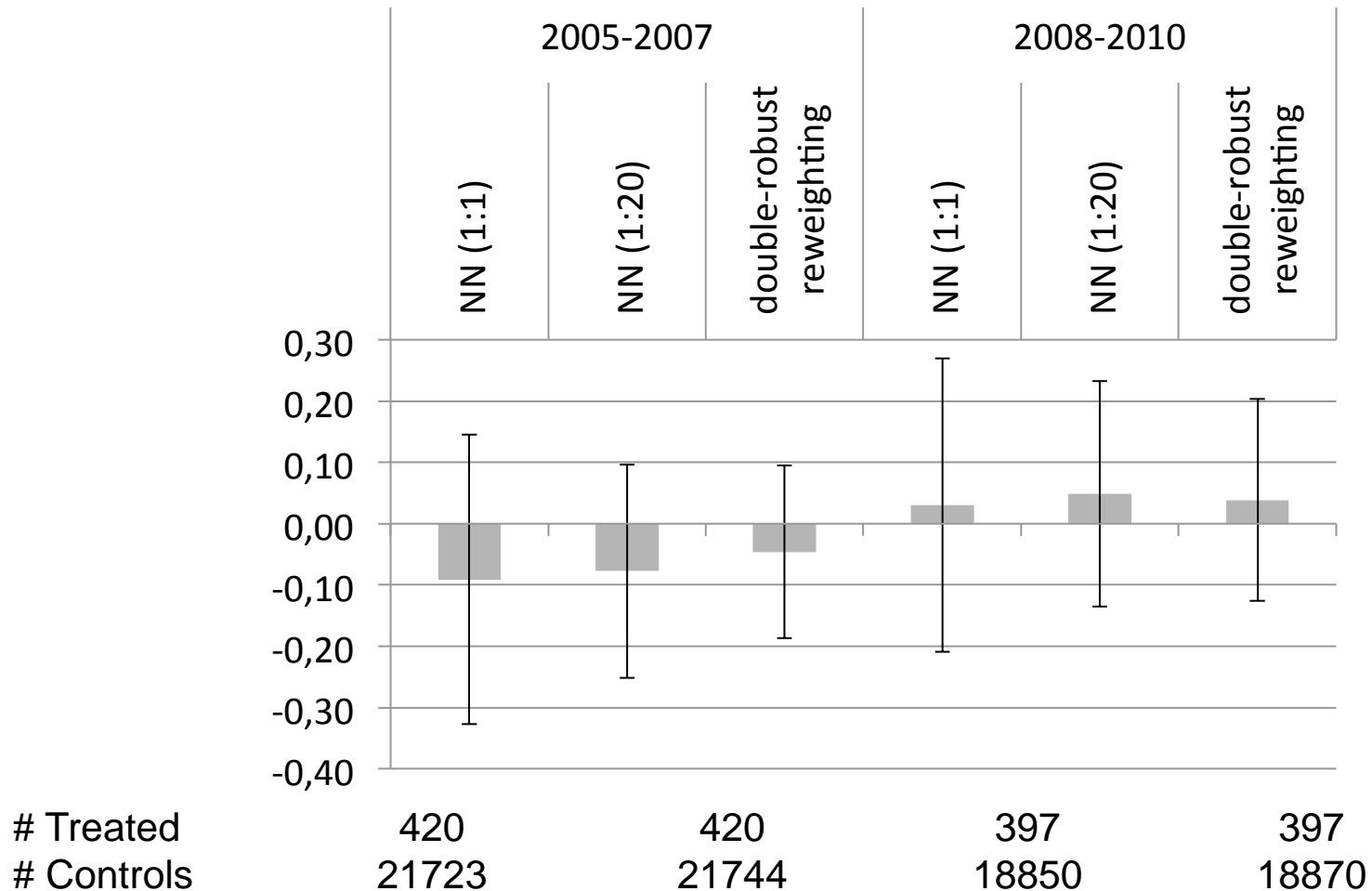
Controls

27637

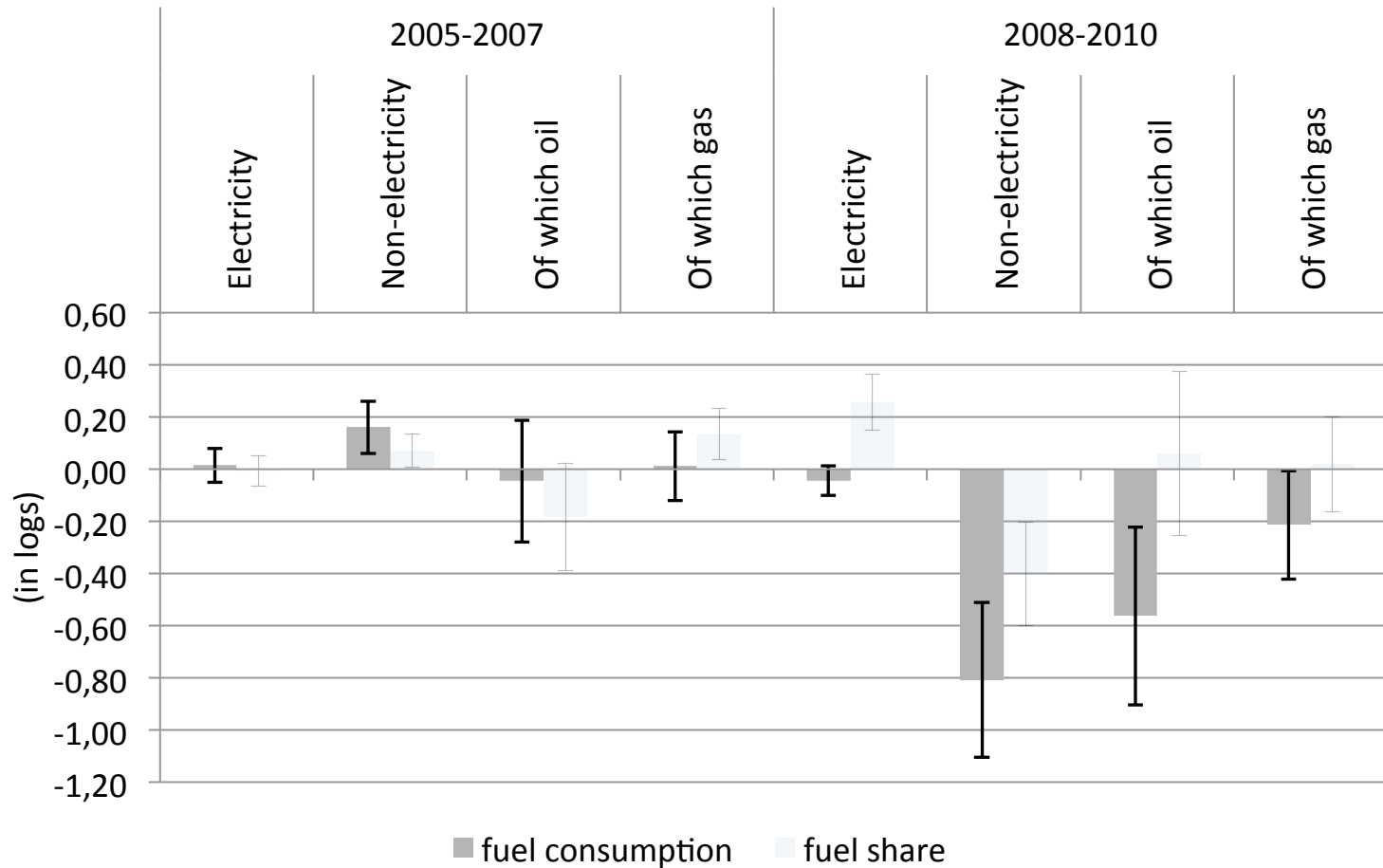
23742

Technological improvements?

No impact on investment

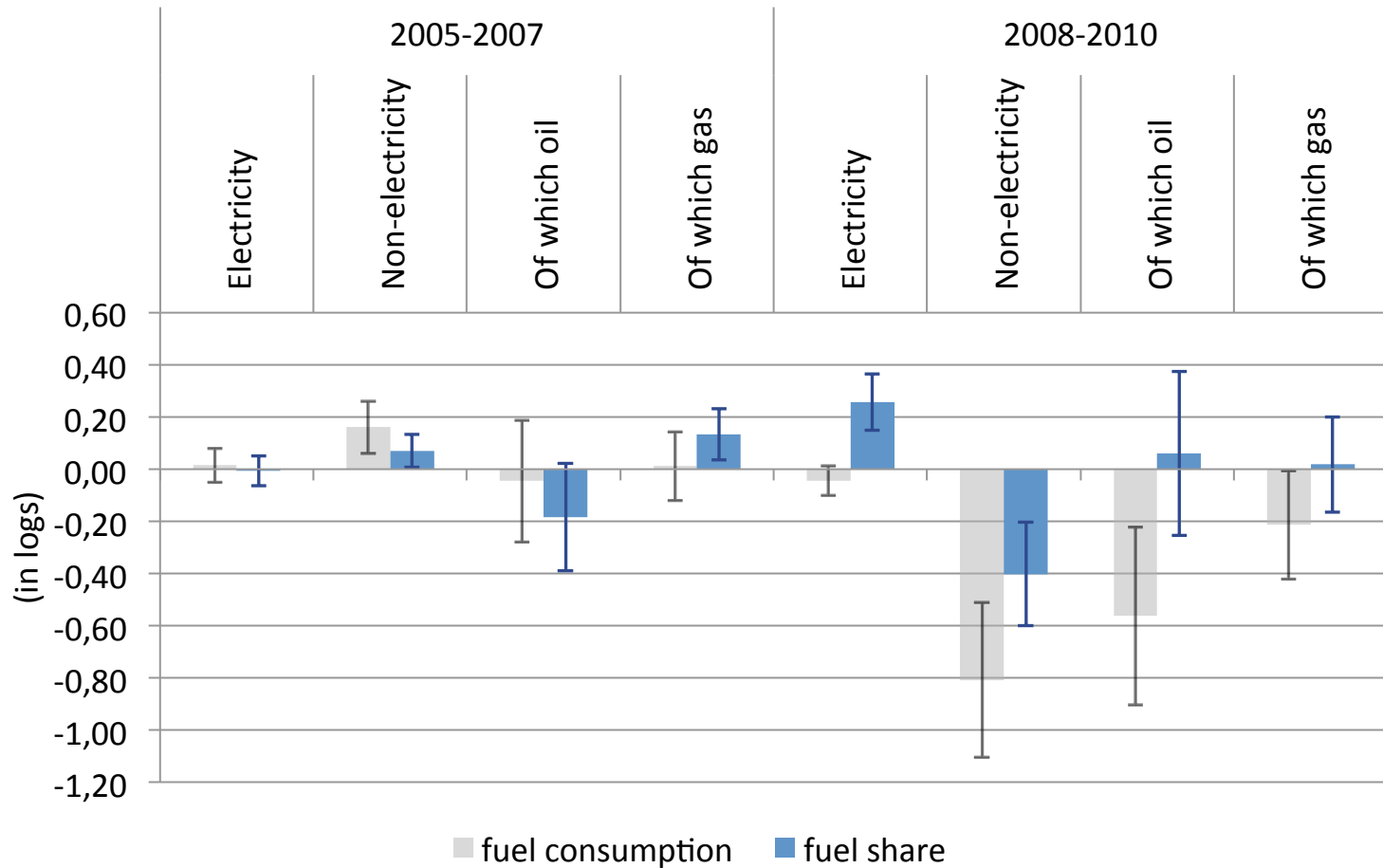


Firms reduce emissions by switching out of fossil fuels – absolute effect



ATT for NN 1:1 specification

Firms reduce emissions by switching out of fossil fuels – fuel share effect



ATT for NN 1:1 specification

Qualitative evidence

- Interviews with managers at 138 German manufacturing firms in 2009, taken from Martin *et al* (*AER* forthcoming)
- Bias-reducing method by Bloom and van Reenen (2007, *QJE*)
- “Can you tell me what measures you have adopted in order to reduce GHG emissions or energy consumption on this site? Have you bought any new equipment, or have you changed the way you produce?”

Estimate partial correlation between treatment and adoption rates

Estimate a probit model for the adoption of each measure

$$\Pr(\textit{adopt}|X) = \Phi(\alpha_0 + \alpha_T \textit{ETS} + \textit{Controls})$$

Where controls include employment size, interviewer fixed effects and respondent's education, gender and tenure

Adoption of abatement measures (1)

	(1) All measures adopted	(2)	(3) Most significant measure	(4)
	Share of adopters (%)	Effect of ETS	Share of adopters (%)	Effect of ETS
I. Heating and cooling				
1. Optimized use of process heat	37.7*** (4.1)	1.02*** (0.31)	20.5*** (3.8)	1.01*** (0.34)
2. Modernization of cooling / refrigeration system	9.4*** (2.5)	-0.22 (0.30)	0.9 (0.9)	
3. Optimization of air conditioning system	4.4** (1.7)	0.15 (0.42)	0.9 (0.9)	
4. Optimization of exhaust air system / district heating system	27.5*** (3.8)	0.01 (0.23)	9.8*** (2.8)	-0.64* (0.34)
II. More climate-friendly energy generation on site				
1. Installation of CHP plant	13.0*** (2.9)	0.17 (0.28)	6.3*** (2.3)	0.05 (0.34)
2. Biogas feed-in into local CHP plant or domestic gas grid	2.9** (1.4)	0.20 (0.46)	5.4** (2.1)	
3. Switching to natural gas	2.9** (1.4)	-0.38 (0.44)	0.9 (0.9)	
4. Exploitation of renewable energy source	13.8*** (2.9)	-0.17 (0.34)	9.8*** (2.8)	0.08 (0.50)
III. Machinery				
1. Modernization of compressed air system	14.5*** (3.0)	0.07 (0.25)	5.4** (2.1)	-0.29 (0.43)
2. Other industry-specific production process optimization/machine upgrade	63.0*** (4.1)	0.41** (0.20)	23.2*** (4.0)	0.29 (0.27)
3. Production process innovation	8.0*** (2.3)	0.13 (0.37)	1.8 (1.3)	

Adoption of abatement measures (2)

IV. Energy management

1. Introduction of energy management system	8.0*** (2.3)	-0.14 (0.30)	1.8 (1.3)	
2. Submetering / upgrade of existing energy management system	7.3*** (2.2)	0.56 (0.42)	0.9 (0.9)	
3. (External) energy audit	7.3*** (2.2)	-0.14 (0.30)	-	
4. Installation of timers attached to machinery	4.4** (1.7)	-0.89** (0.35)	-	
5. Installation of heating systems	2.2* (1.3)	-0.59 (0.51)	2.7* (1.5)	-0.52 (0.52)

V. Other measures on production site

1. Modernization of lighting system	12.3*** (2.8)	-0.68** (0.32)	1.8 (1.3)	
2. Energy-efficient site extension/ improved insulation/building management	18.1*** (3.3)	-0.87*** (0.23)	5.4** (2.1)	-0.76 (0.46)
3. Employee awareness campaigns and staff trainings	12.3*** (2.8)	-0.29 (0.28)	-	
4. Non-technical reorganization of the production process	2.2* (1.3)	-0.13 (0.41)	0.9 (0.9)	
5. Installation of energy efficient IT system	6.5*** (2.1)	0.10 (0.40)	-	
6. Improved waste management / recycling	5.1 *** (1.9)	0.54 (0.45)	0.9 (0.9)	

Notes: Based on telephone interviews with managers of 138 German manufacturing firms, 95 of which were EU ETS participants in 2009. Columns (1) and (3) report the mean and standard deviation (in parentheses) of the adoption rate for a given measure. Columns (2) and (4) report the coefficient on EU ETS participation in a probit regression of adoption, controlling for employment size, interviewer fixed effects, and respondent characteristics. Standard errors in parentheses are clustered at the 3-digit sector level.

Quotes: Optimized use of process heat

- **Reuse steam** used to heat water
- **Wärmerückgewinnung**, Holzhackschnitzel
- **Recycling of hot water**
- Own power plant, burning in boilers optimized, substrassen 2 anstatt 3, **heat recovery**, programmes of cleaning system are being checked and water consumption and heat is being checked
- Heat recovery, Frequenzumrichter, Vakuumpumpen disposed. **Biggest impact: Heat recovery**
- **Multiple utilization of waste heat from steam boilers**, reducing temperature of waste heat in chimney/funnel, **waste heat recovery**, controlling of supply and exhaust air kontrollieren(Abluft waermt Zuluft)
- Optimization of drying processes, **waste heat recovery**
- Optimization of pumps (turning down rotation speed), **waste heat recovery**, heat exchangers
- switch to natural gas, renovation, frequency changers, process heat isolation, steam recovery
- bought new boilers, **waste heat recovery** installed, more efficient drying methods
- Automatic turning off of air conditioning and infrastructure for production, buying of motors with highest energy efficiency, efficiency of compressed air maximized (i.e. repairing of leakage, etc), **waste heat recovery**
- Optimization of energy mix used (some gases are more efficient than others), **making use of previously escaping vapor heat**
- **Heat recovery in low temperature parts**
- Wärmeträgeröle gegen Wasserdampf ausgetauscht, Anlagen zusammengelegt, Abwasser
- **Wärmerückgewinnung**
- Regenerativkammern zur **Wärmerückgewinnung**
- **Wärmetauscher**
- Insulation, **heat recovery**
- **Waste heat recovery**, exhaust heat from facilities (heated air is being blown back into the building in order to save heating – it's not a heat pump, but a direct redirection of the exhaust heat)

Conclusions

- Trial phase of the EU ETS had virtually no effect
- Phase II of EU ETS caused emissions to fall by 25pp (8.3pp per year) relative to non-treated firms
- Achieve through intensity reductions (fuel switching), not scale
- In particular, reduction of non-electricity fuels (oil and gas) and more efficient heat use.
- No evidence of negative impact of EU ETS on employment or output
- No evidence of negative impact on exports.



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Thank you!

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Existing Literature – emissions

- Estimating counterfactual via extrapolation of past trends: EU ETS was effective
 - Ellerman & Buchner (2007, REEP), Buchner and Ellerman (2008, ERE): -2.4% to -4.7% in 2005-06.
 - Ellerman, Convery & de Perthuis (2010): -3% in phase I
 - Ellerman & Feilhauer (2008) for Germany: -6.3% industrial emissions, -4.1% power sector (average -5%)
 - Anderson & DiMaria (2011, ERE): -2.8% EU wide, using panel data econometrics to impute baseline emissions.
- Problem: Data on pre-treatment emissions? Data on non-treated firms?

Existing Literature – performance and competitiveness

- Ex-ante: e.g. CGE analyses
- Surveys and case studies, e.g. McKinsey/Ecofys (2005, 2006), Kenber et al. (2009)
- Some ex-post econometric studies:
 - Anger & Oberndorfer (2008, Energy Policy): No correlation between revenue or employment and permit allocation at German firms
 - Commins, Lyons, Schiffbauer & Tol (2011, Energy Journal): **drop in labor productivity and profits** in EU ETS sectors compared to other sectors
 - Abrell, Ndoye & Zachmann (2011): **Small decrease in employment**
 - Bushnell, Chong & Mansur (2012, AEJ-EP): **Positive profit impact based** on event study of Stock prices after collapse in carbon price

Identifying Assumptions

- Any bias in the unconditional DiD is removed by adjusting for differences in observable covariates: The distribution of $Y_{it}(0)$ is the same among participating and non-participating firms.
- Support of the distribution of the conditioning covariates in the treatment and control groups overlap.
- Potential outcomes at one facility are independent of the treatment status of another facility.

Next step: A closer look at international competitiveness

- Bring product-level data to bear on this question:
 - Export quantities and values by destination country at the 8-digit code (French customs data, can be matched to firm panel)
 - Unit values for all 9-digit codes (German panel)
- Two approaches:
 - Exploit differences in exporting patterns:
 - EU ETS vs. Non ETS firms
 - Pre and post treatment
 - High-carbon vs. low-carbon products
 - ETS vs. non-ETS destination country
 - Exploit differences in prices: can firms pass the cost of carbon trading through to product markets?

Descriptive Statistics

Variable	(1) Mean	(2) Std. Dev.	(3) p10	(4) p50	(5) p90	(6) N
<i>A. Full sample (mid-98%)</i>						
CO ₂ emissions from energy (t)	1,912	5,618	35	314	4,098	40,834
CO ₂ intensity (g/€ 1000)	108,581	143,612	8,250	62,793	248,907	40,709
Employees	104	158	22	49	233	40,325
Gross output (€ 1000)	17,597	38,223	1,435	5,299	40,580	40,204
Exports (€ 1000)	4,978	15,776	0	198	11,542	40,947
Export share of output	0.16	0.22	0.00	0.04	0.53	40,931
Average wage rate (€)	28,649	9,681	15,998	28,458	41,213	40,409
<i>B. ETS participants</i>						
CO ₂ emissions from energy (t)	-	795,888	6,146	51,716	457,851	408
CO ₂ intensity (g/€ 1000)	-	1,449,921	84,392	670,420	2,604,891	413
Employees	-	11,370	52	388	4,103	433
Gross output (€ 1000)	-	4,191,998	6,748	95,703	1,125,042	430
Exports (€ 1000)	-	2,853,722	324	28,064	647,477	369
Export share of output	-	0.27	0.00	0.29	0.70	408
Average wage rate (€)	-	9,393	26,729	37,214	48,408	408
<i>C. Non-ETS participants (matched sample)</i>						
CO ₂ emissions from energy (t)	-	372,759	510	12,047	891,534	278
CO ₂ intensity (g/€ 1000)	-	1,786,216	37,991	155,349	1,769,886	283
Employees	-	1,994	42	208	4,384	296
Gross output (€ 1000)	-	759,593	5,728	64,809	825,606	293
Exports (€ 1000)	-	323,759	936	21,537	802,049	248
Export share of output	-	0.25	0.00	0.28	0.64	278
Average wage rate (€)	-	9,283	25,767	39,210	49,010	278

Notes: CO₂ intensity in terms of gross output (g/€ 1000). Means for matched sample cannot be obtained for reasons of data privacy.

Source: Research Data Centres of the Federal Statistical Office and the Statistical Offices of the Länder (2012): AFiD-Panel Industriebetriebe, 2005-2010, own calculations.

Pre-treatment outcomes in the matched sample

Null hypothesis: Equality of pre-treatment outcomes

Variable	A. Levels			B. Trends		
	<i>p</i> -value	Number of treated	Number of controls	<i>p</i> -value	Number of treated	Number of controls
CO ₂ emissions	0.0911	408	278	0.0505	405	.
CO ₂ intensity	0.0197	413	283	0.2025	409	.
Gross output	0.0054	430	293	0.3141	428	.
Employees	0.0051	433	296	0.6177	431	.
Exports	0.0073	369	248	0.1047	336	.
Export share	0.1634	408	278	0.2483	406	.
Average wage rate	0.0086	408	278	0.0603	285	.

Notes: Number of control firms for matched sample are not reported for confidentiality reasons.
 Source: Research Data Centres of the Federal Statistical Office and the Statistical Offices of the Länder (2012): AFiD-Panel Industriebetriebe, 2005-2010, own calculations.

Impact on carbon emissions

	(1)	(2)	(3)	(4)	(5)
	Estimation Algorithm			Number of	
	NN (1:1)	NN (1:20)	OLS w/R	Treated	Controls
A. CO ₂ emissions: $\Delta \ln(CO_2)$					
Phase I	0.00 (0.03)	0.02 (0.02)	0.03 (0.03)	452	27,710
Phase II	-0.28** (0.05)	-0.25** (0.03)	-0.26** (0.03)	408	23,908
B. CO ₂ intensity of gross output: $\Delta \ln(\frac{CO_2}{GO})$					
Phase I	0.04 (0.05)	0.03 (0.03)	0.05* (0.03)	451	27,637
Phase II	-0.18** (0.05)	-0.20** (0.04)	-0.30** (0.03)	412	23,742

Notes: NN(1:1) and NN(1:20) denote nearest neighbor matching with one and 20 neighbors, respectively. OLS w/R denotes the reweighted OLS estimator. Standard errors in parenthesis. *** p<0.01, ** p<0.05, * p<0.1. Source: Research Data Centres of the Federal Statistical Office and the Statistical Offices of the Länder (2012): AFiD-Panel Industriebetriebe, 1998-2010, own calculations.

Impact on Performance

	(1)	(2)	(3)	(4)	(5)
	Estimation Algorithm			Number of	
	NN (1:1)	NN (1:20)	OLS w/R	Treated	Controls
A. Employees ($\Delta \ln L$)					
Phase I	0.00 (0.02)	-0.02 (0.01)	-0.02 (0.01)	454	28,396
Phase II	0.03 (0.02)	0.01 (0.01)	0.01 (0.01)	433	24,237
B. Gross output ($\Delta \ln GO$)					
Phase I	0.01 (0.03)	0.01 (0.02)	0.01 (0.02)	449	28,465
Phase II	0.07*** (0.03)	0.05*** (0.02)	0.04** (0.02)	430	24,240
C. Exports: $\Delta \ln(X)$					
Phase I	0.06 (0.06)	0.10** (0.04)	0.11*** (0.04)	371	17,864
Phase II	0.18*** (0.06)	0.09** (0.04)	0.07* (0.04)	348	15,463

Notes: NN(1:1) and NN(1:20) denote nearest neighbor matching with one and 20 neighbors, respectively. OLS w/R denotes the reweighted OLS estimator. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Source: Research Data Centres of the Federal Statistical Office and the Statistical Offices of the Länder (2012): AFiD-Panel Industriebetriebe, 1998-2010, own calculations.

Pre-treatment Effects 2000-04

	(1)	(2)	(3)	(4)	(5)
	Estimation Algorithm			Number of	
	NN (1:1)	NN (1:20)	OLS w/R	Treated	Controls
CO ₂ emissions: $\Delta \ln(CO_2)$					
	-0.08	-0.09**	-0.09**	356	12,778
	(0.07)	(0.03)	(0.03)		
CO ₂ intensity: $\Delta \ln(CO_2/GO)$					
	-0.17*	-0.10**	-0.09**	357	12,784
	(0.1)	(0.03)	(0.03)		

Notes: NN(1:1) and NN(1:20) denote nearest neighbor matching with one and 20 neighbors, respectively. OLS w/R denotes the reweighted OLS estimator. Standard errors in parenthesis. *** p<0.01, ** p<0.05, * p<0.1. Source: Research Data Centres of the Federal Statistical Office and the Statistical Offices of the Länder (2012): AFiD-Panel Industriebetriebe, 1998-2010, own calculations.

Table 6: Impact on fuel use

	(1)	(2)	(3)	(4)	(5)
	Estimation Algorithm			Number of	
	NN (1:1)	NN (1:20)	OLS w/R	Treated	Controls
A. Electricity consumption: $\Delta \ln(ELEC)$					
Phase I	0.01 (0.03)	0.03 (0.02)	0.02 (0.03)	453	27,699
Phase II	-0.04 (0.03)	-0.03 (0.02)	-0.04** (0.02)	428	23,867
B. Consumption of all non-electricity fuels: $\Delta \ln(EPRIMARY)$					
Phase I	0.16*** (0.05)	0.13*** (0.04)	0.11*** (0.03)	435	24,601
Phase II	-0.81** (0.15)	-0.83** (0.11)	-0.87** (0.1)	376	21,331
C. Consumption of natural gas: $\Delta \ln(GAS)$					
Phase I	0.01 (0.07)	0.10** (0.04)	0.11** (0.04)	412	16,817
Phase II	-0.21** (0.11)	-0.32** (0.08)	-0.33** (0.07)	217	10,506
D. Consumption of petroleum products: $\Delta \ln(OIL)$					
Phase I	-0.05 (0.12)	-0.02 (0.08)	-0.15** (0.07)	232	8,857
Phase II	-0.56** (0.17)	-0.45** (0.11)	-0.48** (0.13)	163	7,815

Table 7: Impact on fuel shares in total energy use

	(1)	(2)	(3)	(4)	(5)
	Estimation Algorithm			Number of	
	NN (1:1)	NN (1:20)	OLS w/R	Treated	Controls
A. Electricity share: $\Delta \ln(ELEC/ENERGY)$					
Phase I	-0.01 (0.03)	-0.02 (0.02)	-0.04* (0.02)	441	27,716
Phase II	0.26*** (0.06)	0.27*** (0.04)	0.28*** (0.03)	378	23,863
B. Share of non-electricity fuels: $\Delta \ln(EPRIMARY/ENERGY)$					
Phase I	0.07** (0.03)	0.08*** (0.02)	0.08*** (0.02)	443	24,586
Phase II	-0.40** (0.10)	-0.42** (0.08)	-0.47** (0.07)	380	21,320
C. Share of natural gas: $\Delta \ln(GAS/ENERGY)$					
Phase I	0.13*** (0.05)	0.12*** (0.03)	0.11*** (0.04)	414	16,810
Phase II	0.02 (0.09)	-0.14** (0.06)	-0.19** (0.05)	220	10,509
D. Share of petroleum products: $\Delta \ln(OIL/ENERGY)$					
Phase I	-0.18* (0.10)	-0.08 (0.08)	-0.21** (0.07)	230	9,156
Phase II	0.06 (0.16)	0.18 (0.12)	0.12 (0.15)	167	7,842

Interview summary statistics

Table B.1: Interview response rates by country

Variable	Germany	All countries
Number of firms interviewed	138	761
- of which in EU ETS	95	429
- of which not in EU ETS	43	332
Number of firms contacted	337	1451
Number of firms refused	199	691
Response rate	41%	52%

Table B.2: Firm characteristics by ETS participation status

	ETS Firms			non ETS Firms		
	Mean	Std. Dev.	Obs.	Mean	Std. Dev.	Obs.
Firm						
Age (years)	47	48	89	49	80	42
Turnover (EUR million)	1,028.15	2,319.12	74	505.81	2,226.71	32
Number of employees	1,749	4,404	85	609	1,477	38
EBIT (EUR million)	35.96	139.97	65	1.82	17.06	18
Number of shareholders	3	6	95	2	1	43
Number of subsidiaries	11	62	95	2	5	43
Firm's Global Ultimate Owner						
Turnover (USD million)	13,844	17,470	25	11,996	20,955	9
Number of employees	24,083	32,157	25	49,104	73,834	8

Notes: Based on 2007 data. None of the respective means for ETS and non ETS firms are significantly different at the 10% level or better. Source: ORBIS database (Bureau van Dijk), own elaboration.

Table C.1: Propensity score estimation by stratum

	(1)	(2)	(3)	(4)
	Phase I		Phase II	
	Process-regulated sectors	Other sectors	Process-regulated sectors	Other sectors
CO ₂ emissions	43*** (5)	45*** (6)	56*** (6)	48*** (7)
Employees	699 (1731)	4567*** (891)	3058*** (1372)	3922*** (559)
Gross output	7.0 (7.0)	-2.0 (4.0)	-6.0** (3.0)	0.3 (2.0)
Average wage rate	1045*** (221)	1170*** (216)	903*** (249)	1110*** (230)
Export share of output	1.94*** (0.52)	1.03** (0.48)	2.15*** (0.57)	1.31** (0.52)
(CO ₂ emissions) ²	-0.004*** (0.001)	-0.020*** (0.003)	-0.006*** (0.001)	-0.010*** (0.002)
(Employees) ²	-266*** (84)	-72* (37)	-314*** (84)	-45*** (9)
(Gross output) ²	-0.0004 -0.0003	0.0005 -0.0006	0.0001 -0.0001	0.0001 -0.0001
(Average wage rate ²)	-9*** (3)	-10*** (3)	-7** (3)	-9*** (3)
(Export share of output) ²	-1.39* (0.72)	-0.92 (0.58)	-1.61** (0.8)	-1.01 (0.62)
Sector fixed effects	yes	yes	yes	yes
Region fixed effects	yes	yes	yes	yes
<i>N</i>	2,893	25,269	2,499	21,817

Note: All covariates in 2003 logs. Parameters for CO₂ emissions, employees, gross output, and the average wage rate are in 10 million, parameters for the corresponding squared terms are in 10 billion. Standard errors in parenthesis. *** p<0.01, ** p<0.05, * p<0.1. Source: Research Data Centres of the Federal Statistical Office and the Statistical Offices of the Länder (2012): AFiD-Panel Industriebetriebe, 1998-2010, own calculations.

Standardized bias and pseudo R2 over both strata.

	(1)	(2)	(3)	(4)
	2005-2007		2008-2010	
	NN (1:1)	NN (1:20)	NN (1:1)	NN (1:20)
CO2 emissions from energy	19.5***	19.5***	10.9	21.4***
Employees	14.7**	18.6***	19.7***	18.4**
Gross output	17**	19.9***	19.9***	18.9***
Average wage rate	-11.7*	x	-9.6	-9.5
Export share of output	x	x	10.9	x
CO2 emissions from energy ²	15.8**	15.6**	13.6*	15.7**
Employees ²	14**	14.8**	15.3**	15.1**
Gross output ²	14.7**	15.1**	15.5**	15.3**
Average wage rate ²	-12*	x	-8.2	-9.7
Export share of output ²	7.9	x	13.1*	5.8
Sector fixed effects (2-digit)	yes	yes	yes	yes
Region fixed effects	yes	yes	yes	yes
Pseudo-R2	0.024***	0.023***	0.027***	0.024***
N	28 162	28 162	24 316	24 316

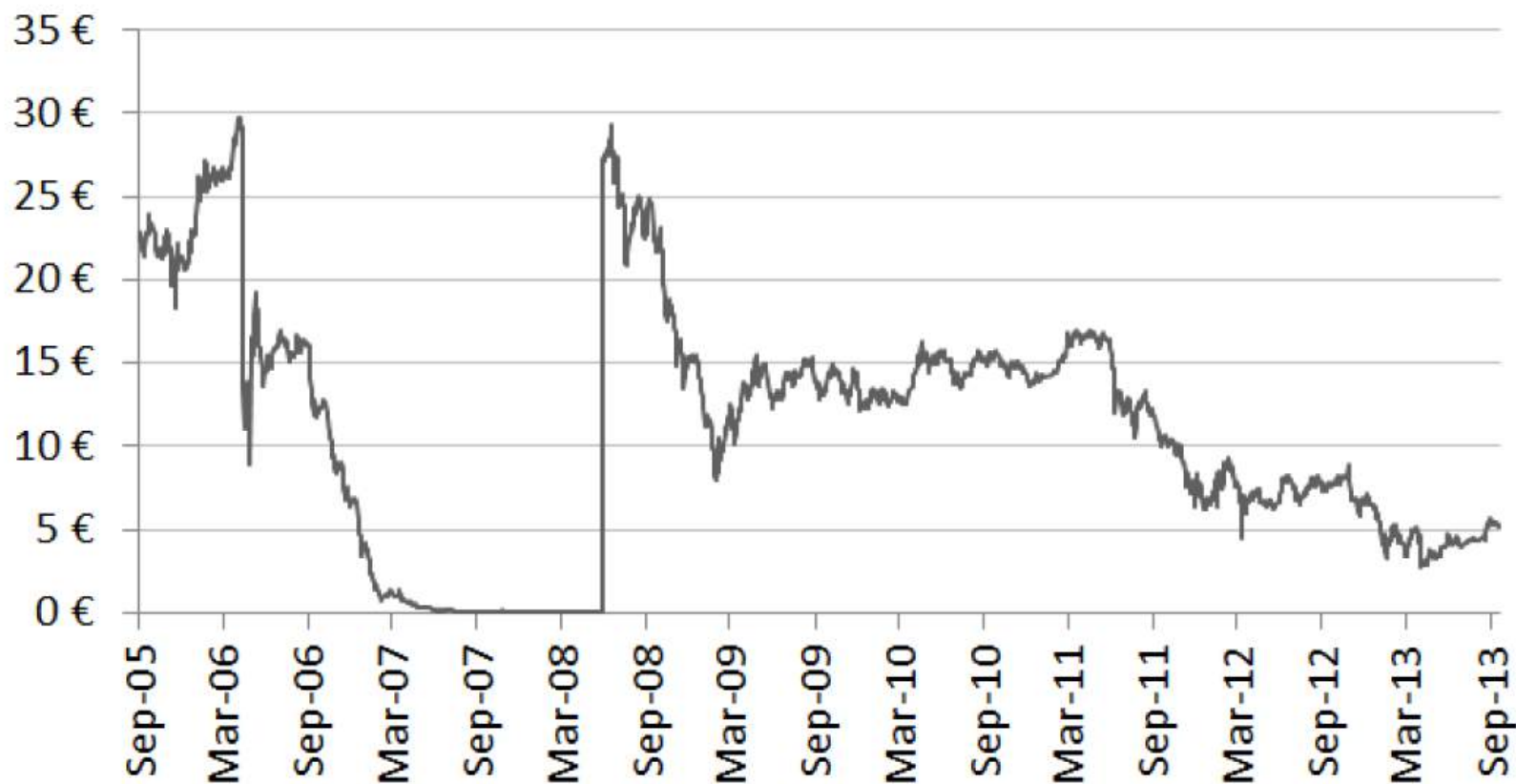
Note: Balancing is better for smaller standardized bias and smaller pseudo-R2. Sample based on matching with outcome variable CO2 emissions. "x": |Standardized bias| < 5 or p > 0.8, exact values have not been cleared by the research data center for privacy protection. *** p < 0.01, ** p < 0.05, * p < 0.1. Source: Research Data Centres of the Federal Statistical Office and the Statistical Offices of the Länder (2012): AFiD-Panel Industriebetriebe, 2005-2010, own calculations.

Differential impact of pre-treatment fluctuations

	(1)	(2)	(3)	(4)	(5)
	Estimation Algorithm			Number of	
	NN (1:1)	NN (1:20)	OLS w/R	Treated	Controls
A. Gross output: $\Delta \ln(GO)$					
2001-2002	-0.03 (0.04)	-0.01 (0.01)	0.00 (0.01)	371	15,362
2001-2004	0.03 (0.06)	0.03 (0.02)	0.02 (0.02)	352	13,126
B. Employment: $\Delta \ln(L)$					
2001-2002	-0.01 (0.03)	0.00 (0.01)	0.00 (0.01)	372	15,367
2001-2004	0.01 (0.04)	-0.01 (0.01)	-0.01 (0.01)	352	13,129

Notes: Matching covariates are from 1999. Number of firms is for nearest neighbor matching. Double-robust reweighting covers more firms because control firms outside the region of common support are included as well. Standard errors in parenthesis. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Source: Research Data Centres of the Federal Statistical Office and the Statistical Offices of the Länder (2012): AFiD-Panel Industriebetriebe, 1999-2010, own calculations.

EU Allowance Price Over Time



Notes: The figure plots historic spot market prices of EU Allowances (EUAs).

Source: Point Carbon (2005-2014), own representation.

CO2 impact by stratum

	(1)	(2)	(3)	(4)	(5)
	Estimation Algorithm			Number of	
	NN (1:1)	NN (1:20)	OLS w/R	Treated	Controls
A. CO ₂ emissions from process-regulated sectors: $\Delta \ln(CO_2)$					
Phase I	0.08* (0.04)	0.05 (0.03)	0.07** (0.03)	264	2,629
Phase II	-0.33** (0.06)	-0.27** (0.05)	-0.28** (0.04)	237	2,262
B. CO ₂ emissions from other sectors: $\Delta \ln(CO_2)$					
Phase I	-0.10* (0.05)	0.00 (0.03)	-0.08** (0.04)	188	25,081
Phase II	-0.22** (0.07)	-0.21** (0.04)	-0.20** (0.04)	171	21,646
C. CO ₂ intensity of output from process-regulated sectors: $\ln(CO_2/GO)$					
Phase I	0.04 (0.04)	0.03 (0.03)	0.03 (0.02)	265	2,627
Phase II	-0.36** (0.06)	-0.34** (0.05)	-0.34** (0.04)	242	2,265
D. CO ₂ intensity of output from other sectors: $\ln(CO_2/GO)$					
Phase I	-0.04 (0.06)	0.00 (0.04)	0.03 (0.04)	187	25,105
Phase II	-0.23** (0.07)	-0.21** (0.05)	-0.25** (0.06)	171	21,642

Impact on export share in gross output

	(1)	(2)	(3)	(4)	(5)
	Estimation Algorithm			Number of	
	NN (1:1)	NN (1:20)	OLS w/R	Treated	Controls
A. Matching based on covariates in 2003 (baseline specification)					
Phase I	0.05 (0.05)	0.06 (0.04)	0.07** (0.03)	378	18,184
Phase II	0.05 (0.06)	0.06 (0.04)	0.03 (0.04)	371	16,635
B. Matching based on covariates in 1999					
Phase I	0.10* (0.06)	0.07 (0.04)	0.11*** (0.04)	321	14,652
Phase II	0.03 (0.07)	0.05 (0.04)	0.01 (0.03)	321	13,670
C. Coarse matching on CO_2/L in 2003					
Phase I	0.01 (0.06)	0.05 (0.04)	0.02 (0.03)	x	x
Phase II	0.12* (0.06)	0.07* (0.04)	0.05 (0.03)	367	9,924

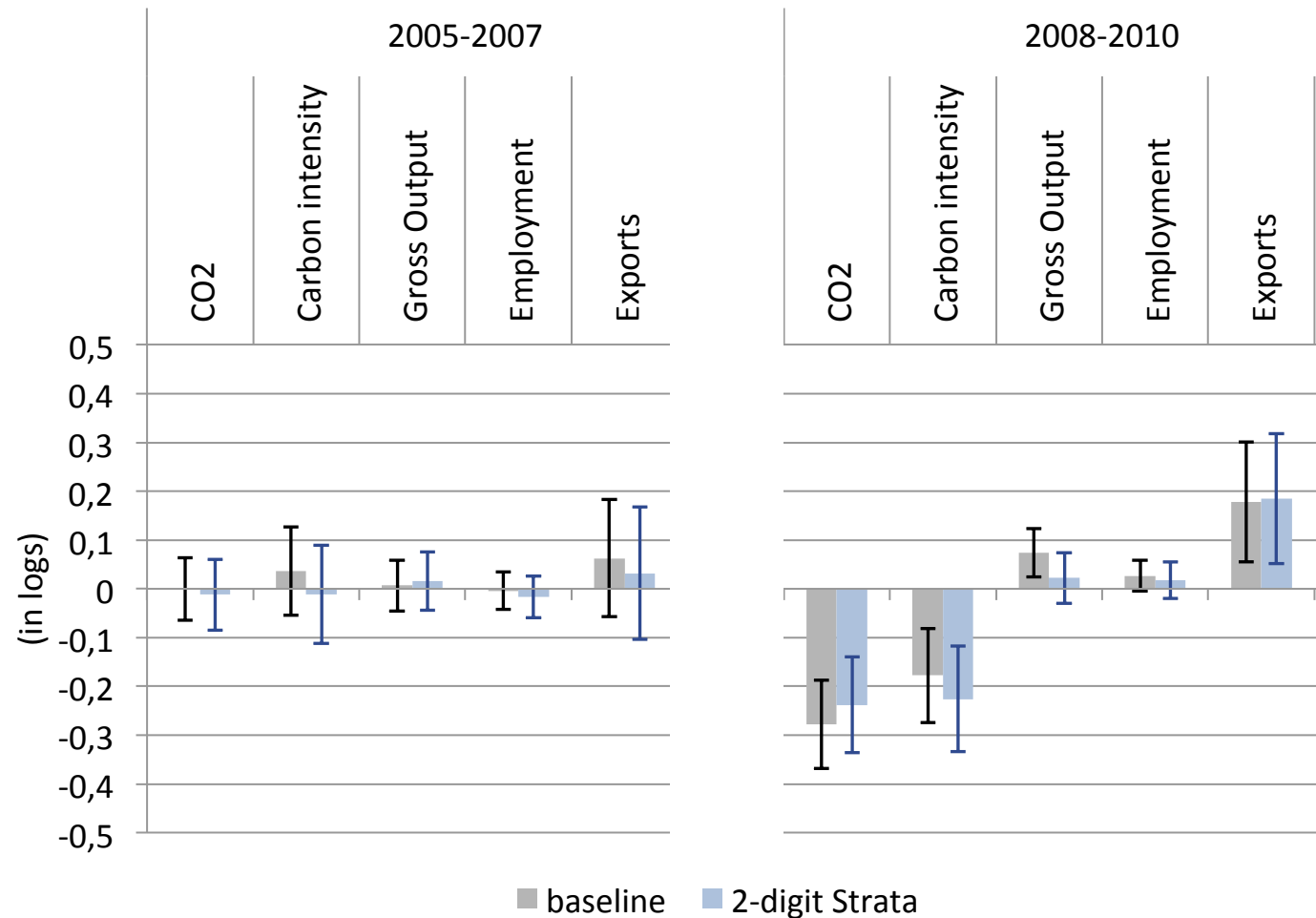
Table C.4: Coarse matching on $\frac{CO_2}{L}$ and 2-digit sector. Base year 2003

	(1)	(2)	(3)	(4)	(5)
	Estimation Algorithm			Number of	
	NN (1:1)	NN (1:20)	OLS w/R	Treated	Controls
A. CO ₂ emissions: $\Delta \ln(CO_2)$					
Phase I	0.00 (0.03)	-0.01 (0.02)	0.01 (0.02)	444	16,144
Phase II	-0.23** (0.04)	-0.22** (0.03)	-0.33** (0.03)	405	13,978
B. CO ₂ intensity of gross output: $\Delta \ln(CO_2/GO)$					
Phase I	0.03 (0.04)	0.03 (0.03)	0.03 (0.02)	444	16,166
Phase II	-0.23** (0.05)	-0.25** (0.03)	-0.35** (0.03)	410	14,133
C. Employment: $\Delta \ln(L)$					
Phase I	-0.02 (0.02)	-0.03** (0.01)	-0.05** (0.01)	450	16,271
Phase II	0.00 (0.02)	0.00 (0.01)	-0.01 (0.01)	430	14,393
D. Gross output: $\Delta \ln(GO)$					
Phase I	-0.03 (0.03)	-0.02 (0.02)	-0.01 (0.01)	446	16,300
Phase II	0.04* (0.02)	0.03* (0.02)	0.03** (0.01)	427	14,413
E. Exports: $\Delta \ln(X)$					
Phase I	0.09 (0.07)	0.06 (0.05)	0.05 (0.04)	x	x
Phase II	0.23*** (0.07)	0.14*** (0.05)	0.08** (0.04)	365	9,914

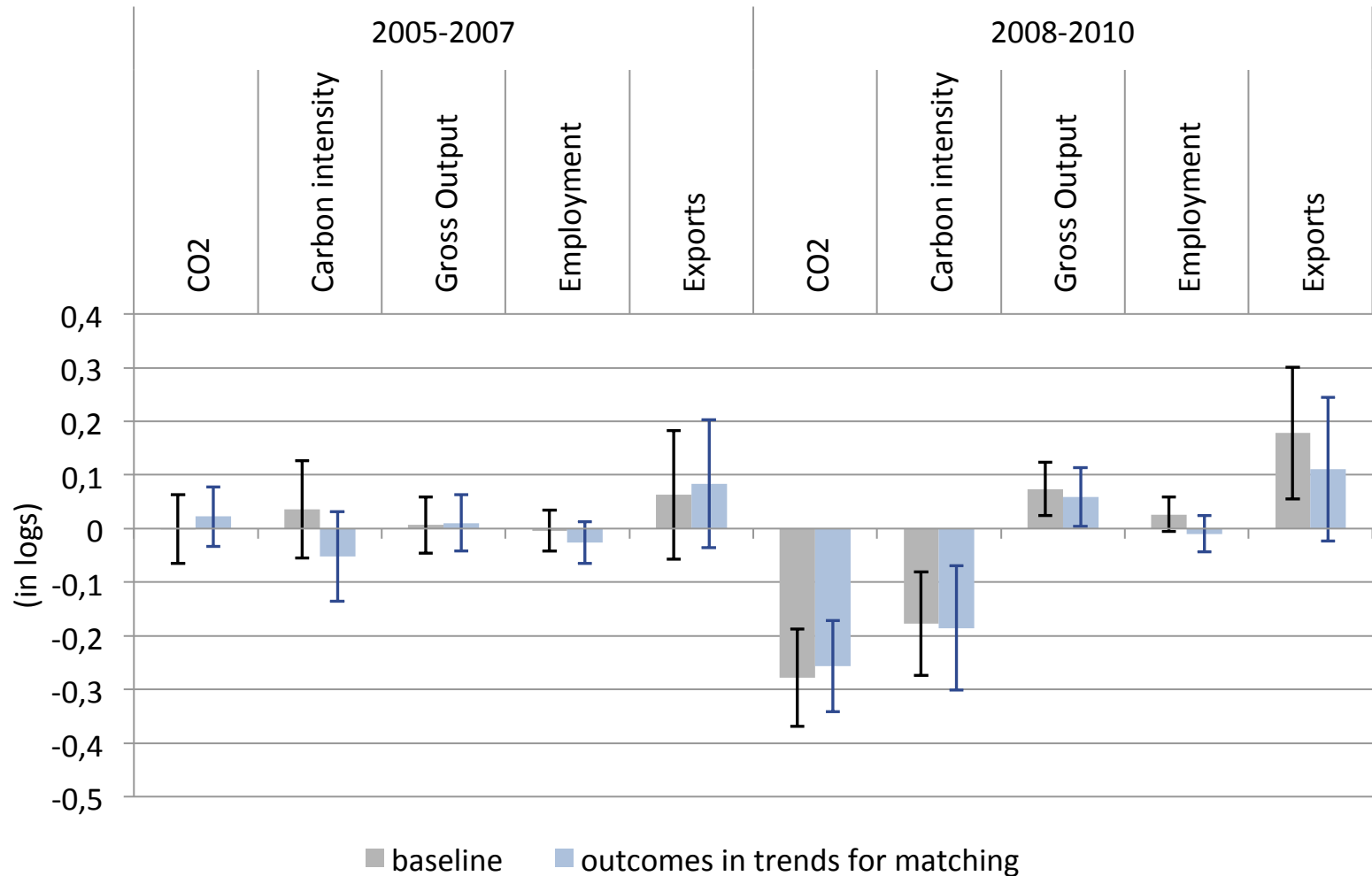
Table C.3: Baseline specification with matching on 1999 covariates

	(1)	(2)	(3)	(4)	(5)
	Estimation Algorithm			Number of	
	NN (1:1)	NN (1:20)	OLS w/R	Treated	Controls
A. CO ₂ emissions: $\Delta \ln(CO_2)$					
Phase I	0.00 (0.04)	0.01 (0.02)	0.08*** (0.03)	379	21,418
Phase II	-0.21** (0.05)	-0.22** (0.04)	-0.27** (0.04)	351	19,071
B. CO ₂ intensity of gross output: $\Delta \ln(CO_2/GO)$					
Phase I	-0.03 (0.04)	-0.01 (0.03)	0.06* (0.04)	379	21,436
Phase II	-0.30** (0.05)	-0.26** (0.04)	-0.33** (0.04)	354	19,088
C. Employment: $\Delta \ln(L)$					
Phase I	0.02 (0.02)	0.00 (0.01)	0.03** (0.01)	381	22,173
Phase II	0.02 (0.02)	0.02 (0.01)	0.01 (0.01)	371	19,368
D. Gross output: $\Delta \ln(GO)$					
Phase I	0.06** (0.03)	0.04* (0.02)	0.07*** (0.02)	376	22,163
Phase II	0.07** (0.03)	0.05** (0.02)	0.05*** (0.02)	369	19,328
E. Exports: $\Delta \ln(X)$					
Phase I	0.20*** (0.07)	0.15*** (0.05)	0.20*** (0.05)	320	14,654
Phase II	0.11* (0.07)	0.11** (0.05)	0.06* (0.04)	319	13,675

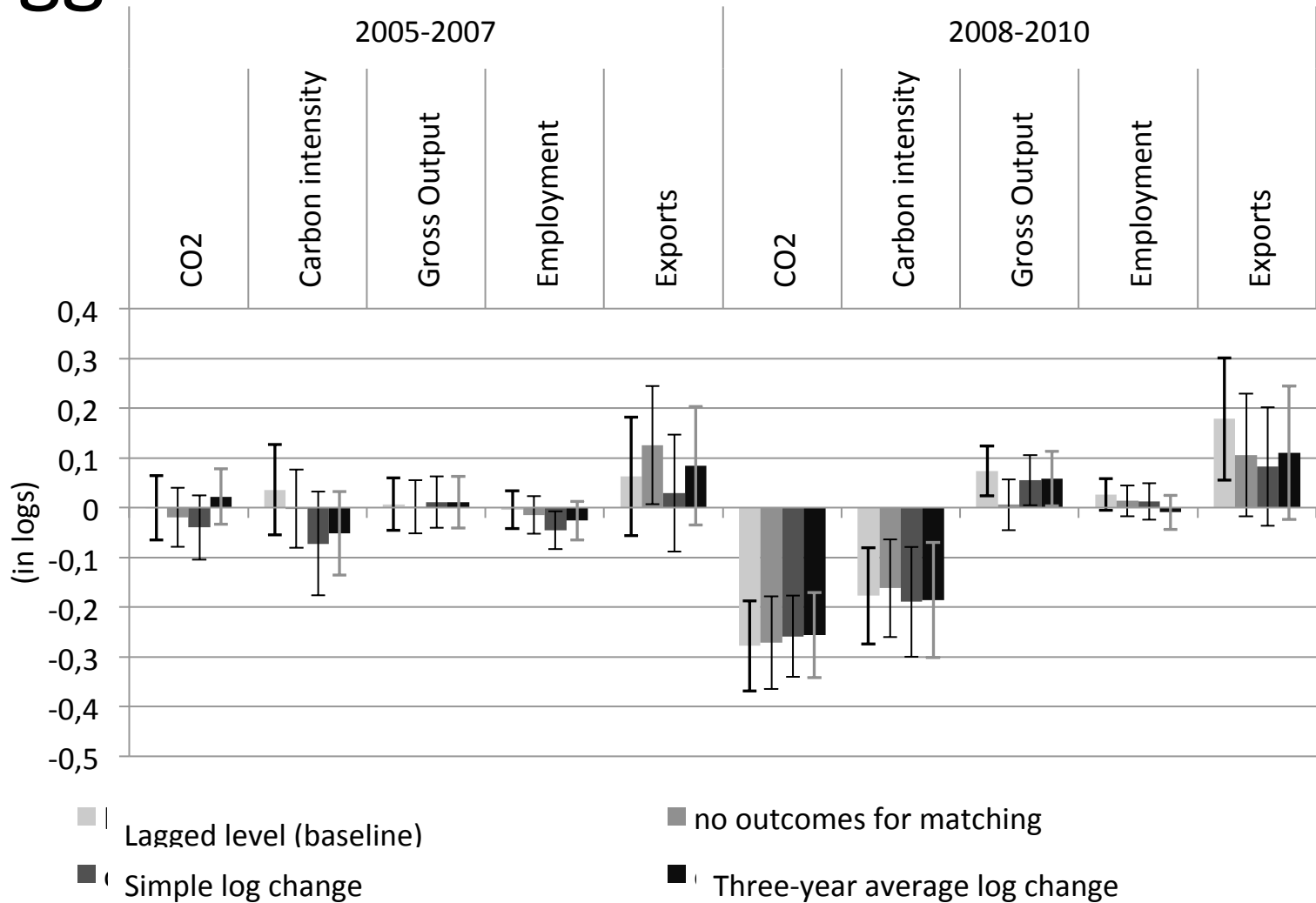
Exact match on 2-digit sectors



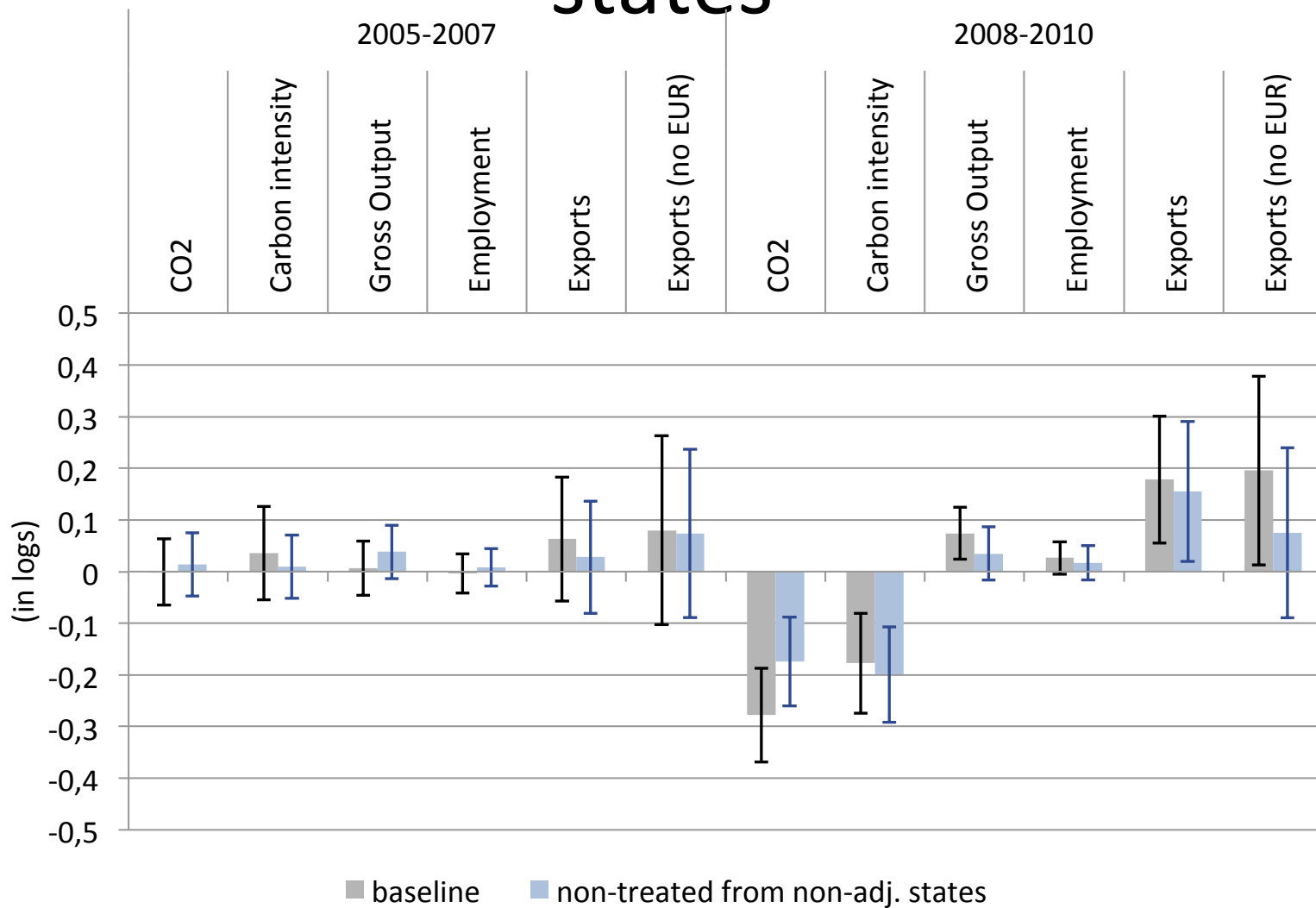
Matching on pre-treatment changes rather than levels



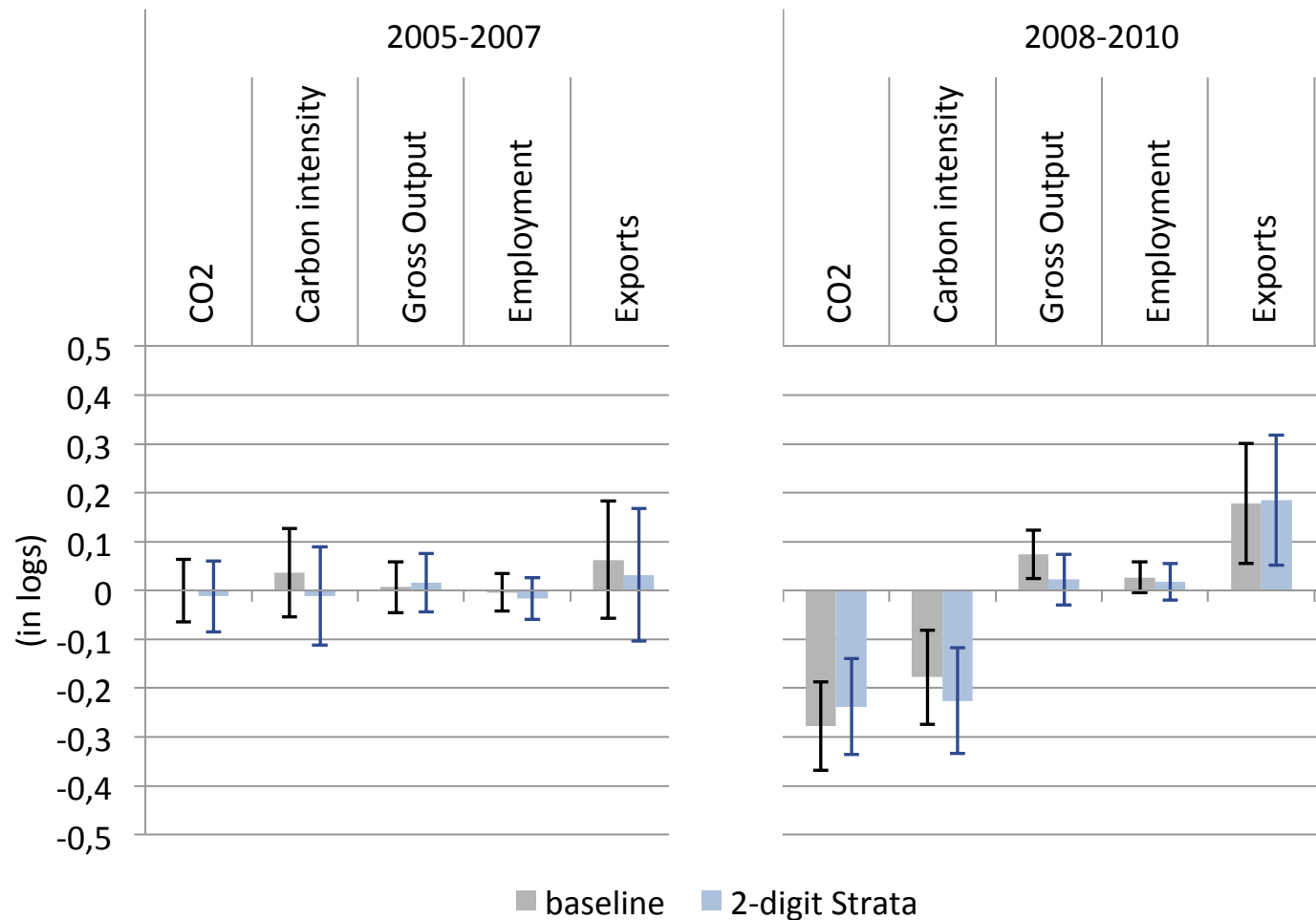
Changing transformations of the lagged outcome variable for matching



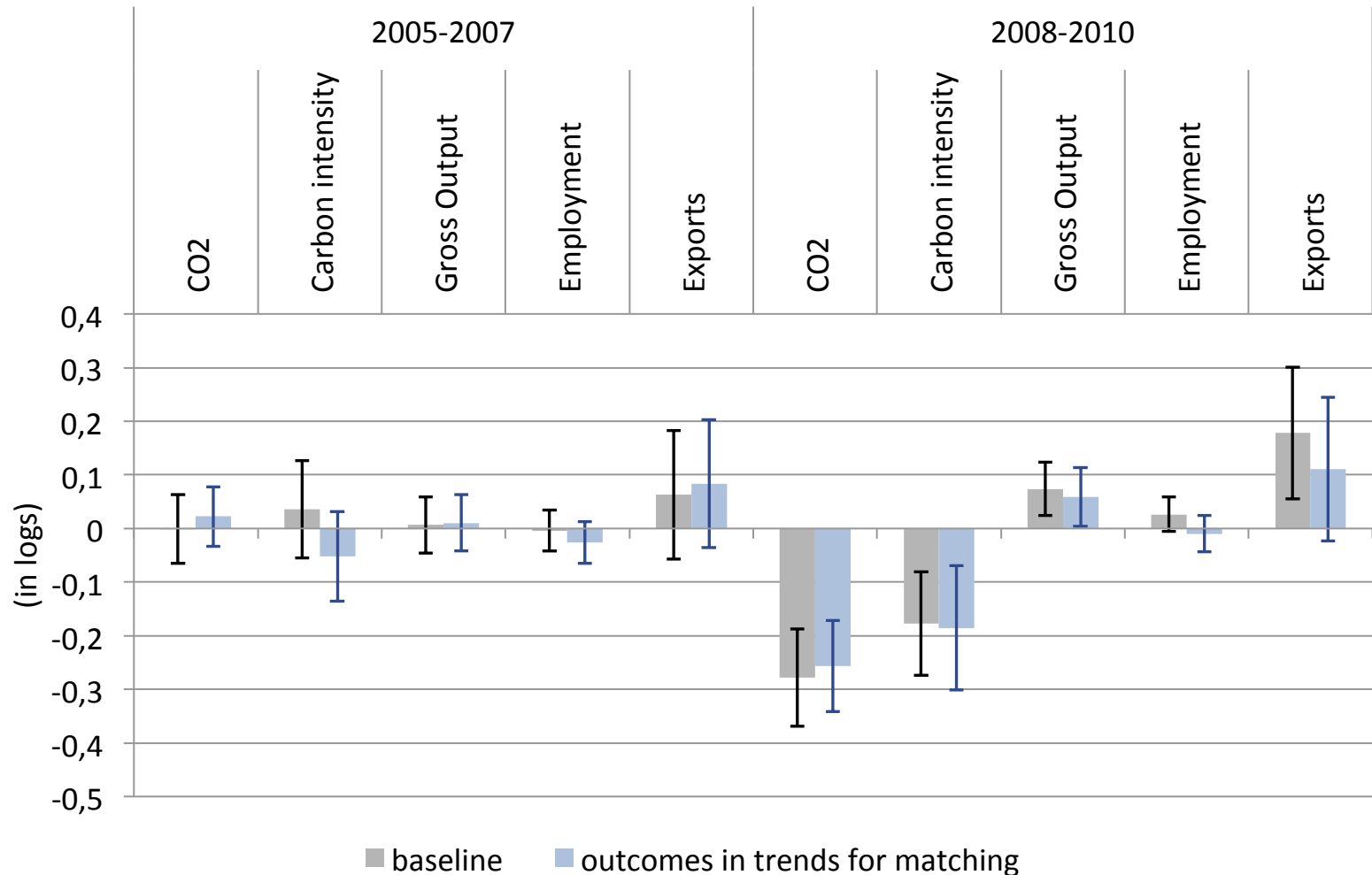
Stable Unit Treatment Value Violated: Controls only from non-adjacent states



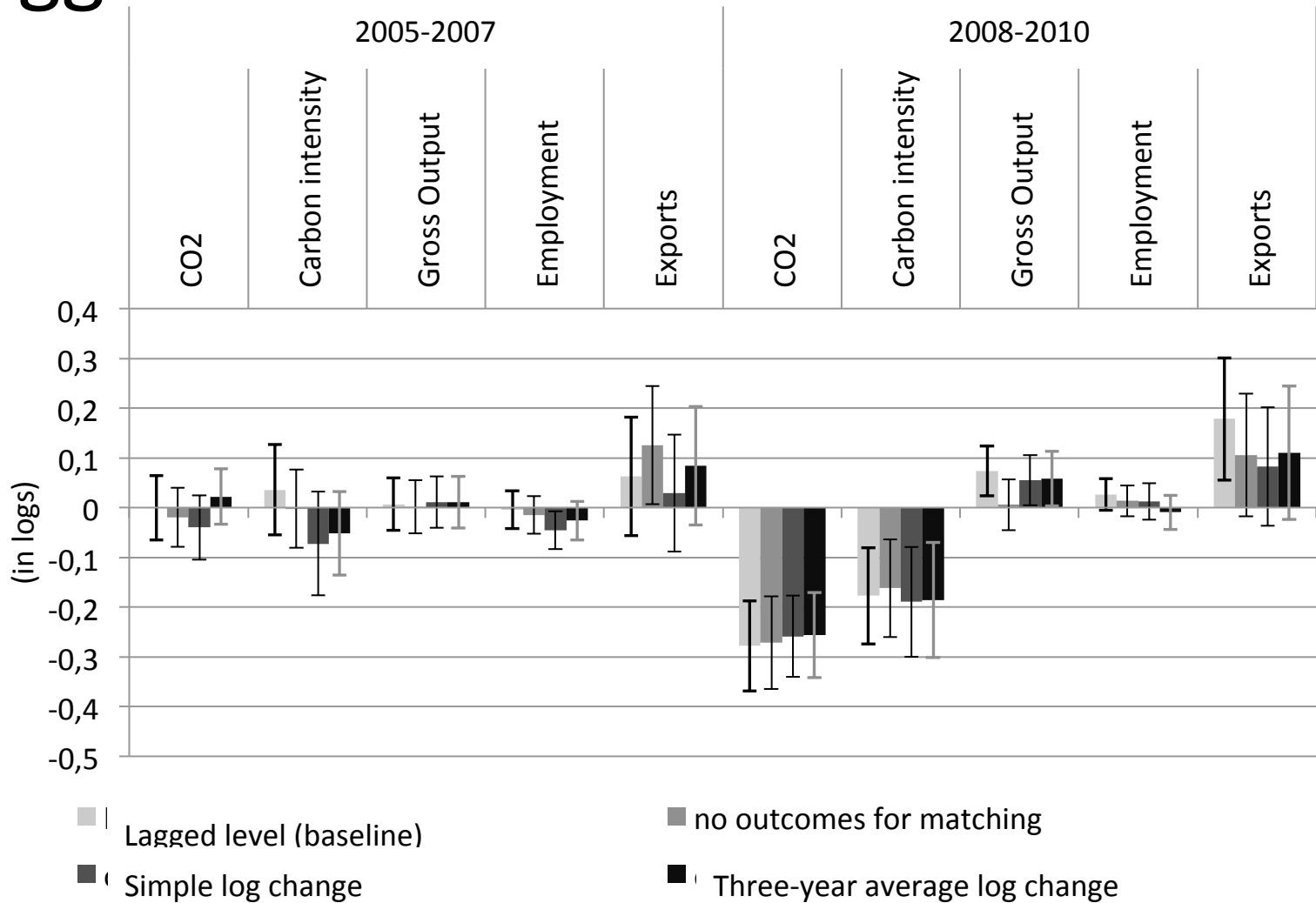
Exact match on 2-digit sectors



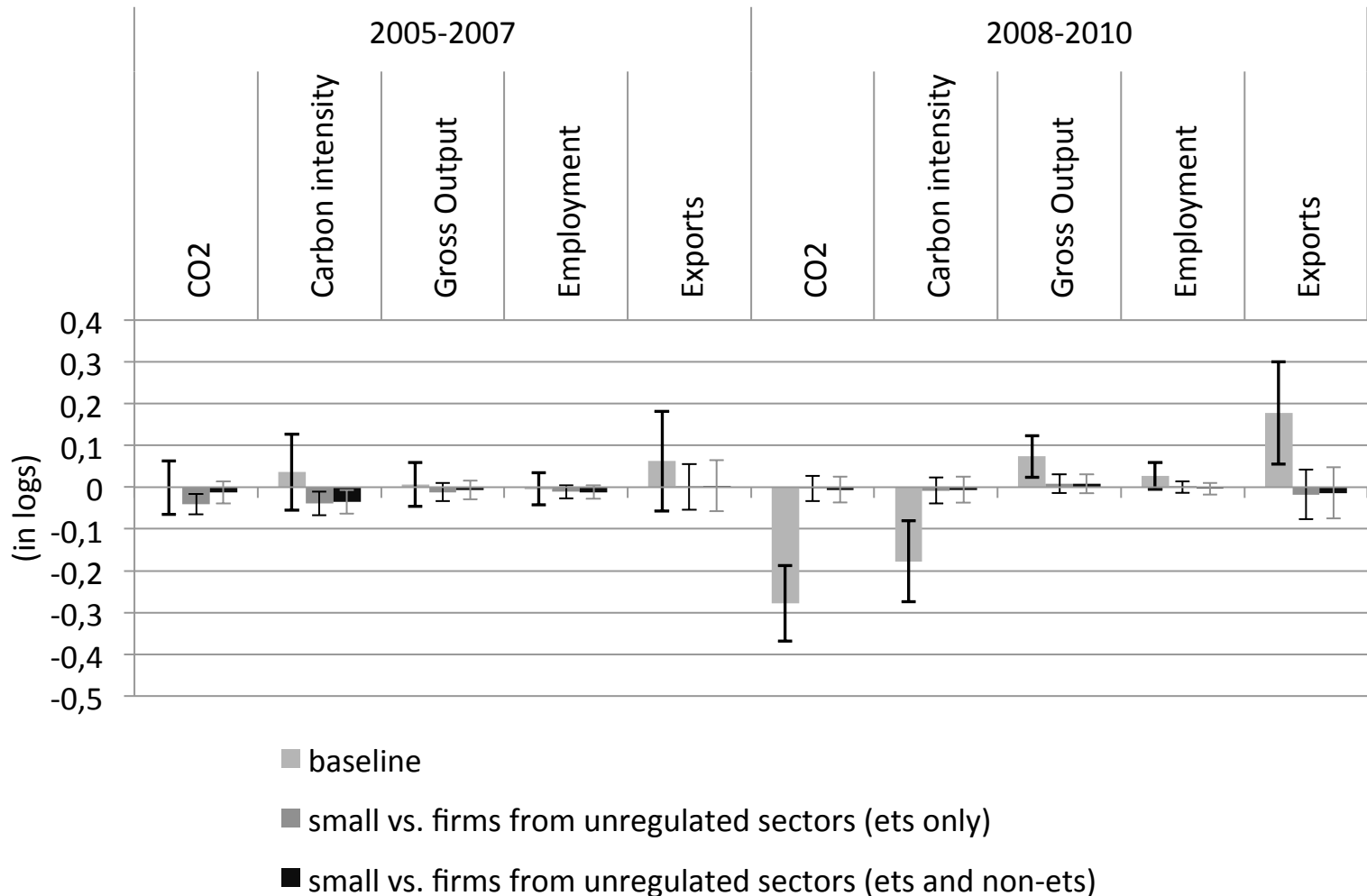
Matching on pre-treatment changes rather than levels



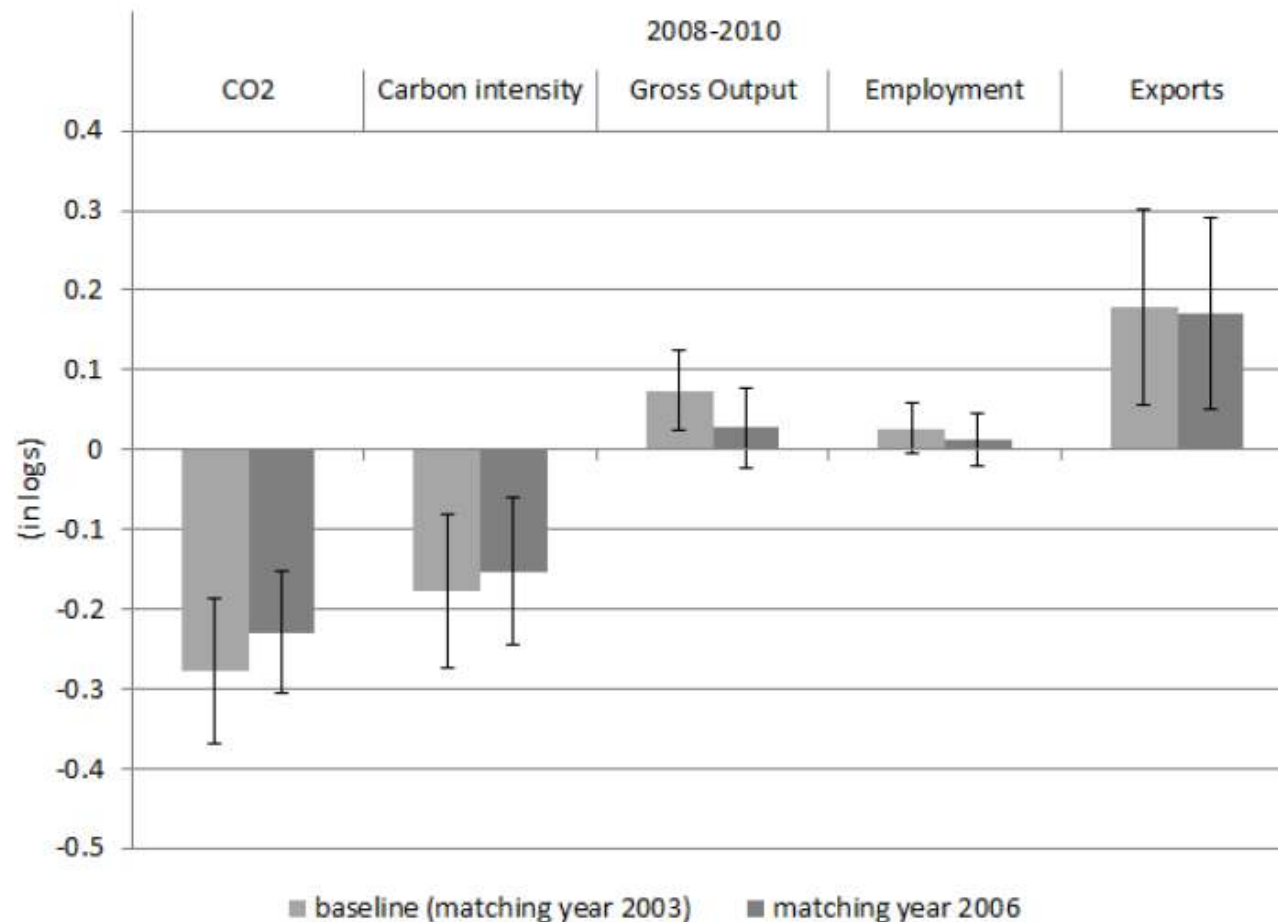
Changing transformations of the lagged outcome variable for matching



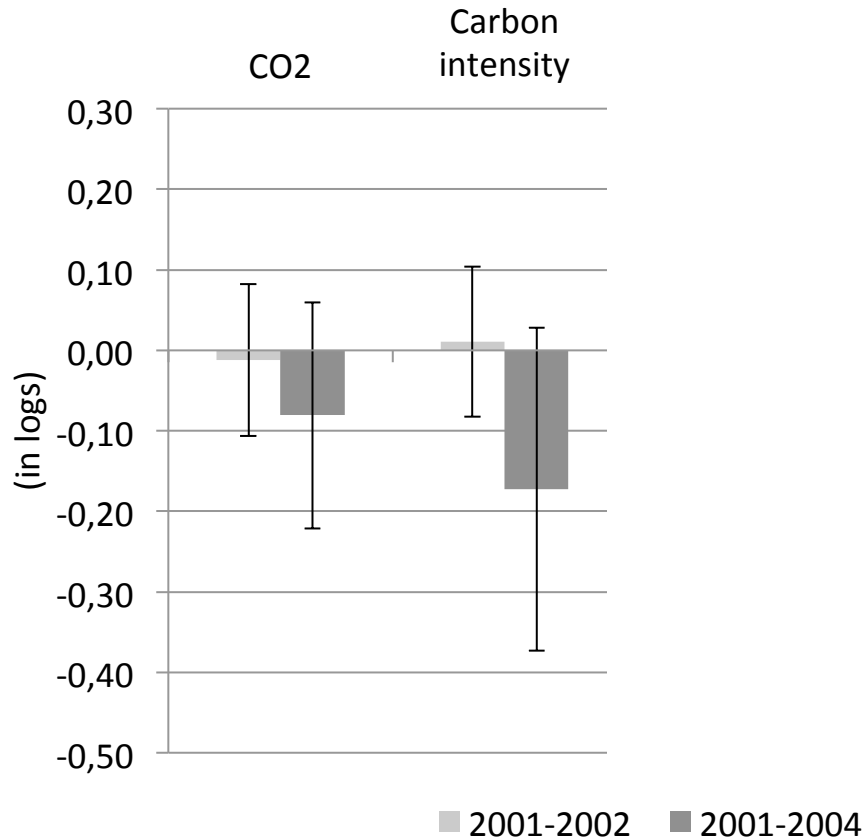
Placebo estimate for controls



Estimate impact of the great recession by group (match on 2006 covariates)

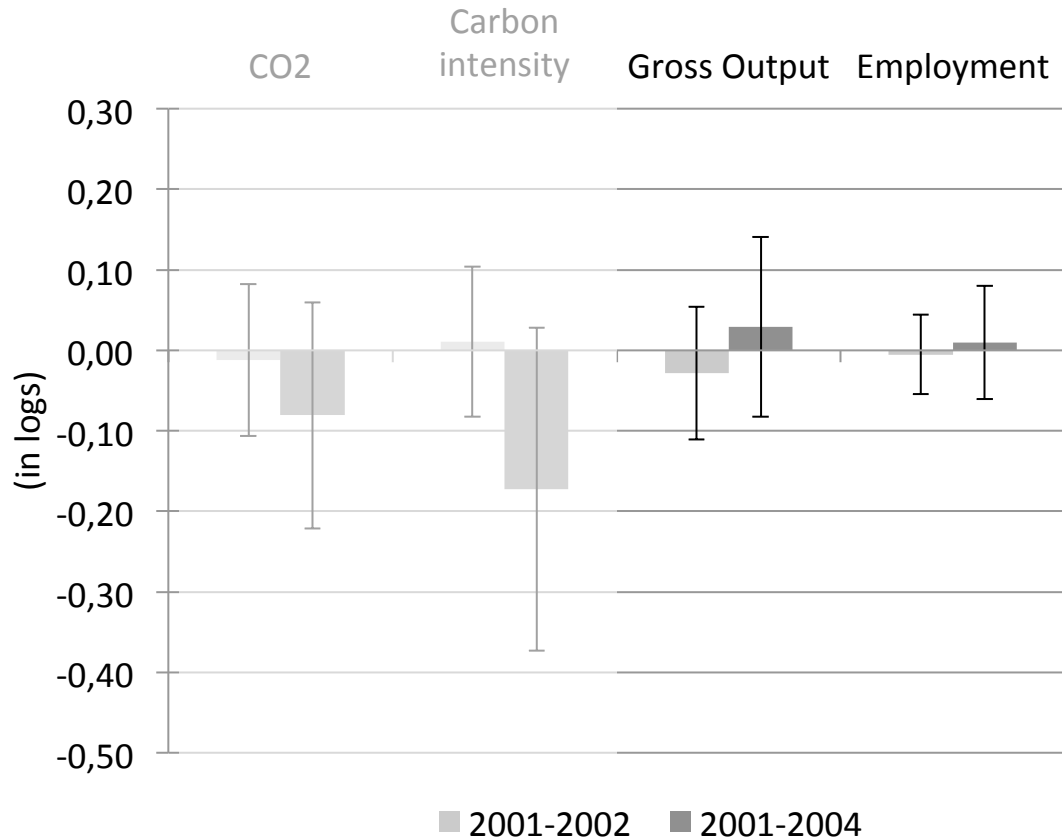


Announcement Effect?



Not precisely estimated. If negative announcement effect is taken at face value, baseline estimates are biased towards 0 (i.e. true effect even larger).

Potential Confounder Recession: No impact of pre-treatment fluctuations



An *ex ante* assessment of the impact of carbon trading

*The current proposal
about Carbon Dioxide
emissions would **damage
Germany's
competitiveness** in an
unacceptable way and is
not practicable.*

Gerhard Schröder,
as German Chancellor, June 2002

