**CHARLES UNIVERSITY**
FACULTY OF SOCIAL SCIENCES
Institute of Economic Studies

# The impact of the EU ETS in the Czech Republic

Master's thesis

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Year of defense: 2021

# Declaration of Authorship

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Prague, July 27, 2021

Lenka Tomaskova

# Abstract

This thesis examines the environmental effect of the European Union Emissions Trading Scheme (EU ETS) in the Czech Republic. Specifically, the impact of the EU ETS on $CO_2$ emissions, carbon-fuel intensity and carbon intensity of production (measured by revenues) is analysed on installation-level financial, environmental and energy data throughout all three phases of the EU ETS over 2005 - 2019. The difference-in-differences approach with propensity score matching is used to infer the causal effect of the regulation. We find no effect of the EU ETS on carbon emissions and carbon intensities in the Czech Republic. This finding holds for various model specifications and different approaches we utilised. In the end, we discuss possible reasons why the EU ETS might not lead to any significant effect in the Czech Republic.

**JEL Classification** O13, F18, Q54, Q58, H23, D22
**Keywords** EU ETS, environmental regulation, propensity score matching, difference-in-differences, the Czech Republic
**Title** The impact of the EU ETS in the Czech Republic

# Abstrakt

Tato práce zkoumá environmentální efekt Evropského emisního obchodování (EU ETS) v České republice. Přesněji, vliv EU ETS na $CO_2$ emise, emisní náročnost užitých paliv a produkce (měřeno výnosy) je analyzován na mikro datech popisujících ekonomiku, emise a užití paliv jednotlivých provozoven zahrnující všechny tři fáze EU ETS v období 2005 - 2019. Metoda difference-in-differences s propensity score matching byla vybrána jako vhodný prostředek k analýze kauzálního efektu této regulace. Naše výsledky nepotvrzují žádný efekt EU ETS na emise uhlíku v České republice. Tento závěr platí pro různé specifikace modelu a volbu modelu. V závěru diskutujeme možné důvody, proč regulace EU ETS nemusela vést k žádnému signifikantnímu efektu v České republice.

| | |
|---|---|
| **Klasifikace JEL** | O13, F18, Q54, Q58, H23, D22 |
| **Klíčová slova** | EU ETS, environmentální regulace, propensity score matching, difference-in-differences, Česká republika |
| **Název práce** | Dopady EU ETS v České republice |

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# Acronyms

| | |
|---|---|
| **ATT** | Average Treatment Effect on Treated |
| **CDM** | Clean Development Mechanism |
| **CHMI** | Czech Hydrometeorological Institute |
| **DID** | Difference-in-Differences |
| **EU ETS** | European Union Emission Trading System |
| **EF** | Emission Factor |
| **ERU** | Emission Reduction Unit |
| **EUA** | European Union Allowances |
| **EUTL** | European Union Transaction Log |
| **GHG** | Greenhouse Gas |
| **IPTW** | Inverse Probability Treatment Weighting |
| **MSR** | Market Stability Reserve |
| **NAP** | National Allocation Plans |
| **PS** | Propensity Score |
| **REZZO** | Air Pollution Emission Source Register |

# Master's Thesis Proposal

| | |
|---|---|
| **Author** | Bc. Lenka Tomášková |
| **Supervisor** | Mgr. Milan Ščasný, Ph.D. |
| **Proposed topic** | The impact of the EU ETS in the Czech Republic |

**Motivation** The ongoing global warming, the major aspect of climate change, has been mainly caused by human influence, especially by emissions of greenhouse gases. The Kyoto Protocol (1997) commits parties to reduce emissions of six greenhouse gases which was complemented by Paris Agreement (2015) proposing revised key targets for 2030. The policy of Emission Trading System for European Union was launched to combat the climate change by setting a cap on the greenhouse gases emissions emitted by the regulated companies. Hence an ex-post analysis of the impact of the policy is crucial as the EU ETS is the major tool to meet the Kyoto target in the EU. The EU ETS has been implemented in 2005 and specific measures were adopted with increasing scope and stringency within four stages: the pilot phase 2005-2007, the second phase 2008-2012, the third phase 2013-2020, and the fourth phase 2021-2030 (European Commission 2019). Since the regulation applies also to the Czech Republic, the impact of EU ETS on the change of amount of firms' emissions will be studied.

Among multiple papers assessing the policy of EU ETS from numerous points of view, the effect on firm level data is studied in various countries during different phases of EU ETS. OECD Working Paper (Dechezleprêtre et al. 2018) evaluated the economic performance of regulated firms in all countries of the EU, but only four countries of EU were the subject of the analysis of emission reduction due to data availability. Analysing the installation-level data for the first two EU ETS periods (2005-2012), they found that while emissions were reduced by 10%, the economic performance of the regulated firms was in fact improved through increased revenues and fixed assets at the level of firms. Zachmann et al. (2011) also confirm by comparing the performance of regulated firms during the first and the second phase that the GHG emissions were reduced.

In the Czech Republic, other than solely environmental effects of EU ETS were studied. Tauchmannová (2017) analysed the scheme of EU ETS in her thesis, the behaviour of companies within the third period was examined by Zimmermannová (2015). Besides EU ETS, also the links between the environmental and financial performance of firms were assessed (Horváthová 2012, Earnhart et al. 2010). In this thesis, we aim at analysing the effect of the EU ETS on performance of the regulated firms in the Czech Republic, focusing on the effect on GHG emissions.

## Hypotheses

> Hypothesis #1a: The EU Emission Trading System led to emission reduction of the regulated firms in the Czech Republic.
>
> Hypothesis #1b: The effect of the EU ETS on GHG emissions stemming from the regulated firms vary for the three phases.
>
> Hypothesis #1c: The effect of the EU ETS on GHG emissions vary across the regulated sectors, while the largest effect was achieved in power sector and sectors with relatively less internationally traded goods.
>
> Hypothesis #2a: The EU ETS has reduced also other non-GHG emission.
>
> Hypothesis #2b: These ancillary benefits are significant, and their magnitude is comparable with other studies. In particular with the study by Ščasný et al. (2015) and Kiuila et al. (2019).

**Methodology** The first part of the thesis will review the existing literature that will cover i) the Czech literature, ii) empirical studies aiming at the environmental effect of the EU ETS, covering both top-down and bottom-up approaches, and iii) conceptual and stylised models to analyse this effect, relying on the firm-level data.

Econometric, panel level data analysis will follow to examine the effect of the EU ETS on GHG and other air quality pollutants emissions. Specifically, we will construct a panel from 2005 to 2019 for the firms operating in regulated sectors in the Czech Republic. To evaluate the effect of a policy intervention, we will not only need the treatment group comprised of the regulated firms by the EU ETS, but also a control group of firms unregulated by the EU ETS to be able to estimate the effect.

We will use propensity score matching to match a regulated and an unregulated firm together. It attempts to reduce the bias due to all observed covariates (Rosenbaum & Rubi 1983). And then difference-in-differences method will be applied to capture the effect.

Data concerning the emission production will be obtained from REZZO database, maintained by Czech Hydro-Meteorological Institute (already obtained by the supervisor). The data about economic performance of the firms is available in the MagnusWeb database.

**Expected Contribution** The thesis will extend the existing literature studying the impact of EU ETS on solely one country, in our case the Czech Republic. We will focus on capturing the effect on directly regulated pollutants, i.e. CO2 emissions, and not directly regulated ones, i.e. air quality pollutants. Furthermore, long panel data will allow us to analyse the environmental firm performance and to study the effect of EU ETS during long time period that will cover almost the whole three phases of the EU ETS scheme (due to COVID-19 the effect in 2020 cannot be analysed using the same model and specification anyway).

With the findings of the thesis, we will study how the policy of combating the climate change implemented in the form of the EU ETS has contributed to the emission reduction in the Czech Republic.

## Outline

1. Introduction
2. Literature Review & Theoretical Background
3. Data and Empirical model
4. Results
5. Discussion of Results and Conclusion

## Core bibliography

Abrell, Jan, Anta Ndoye Faye, and George Zachmann. Assessing the Impact of the EU ETS Using Firm Level Data, 15 July 2011.

Angrist, Joshua, and Jörn-Steffen Pischke. Mostly Harmless Econometrics: An Empiricist's Companion. In Mostly Harmless Econometrics: An Empiricist's Companion, 2008.

Chèze, Benoît, Julien Chevallier, Nicolas Berghmans, and Emilie Alberola. On the CO2 Emissions Determinants during the EU ETS Phases I and II: A Plant-Level Analysis Merging the EUTL and Platts Power Data, 1 January 2020.

Dechezleprêtre, Antoine, Daniel Nachtigall, and Frank Venmans. The Joint Impact of the European Union Emissions Trading System on Carbon Emissions and Economic Performance, 6 December 2018. https://doi.org/10.1787/4819b016-en.

Earnhart, Dietrich, and Lubomir Lizal. Effect of Corporate Economic Performance on Firm-Level Environmental Performance in a Transition Economy. Environmental and Resource Economics 46, no. 3 (1 July 2010): 303–29. https://doi.org/10.1007/s10640-009-9342-0.

European Commission. EU Climate Action and the European Green Deal. Climate Action, 23 October 2019. https://ec.europa.eu/clima/policies/eu-climate-action_en

Horváthová, Eva. The Impact of Environmental Performance on Firm Performance: Short-Term Costs and Long-Term Benefits? Ecological Economics, The Economics of Degrowth, 84 (1 December 2012): 91–97.

Jūratė Jaraitė, and Corrado Di Maria. Did the EU ETS Make a Difference? An Empirical Assessment Using Lithuanian Firm-Level Data. The Energy Journal 37, no. 1 (2016): 1.

Kiuila, Olga, Anil Markandya, and Milan Ščasný. "Taxing Air Pollutants and Carbon Individually or Jointly: Results from a CGE Model Enriched by an Emission Abatement Sector." Economic Systems Research 31, no. 1 (March 2019): 21.

Ščasný, M., Massetti, E., Melichar, J. et al. Quantifying the Ancillary Benefits of the Representative Concentration Pathways on Air Quality in Europe. Environ Resource Econ 62, 383–415 (2015). https://doi.org/10.1007/s10640-015-9969-y

Rosenbaum, Paul R., and Donald B. Rubin. The Central Role of the Propensity Score in Observational Studies for Causal Effects. Biometrika 70, no. 1 (1 April 1983): 41–55. https://doi.org/10.1093/biomet/70.1.41

Tauchmannová, Barbora. Evropský Systém Obchodování s Emisními Povolenkami (EU ETS), Jeho Fungování a Úspěšnost. Master Thesis, Charles University, 2017.

Zimmermannová, Jarmila. Pilot Analysis of the Behaviour of Companies Within the 3rd Trading Period of the EU ETS in the Czech Republic. Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis 63, no. 6 (26 December 2015): 2213–20. https://doi.org/10.11118/actaun201563062213.

# Chapter 1

# Introduction

The overall temperature on Earth has risen without a doubt. Evidence of it dates back to 1880 when temperature records began. If we consider the ten warmest years since that year, nine of them happened after 2005. In 2018, the average global temperature was 0.97°C higher than the 1880-1900 levels (Olivier & Peters 2020).

If this trend of rising temperature is allowed to continue, people will face several climate threats. Until now, many ecosystems have been observed changing due to global warming, and depending on the magnitude of global warming, geographic location and vulnerability, future changes to the climate are certain to affect our well-being. Among many anticipated consequences, there is the rise of sea level, an increase of mean temperature including extreme temperatures in many areas, a higher probability of frequent droughts and water scarcity in some regions, as well as a greater amount of heavy precipitation in other regions (IPCC 2018).

As IPCC (2018) states, global warming will likely reach 1.5°C above pre-industrial levels in the next 20 years if the current increasing rate of warming persists. It was estimated that approximately 1°C of global warming has been caused by human activities, mainly by burning fossil fuels, farming livestock or deforesting, which contribute enormously to $CO_2$ emissions that account for 64% of man-made global warming (European Commission 2016). A 2% increase in total greenhouse gas emissions was observed in 2018, caused predominantly by $CO_2$ emissions arising from fossil-fuel combustion.

Under the Paris Agreement, the participating countries have pledged to limit the average global temperature rise to below 2°C and pursue efforts to limit the change to 1.5°C primarily by reducing each country's greenhouse gas emissions (United Nations 2016). With the position of the third greatest emitter of greenhouse gases (GHG), the European Union integrated a fight against the GHG emissions into its politics long before. Not only as a reaction to the Kyoto Protocol (1997), a new policy of limiting the $CO_2$ emissions (and later also other GHG emissions) was introduced in 2003 in the form of a cap-and-trade system (European Commission 2020a) as there were already a successful carbon markets in the USA (EPA 2014) or in the UK (NAO 2004). The European Union Emissions Trading System (EU ETS) has been operating since 2005, aiming to reduce GHG emissions cost-effectively by allowing the companies involved to trade emission allowances. It is now the biggest international carbon market with more than 11 thousand regulated installations, and it covers around 45% of the EU's GHG emissions (European Commission 2015).

As Member State of the EU, the Czech Republic naturally also participates in the EU ETS and contributes to achieve greenhouse gas emission targets set by the agreements. The Czech Republic is greatly dependent on coal sources, and among the European countries, is in the top four countries in GHG tonnes per capita (Eurostat 2021). As recent literature provides inconclusive findings that focus on other European countries, it is needed to examine also such high-carbon installations' response to the policy. Thus, the aim of this diploma thesis is to estimate the effect of the European trading system with emission allowances on emissions and emission intensities in the Czech Republic.

The thesis is structured as follows. Chapter 2 describes the treaties on climate change, an overview of the development of GHG emissions in the Czech Republic, the design of the EU ETS and how the cap-and-trade system works. Moreover, it states key findings of previous studies of environmental effects of the EU ETS together with papers focusing on any relationship between the EU ETS and the Czech Republic. Data collected and available for the estimation is included in Chapter 4, the process of estimation of $CO_2$ emissions is presented as well. Chapter 3 provides the study design. We focus on the average treatment effect on treated, its estimation and probability score matching method. Our main findings are summarized in Chapter 5, which also contains additional models and a discussion.

# Chapter 2

# Institutional background and literature review

The European Emissions Trading System has undergone multiple modifications since its first implementation in 2005. The policy reacts to multiple treaties on climate change and serves as a means to achieve given goals in abatement. Policy makers broaden EU ETS' coverage over time, especially between single phases. They learn from previous outcomes and integrate higher-quality measures to make the system more efficient, and to motivate the regulated installations to innovate. As Marcantonini et al. (2017) state, the innovations follow a positive trend; however, strengthening the incentives is necessary to improve efficiency.

This chapter aims to describe the background of the EU ETS in three main sections. Firstly, the main pledges of emission reduction are presented, which was the impulse to initiate a new environmental policy in the European Union. Secondly, a large part is dedicated to the design of the EU ETS policy. Which sectors are subjected to the policy, which means are used, and how the development of policy measures proceeds is done. Lastly, since the EU ETS affects many areas of the economy, its impact has been studied thoroughly from many perspectives. We present related studies whose focus was either on emission reduction or on the Czech Republic.

## 2.1 Treaties on climate change

The United Nations Framework Convention on Climate Change (UNFCCC) triggered the necessary political debates about the increasingly changing climate in 1992. Moreover, it set the targets of reducing greenhouse gas (GHG) emissions to stabilise the concentration of GHG emissions in the atmosphere at such a level that would not harm the climate. One hundred and ninety-seven countries that have ratified the Convention are Parties to the Convention (United Nations 1992).

The following Kyoto protocol (1997) legally binds developed country Parties to their reduction targets during two periods. The first period lasted from 2008 to 2012, the second one from 2013 to 2020 [1]. The targets of emission reduction of six main GHG are listed in Annex B of the Kyoto Protocol. During the first phase, the plan for the Czech Republic was to reduce GHG emissions by 8% compared to the level of emissions in 1990 (UNFCCC 2008).

Under the Paris Agreement (2016), the common ecological agreement proceeds; moreover, it proposes stricter targets to combat climate change. The crucial point is to maintain the increasing global average temperature below 2°C compared to pre-industrial levels, and ideally limit the temperature increase to only 1.5°C. There are now 186 countries that have ratified the agreement (United Nations 2016). Each country has to present an outline of their post-2020 climate actions, known as nationally determined contributions (NDCs) (UNFCCC 2020d).

Specific steps towards the implementation of the Paris Agreement were taken at the COP24 in Katowice in 2018. After political discussions and compromises, the Katowice climate package presents the necessary information that governments have to report in their NDCs, the functioning of the Transparency Framework, or how to measure the progress of achieving the goals through Global Stocktake (UNFCCC 2020b).

However, to be able to meet the commitments, ongoing activities have to be stricter. Each year the Emissions Gap Report has presented, for the past decade, the difference between what countries have committed to pursue to

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[1] The amendment of Kyoto protocol was introduced at the 2012 UN Climate Change Conference in Doha (UNFCCC 2020a).

reduce GHG emissions individually and what has to be done collectively to achieve the agreed temperature goals. Moreover, the gap has widened four times since 2010 due to a rise in global emissions, which leads to a new, more ambitious decision about countries' targets that should be made. This confirms the insufficiency in countries' climate pledges (Höhne et al. 2020).

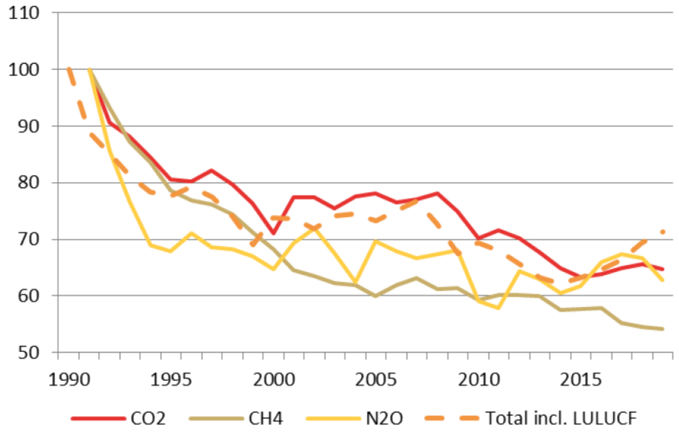
## 2.2 GHG emissions in numbers

In 2018 the GHG emissions increased in the world by 2% (excluding those from land-use change) to 51,8 Gt $CO_2$-eq. This is mainly because of a 2% increase in $CO_2$ emissions, with the main source being fossil-fuel combustion and industrial non-combustion processes. The greatest emitter of GHG emissions is China (26%), followed by the USA (13%) and the European Union (more than 9%). The EU reported a 1.5% decrease in 2018 to 4.4 Gt $CO_2$-eq. thanks to Germany (-3.5%) and the other 14 Member states. On the other hand, the greatest increase of GHG emissions is recorded by Poland (+1.6%), followed by Belgium and the Czech Republic (Olivier & Peters 2020).

The Czech Republic is heavily dependent on its coal sources and its following usage. Among the European countries, the Czech Republic was in the top 4 countries with the highest GHG emissions per capita in 2019, specifically it was almost 13 t $CO_2$ per capita (Eurostat 2021). $CO_2$ contributed to the national GHG emissions by 82%, followed by $CH_4$ (10%) and $N_2O$ (5%) in 2019, the total amount of GHG emissions was then 123 million tonnes of $CO_2$-eq (excl. indirect, excl. LULUCF). From the base year 1990, the overall GHG emissions have decreased by 37.7%. When we consider only $CO_2$ emissions, the decrease was very similar in numbers with the value of 38.6%. 68.7% of total emissions originated in the Energy sector, whose emissions were lowered by 41.9% relative to the base year 1990. There is a downward sloping trend also for other main sectors such as agriculture, land use and industrial processes. However, the waste sector recorded an increase of emissions by 82.57%, which accounts for 28% of total GHG emissions (CHMI 2021). The percentage changes by the most harmful GHG over the period 1990-2019 are presented in Figure 2.1.

The transition to a market-based economy, the restructuring of the economy, and the decline of heavy industry production had the greatest impact

Figure 2.1: Trend in $CO_2$, $CH_4$ and $N_2O$ emissions 1990 - 2019 in index form (base year = 100%)



*Source:* CHMI (2021).

on significant emission reduction over the period 1990 - 1994 (Ministry of the Environment of the Czech Republic 2017). Earnhart & Lizal (2008) stress that the most important driver of the emission reduction during the 1990s was a stricter environmental protection policy. The subsequent significant reduction correlates with the economic recession after 2008 (Ministry of the Environment of the Czech Republic 2017).

The main short term target for the Czech Republic is to reduce the total national emissions by at least 32 Mt $CO_2$-eq. by 2020 in contrast to 2005, resp. by at least 44 Mt $CO_2$-eq. by 2030 (the equivalent of 40% decrease compared to 1990). The reduction of 80% to 95% total GHG emission by 2050 compared to 1990 levels serves as the long term goal reflecting the EU commitments (Ministry of the Environment of the Czech Republic 2017). In July 2021, the EU adopted multiple legislative proposals how even climate neutrality should be achieved in the EU by 2050, raising the GHG emission reduction target to 55% for 2030 (European Commission 2021).

Besides the absolute changes in emissions, it is also necessary to focus on carbon intensity. This metric helps to understand the emissions in relative terms. Emissions emitted per fuel consumed describe if the energy mix is low- or high- carbon. We should keep continuously abandoning fossil fuels and utilise more energy from renewable sources, for example, to be a low-carbon intense country. The Czech Republic achieved a reduction in its emission intensity of fuel consumption by 26.4% between 2000 and 2019 and kept the reduction pace below the European Union average (Eurostat 2021). Moreover, the emissions can also be assessed in the form of emissions relative to revenues or GDP (in the case of countries). The same pattern is followed here. The Czech Republic managed to reduce its carbon intensity of production by 32% in 2000 - 2019 (Carbon Dioxide Information Analysis Center 2021).

## 2.3 Design of the EU ETS

The EU Emissions Trading Scheme (ETS) was adopted in 2003 under the Directive 2003/87/EC. It is the first international trading system with emissions and also the biggest carbon market. Besides all European Union countries, Iceland, Lichtenstein and Norway are also involved. It accounts for about 45% of the EU's GHG[2] emissions, which means limiting emissions from more than 11,000 heavy energy-using installations and airlines (European Commission 2015).

The following paragraphs present the core scheme of the policy.

### 2.3.1 Cap-and-trade System and NAP

The EU chose a cap-and-trade system over the traditional command-and-control approach. It cannot mandate a classical limit per installation, but it provides companies with flexibility. The cap, which gets stricter over time, limits emitted GHG emissions. The carbon price is set through trading. This allows companies under the policy to determine how to meet the fixed cap cost-effectively. A cap-and-trade system minimizes the negative effects of the policy on competitiveness and prevents emissions leakage (Wood 2018).

It was decided to lower the GHG emissions by 20% in 2020 compared to 1990 levels. Fixed installation cap decreases each year by a linear reduction factor of 1.74% compared to 2010, applicable for phase III. In phase I and II, the cap had been set bottom-up from 27 National Allocation Plans (NAP) for

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[2] There are six main GHG: Carbon dioxide ($CO_2$), Methane $CH_4$, Nitrous oxide $N_2O$, Hydrofluorocarbons HFCs, Perfluorocarbons PFCs, Sulphur hexafluoride $SF_6$.

each country which has changed to a single EU-wide cap set centrally for the subsequent phases (European Commission 2015).

### 2.3.2 Gases and sectors covered

Sectors that are regulated by the policy during phase III (2013 - 2020) are "energy-intensive industries, including power stations and other combustion plants with at least 20MW thermal rated input (except hazardous or municipal waste installations), oil refineries, coke ovens, iron and steel, cement clinker, glass, lime, bricks, ceramics, pulp, paper and board, aluminium, petrochemicals, ammonia, nitric, adipic, glyoxal and glyoxylic acid production, $CO_2$ capture, transport in pipelines and geological storage of $CO_2$" (European Commission 2020c, p. 7). Furthermore, small installations (with emissions lower than 25 kt $CO_2e$) can be excluded from the system under the condition that an equivalent measure is applied. The regulation of the aviation scope is limited to flights within the European Economic Area (EEA) until 2023 (European Commission 2020c).

Each installation has to report verified emissions. Mainly calculation-based methodology is used. Only 1.5% of installations reported emissions using a continuous emissions measurement system (frequently used in the Czechia) (European Commission 2020c). The emissions demanded to be reported are "carbon dioxide ($CO_2$) emissions, nitrous oxide ($N_2O$) emissions from nitric, adipic, glyoxylic acid and glyoxal production, and perfluorocarbons (PFC) emissions from aluminium production" (European Commission 2020c, p. 7).

### 2.3.3 EU allowances

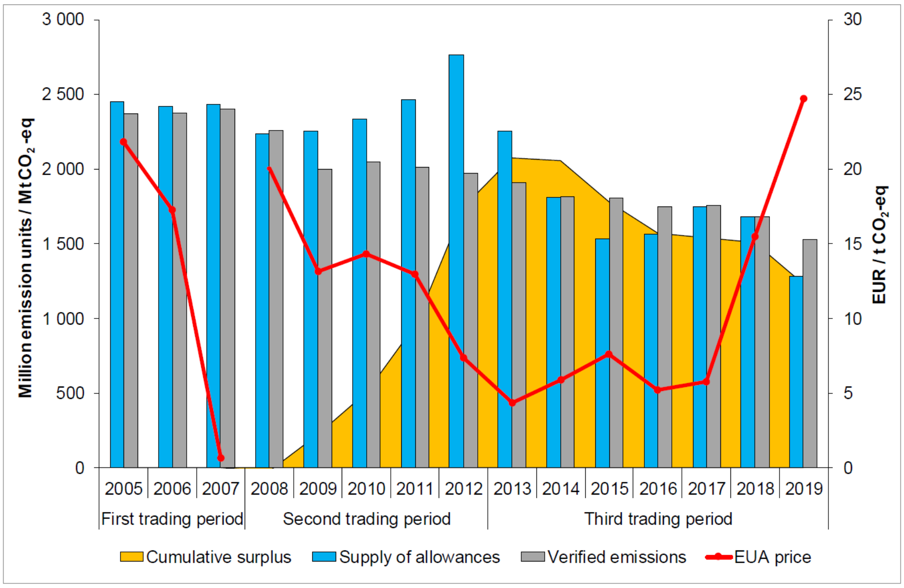
The companies can trade European Union Allowances (EUA) to meet the cap each year if necessary. Each EAU gives the holder the right to emit either one tonne of carbon dioxide or a comparable amount of nitrous oxide or perfluorocarbons. Allowances are allocated to installations either by grandfathering (allocated for free, mostly based on historical levels of emissions) or auctioned (European Commission 2015). Dechezleprêtre et al. (2018) demonstrate a significant reduction in the treatment effect of the EU ETS when the allowances are freely allocated, and they estimate that the emissions would be 25% lower if only half of the allowances were freely allocated. The downward sloping trend of free distribution of allowances continues, and in 2020 the ratio of freely distributed allowances was only 30% (European Commission 2015). Nevertheless, it will not converge to zero since free allocation tends to prevent the risk of carbon leakage (European Commission 2020c).

The type of allocation varies from sector to sector; power generators, in general, have not received any free allowances since phase III. However, eight eligible Member States (Czechia included) made use of Article 10c of the EU ETS Directive, where some free allowances were distributed to electricity generators to support the investments in modernisation (European Commission 2020c).

The short-term solution to the surplus of allowances, which totalled around 2 billion EUA at the beginning of phase III, is to change the distribution of allowances - postponing the auctioned allowances from 2014 - 2016 to 2019 - 2020. This "back-loading" short-term system has been replaced by a long-term solution, Market Stability Reserve (launched in January 2019), which adjusts the supply of EUA to be auctioned (European Commission 2020a). The surplus of allowances decreased in 2019 to 1.39 billion allowances (European Commission 2020c). Its function can be compared to the function of the Central Bank that cares about the amount of the means in the economy. Even though the MSR impact is greatly influenced also by other environmental policies, the strengthened policy of MSR (including a future increase of linear reduction factor and a new limit of total EUA that can be contained in MSR) could quadruple the price of EUA, and the $CO_2$ emissions could decrease by 21.3 Gt $CO_2$ (Bruninx et al. 2019).

In 2005 the EUA price averaged to about 22€ per tonne of $CO_2$-eq. After 2006 the prices fell sharply due to releasing data from 2005, which showed the surplus of allowances in many states (Convery et al. 2008). Consequently, the surplus of allowances cumulated over the years with its peak at the end of the second phase. This is clearly depicted in figure 2.2. The second price decrease corresponds with the economic recession, followed by the link to the overallocation of EUA. At the end of phase III, the EUA price oscillated around 25 € (Nissen et al. 2020). Furthermore, as of the first half of 2021, the carbon

Figure 2.2: Emissions, allowances, surplus and prices in the EU ETS, 2005-2019



**Note:** The cumulative surplus represents the difference between allowances allocated for free, auctioned or sold plus international credits surrendered or exchanged from 2008 to date minus the cumulative emissions. It also accounts for net demand from aviation during the same time period.

*Source:* Nissen et al. (2020)

price triggered and hit a record of 50€ per tonne, driven by new more ambitious climate goals (Reuters 2021).

The total revenues from the auctions in 2019 exceeded €14 billion by all Member Parties, €630 million in the Czech Republic. 77% of these revenues were dedicated to climate and energy-related purposes in that year (European Commission 2020c).

## CDM, ERU

Additionally, the Kyoto Protocol also presented new ways to enhance the incentives to invest in a more sustainable low-carbon economy through market-based mechanisms. If the Parties meet stipulated requirements, they can participate in both CDM and JI mechanisms. Clean Development Mechanism (CDM) encourages developed countries (under the EU ETS) to commence a project in a developing country with the aim to lower emissions. Projects are afterwards converted into certified emission reduction (CER) credit. The joint implementation (JI) mechanism works the same except that the target country is also industrialized, and the earned units are called emission reduction units (ERUs). Both CER and ERU correspond to one tonne of $CO_2$. In the fourth phase, both mechanisms will be replaced (UNFCCC 2020c). The effect of CDM projects is very auspicious in China, especially in the innovation in renewable energy and energy efficiency. Moreover, a spillover effect of CDM projects to non-CDM companies is present (Cui et al. 2020).

### 2.3.4 Phases of the EU ETS

The EU Emissions trading system commenced in 2005 with a pilot phase that lasted three years. Only carbon dioxide ($CO_2$) from the power sector and other energy-intensive industries was regulated. Free allocation (as the main form of EUA allocation) of allowances through grandfathering appeared later as the greatest concern about the pilot phase (European Commission 2015). Ellerman & Buchner (2008) point out that there was an over-allocation of allowances. The total number of $CO_2$ emissions was 3% lower than the number of allocated allowances during the first two years. One possible explanation is underestimating the amount of abatement because the $CO_2$ prices were included in the production decision-making by the managers of affected facilities. Furthermore, unexpected abatement always occurs, as previous experience in the US with emissions trading regimes has shown.

European Commission (2020a) reports the absence of reliable emissions data; thus, the caps were set based on estimates leading to the overallocation and later on to the downfall of prices. Contrary, Anderson & Di Maria (2011) state that not only over-allocation and abatement occurred, but also under-allocation and emissions inflation were present. They suggest that over-allocation could be less probable in the case of a top-down system, a centrally set cap.

The second phase (2008 - 2012) started with a bottom-up set cap of 2,049 $MtCO_2e$ (0,047 $MtCO_2e$ lower than the cap in 2005). Its years coincide with the first commitment period of the Kyoto Protocol. The main alterations were that Nitrous oxide ($N_2O$) was included, the aviation sector was added, and three non-EU countries joined the EU ETS system. Penalties for noncompliance rose from €40 to €100. Along with EUA, CERs and ERUs (Kyoto protocol emission units) could have been used (European Commission 2015).

A number of conometric papers (Abrell et al. 2011; Dechezleprêtre et al. 2018; Wagner et al. 2014) (presented in detail in section 2.4.1) reached the conclusion of the effectiveness of the EU ETS, especially in phase II, but not in the first phase due to the problems mentioned above. On the other side, we cannot overlook the economic recession which overlapped with this phase. Among multiple drivers of power plants' $CO_2$ emission reduction, the economic crises during the first two years of phase II had the greatest impact, according to Chèze et al. (2020). The recession caused approximately 150 $MtCO_2e$ abatement in the power sector, thanks to lower electricity demand and lower fuel prices (Laing & Sato 2013). Consequently, a large surplus of allowances and credits occurred, influencing the EUA price again (European Commission 2020a).

The Kyoto Protocol's second period matches with the third phase of the EU ETS (2013 - 2020), and its target for 2020 is to lower the emissions by 20% (compared to 1990 GHG levels). More gases ($N_2O$ and PFCs included) and sectors are regulated (see section 2.3.2). The coverage of approximately 45% of all European GHG emissions means regulation of more than 11 thousand heavy energy-using installations. The cap is now set in a top-down manner and is reduced each year by a linear reduction factor (1.74%, about 38 mill allowances) which totals in 2020 to a cap of 1,816 $MtCO_2e$. The allocation of allowances greatly differs from previous phases - almost 60 % of allowances are auctioned, the remaining ones are allocated through the benchmark approach (European Commission 2020a).

Starting this year, the fourth phase takes place, and its finish is planned for 2030 with a target to reduce GHG emissions produced by companies covered by the EU ETS by 43% compared to 2005 levels. The linear cap strengthens to 2.2% and will be increased after 2030. Two revisions of benchmark values will occur during phase IV to reflect the technological progress correctly. The Market Stability Reserve will continue (since phase 3) to control the tradable amount of allowances (European Commission 2020a).

The characteristics of phase IV are believed to be adjusted as the new studies of phase three, which has just finished, present main points to enhance the quality of the policy. Since even the first three phases differ in many aspects and the policy remains non-stable.

## 2.4 Literature review

The academic literature is rich in the papers studying the effects of the EU ETS. Until now, mainly phases I and II, both finished, have been from the point of view of emission reduction, the financial performance of the regulated companies or the design of the policy.

### 2.4.1 Environmental effects

An intended emission reduction effect during phase II was estimated by Wagner et al. (2014). Their semi-parametric difference-in-differences analysis focused on French manufacturing plants, for which they estimated the emission reduction to be on average 15.7%. A change in the carbon intensity of fuels emerged as the main driver of the reduction. The authors conclude that companies possessing both ETS and non-ETS installations do not present any statistical evidence of within-company leakage. Moreover, the results were later supported by Dechezleprêtre et al. (2018), who analysed installation-level carbon emissions of four countries under the EU ETS; France, Netherlands, Norway and the United Kingdom. Using a matched difference-in-differences study design, they estimated a smaller treatment effect in the range of -0.10 to -0.14. The greatest emission reduction was primarily in the second phase, probably driven by large installations. Furthermore, if the allocation system had distributed only half of the allowances for free, the emission reduction effect would have risen to 25%.

Abrell et al. (2011) had only a shorter period to assess (2005 - 2008), but the sample comprised all EU countries, and they were the first ones to arrive at the conclusion of the effectiveness of the EU ETS during phase II (only one year in their case), and, as well as Dechezleprêtre et al. (2018), they found a correlation between the initial allocation of allowances and the emissions. They demonstrate that two sectors in particular (non-metallic minerals and basic metals) caused the reductions. It was not just the initial allocation of allowances that was questioned, but it was also believed that the over-allocation and thus, very low price of EUA led to low incentives to trade. However, Bayer & Aklin (2020) state a significant emission reduction despite the low prices. During 2008 - 2016, about 1.2 billion tons of $CO_2$ because of the EU ETS were saved.

The German manufacturing sector under the EU ETS confirms the $CO_2$ abatement during phase II as well. Petrick & Wagner (2014) studied a rich dataset of German companies that account for almost one-fifth of total regulated $CO_2$ emissions in the whole EU. They used a difference-in-differences method in a combination with semiparametric matching techniques to estimate the causal impact of the EU ETS. Specifically, the treated companies reduced their $CO_2$ emissions by one fifth compared to non-treated companies. Energy efficiency was improved, and the consumption of natural gas and petroleum products was limited. Reduction of emission intensity of value added is also reported by Colmer et al. (2020), who focused on four thousand French manufacturing companies during the pilot phase and phase II. Moreover, they found no evidence of negative impacts on the scale of production or transferring production to non-regulated companies or markets. Carbon reduction was estimated to 8% to 12% during the second phase, supporting an earlier study conducted in France (Wagner et al. 2014).

A less strong impact on emission reduction was found in Norway (2005 - 2013) by Klemetsen et al. (2016). The emission reduction due to the EU ETS occurred probably during the second phase, which accords with other findings; nonetheless, the results were not valid anymore after the robustness check. The impact is disputable, and the authors suggest over-allocation of quotas leading to low quota price as the probable reason. Hence, the policy did not set incentives high enough to lower the emissions during the first two periods of the EU ETS in Norway.

On the contrary, the results from Lithuania suggest that the participation in the EU ETS did not cause any reductions in $CO_2$ emission, not even in the studied part of the second phase (Jaraitė & Di Maria 2016). The result of no impact can be ascribed to the over-allocation of allowances which opposes the overall result of analysis by Bayer & Aklin (2020). However, they argue that a possible carbon leakage occurred as ETS companies increased the imports of cheaper electricity from abroad due to high gas prices and the closure of one

Table 2.1: Recent literature focusing on the environmental effect of the EU ETS

| Author | Regions | Years | Data level | Method | Key environmental findings | Other findings |
|---|---|---|---|---|---|---|
| Abrell et al. (2011) | EU | 2005 - 2008 | companies | DID with matching | abatement during phase II | initial allocation and emissions correlated, no impact on economic performance |
| Wagner et al. (2014) | France | 2005 - 2010 | installations, companies | semi-parametric DID | 15% emission reduction | 10% reduction on employment during phase II |
| Petrick & Wagner (2014) | Germany | 2005 - 2010 | companies | semiparametric DID | 20% emission reduction | |
| Bel & Joseph (2015) | EU | 2005 - 2012 | installations | GMM-SYS | economic recession as the main driver of abatement | |
| Klemetsen et al. (2016) | Norway | 2005 - 2013 | installations | DID with matching | no effect on emissions or emissions intensity | positive effects on value added and productivity |
| Jaraitė & Di Maria (2016) | Lithuania | 2003 - 2010 | companies | semi-parametric DID | no reduction of emissions | no effect on economic performance |
| Dechezleprêtre et al. (2018) | FR, NL, NO, UK | 2005 - 2012 | installations | DID with matching | 10% to 14% carbon emission reduction, esp. during phase II | no effect on economic performance |
| Bayer & Aklin (2020) | EU | 2008 - 2016 | sectors | generalized synthetic control method | 3.8% emission reduction | |
| Chèze et al. (2020) | EU, power sector | 2005 - 2012 | installations | GMM-SYS | abatement driven by recession during phase II | |
| Colmer et al. (2020) | France | 2005 - 2012 | companies | semiparametric DID | 8-12% emission reduction after phase I | no carbon leakage |

Note: GMM-SYS - system of equations in both first-differences and levels; extension of generalized method of moments reactor of the Ignalina NPP (Jaraitė & Di Maria 2016).

Chèze et al. (2020) estimate drivers of $CO_2$ emission reduction of power plants in the EU during phase I and II by analysing dynamic panel data. Among the potential explanatory variables, e.g. climate and energy policies, economic activity, energy prices or power plant technology, the economic crises during the years 2008 and 2009 appeared to have the greatest impact on the emission reduction. The EU ETS affected to some degree the outcomes only during the first phase. The findings by Bel & Joseph (2015) attribute the abatement during phase II to the economic recession as well. Moreover, they suggest that the effect of the EU ETS was overestimated by other studies.

The environmental effect differs from the analysed countries and sectors. A number of studies regarding the emission reduction agree on the effectiveness of the EU ETS, especially during the second phase (Abrell et al. (2011), Wagner et al. (2014), Petrick & Wagner (2014), Dechezleprêtre et al. (2018), Bayer & Aklin (2020), Colmer et al. (2020)). Few also support the correlation between the type of EUA allocation and the emission reduction in favour of the auctioning type of allocation in order to reach greater reductions (e.g. Abrell et al. (2011)). Nevertheless, when the impact was studied only in a specific country or sector where the researchers had only limited number of installations or companies, it was found that the main cause of emission reduction was not the policy of the EU ETS (Jaraitė & Di Maria (2016), Klemetsen et al. (2016)). The studies with GMM approach conclude that recession was the main driver of the abatement (Bel & Joseph (2015), Chèze et al. (2020)).

### 2.4.2 Evidence from the Czech Republic

The impact of the EU ETS on emission reduction solely in the Czech Republic has not been studied yet (at the time of writing this thesis). However, the policy was studied from other perspectives, mainly analysing the EUA, followed by assessing the system's design and studying the economic impact of the EU ETS.

Zimmermannová (2015) in her analysis focuses on the behaviour and decision-making of Czech heat and electricity producers within the years 2013 and 2014. The combination of allowance prices and $CO_2$ data with a survey was used to answer two hypotheses. Nevertheless, she rejected both of them. Thus, allowances were not actively traded by the companies, and they did not understand the EU ETS as a tradable commodity but rather as an additional tax. Secondly, another hypotheses of understanding the EU ETS as an economic instrument to boost environmental investment was rejected. The price of EUA was not sufficiently motivating to make the companies consider the investments. The fact that the trading system was not motivating in the first phase is also mentioned in the Master's thesis by Tauchmannová (2017). Her whole thesis focuses on the success of the EU ETS as a whole. The flaws of National Allocation Plans (NAP) are described in the case of the Czech Republic. During the first phase, there was no scarcity of allowances, thus no incentives to reduce emissions or to trade allowances.

Also Chvalkovská (2006) assessed the overall EU ETS' microeconomic and macroeconomic impact with an example on the Czech Republic during the first year of implementation. She supports the previous statement of the over-allocation of EUA, but she stresses that the scheme also offered new business opportunities to the Czech companies, and the Czech government obtained revenue from EUA trading. Her estimate of a potential surplus of reduced emissions was between 9% and 12%. According to the author, the advantages outweigh the disadvantages (e.g. poor demand side of the new market, over-allocation, external drivers causing severe shocks), and the first overall impacts of the policy were in the majority positive. Compared to classical price-based instruments, Rizkova (2009) presents the EU ETS to be more feasible politically at the national and international level in her thesis.

Regarding the analysis of EUA in the Czech Republic, Zimmermannova & Cermak (2015) compared the EUA and environmental taxation in 2013. They based the research on studying the behaviour of electricity and heat producers. EAU price was evaluated by these producers as low, and their leading role on the market was only as buyers. Furthermore, the budgetary determination of revenues collected from the auctions with EUA had the same value as environmental taxes and fees. They agreed that, these two environmental approaches were more similar in characteristics in that year than in the previous trading periods. On the other hand, the 'floating tax rate', as they present, was determined as the most significant difference.

Spiesová (2014) studied how revenue from EUA affects basic macroeconomic indicators by applying a simultaneous model. The outcome suggests that if the revenue from EUA in the Czech Republic rises by 1 billion CZK, then there will be a fall of unemployment by 0.15%, government expenses will increase by 1.032 billion CZK, and net export will be raised by 194 million CZK. However, the author doubts her model due to a small number of observations and strong multicollinearity in several cases and admits that the results may be flawed, which could be improved by a greater number of observations.

Another point of view of EUA was described by Němcová et al. (2010), where they investigated the relationship between the price of electricity and EUA on the case of the Czech Republic during phase I. The results were achieved by establishing a structural cointegrated VAR model. They agreed that both prices of emission permits and coal are essential determinants of the level to which the electricity price will converge in the long term. The calculation of elasticities implies that a 1% increase in the price of EUA would mean, in equilibrium, 1.2% growth in electricity prices. Even stronger dependence was anticipated for the next period when the allocation of permits is done through auctions.

Furthermore, a relationship between the economic performance of Czech companies regulated by the EU ETS and their $CO_2$ emission reductions was investigated. With the use of a logarithmic model to be able to measure the elasticities of variables and after applying the general least square model, Brzobohatý & Janský (2010) found that the greater the emitter of $CO_2$ the company is, the lower revenues and costs it has. The results of examining the inverse relation, i.e. how emissions are influenced by companies' profitability, showed that the more profitable the company, the lower the emissions. They conclude that the first phase of the EU ETS was not significantly motivating to make the companies invest in $CO_2$ emission reduction, which complies with the findings of Tauchmannová (2017) presented earlier. Nevertheless, the regulation was improved in the next phases, and the companies' rewards could have arrived during these periods.

# Chapter 3

# Methodology and empirical model

The analysis is to estimate the effect of the EU ETS on the emission reduction and emission intensity reduction of regulated firms in the Czech Republic. To be able to capture the effect, ideally, we would need an installation's outcome with the treatment and without the treatment, which is, of course, not possible. Instead, we will create a comparable group of untreated firms that will serve as a control group. In other words, we want to know what would have happened had the EU ETS not been implemented.

This chapter presents the basic idea of the average treatment effect on treated and its estimation by difference-in-differences. The estimation of causal effect also requires a proper identification strategy. We achieve it by propensity score matching and create suitable data samples, a treatment and a control group. We have chosen this method as the most feasible one according to the data available for the analysis.

Since the policy of the EU ETS regulates installations based on specific parameters, it would also be possible to estimate the effect with regression discontinuity design (RDD). In the RDD method, we would assess installations that are close to the threshold of treatment and analyse their behaviour. Nonetheless, there is more than one specific threshold in the EU ETS; it varies by sector. The decision of regulation is based either on its amount of output, thermal input, or the whole sector is included. Unfortunately, we do not observe data about production output or enough accurate data about thermal input. Therefore, RDD is not possible to use in our analysis.

## 3.1 Average treatment effect

The policy has two potential outcomes, $Y_i(1)$ represents the outcome for an installation $i$ when the installation is regulated by the EU ETS and $Y_i(0)$ is the outcome for installation $i$ not regulated by the EU ETS. Since each installation either is or is not regulated, we cannot estimate the average treatment effect as a simple difference of the outcomes. Thus we are interested in the average treatment effect on the treated (ATT)

$$\alpha_{ATT} = E(Y(1) - Y(0)|X, ETS = 1), \tag{3.1}$$

where $X$ denotes observable covariates and $ETS$ the treatment indicator (Angrist & Pischke 2008). Because $Y(0)$ is unobservable for the treated, a proper substitute has to be chosen and ATT can be estimated from the sample equivalent of the equation

$$\alpha_{ATT} = E(Y(1)|X, ETS = 1) - E(Y(0)|X, ETS = 0). \tag{3.2}$$

As Caliendo & Kopeinig (2008) point out, the factors which determine the treatment decision also usually determine the outcome; hence, the mean outcome of untreated firms ($E(Y(0)|ETS = 0)$) is not recommended in non-experimental studies. In that case, it would lead to a selection bias. The difference between the treatment and control groups would be present even without the treatment.

$$\begin{aligned} E(Y(1)|X, ETS = 1) - E(Y(0)|X, ETS = 0) &= \alpha_{ATT} \\ &+ E(Y(1)|X, ETS = 1) - E(Y(0)|X, ETS = 0) \end{aligned} \tag{3.3}$$

To deal with the selection bias, which is a classical problem in econometrics, we need to ensure that

$$E(Y(1)|X, ETS = 1) - E(Y(0)|X, ETS = 0) = 0. \tag{3.4}$$

Whereas the treatment effect is randomly assigned in social experiments, in non-experimental studies, we have to identify the strategy of estimating the effect properly. Since certain thresholds determine the ETS regulation, there is a higher chance of the presence of selection bias, even though the outcome variable is determined by technology and amount of production rather than only by industry or production capacity. We present only weaker versions of assumptions because we focus only on ATT instead of ATE (average treatment effect).

Concerning the selection bias problem, it is required that the treatment is independent of the outcome in its means, conditionally on the covariates X (Caliendo & Kopeinig 2008). This assumption is referred to as *unconfoundedness* or *ignorability* described by an equation:

$$Y(0) \sqcup ETS|X. \tag{3.5}$$

Assumption of Stable Unit Treatment Value (SUTVA) is described by Angrist et al. (1996) as "The potential outcome for each person $i$ is unrelated to the treatment status of other individuals." (Angrist et al. 1996, p. 36). The SUTVA assumption calls, in the case of the EU ETS, for no spillovers between regulated and unregulated installations. The only affected installations are indeed the regulated ones and the others remain unaffected.

The last assumption is *common support* or *overlap assumption* which requires installations with the same values of covariates $X$ to have a positive probability of being treated

$$P(ETS = 1|X) < 1. \tag{3.6}$$

## 3.2 Identifying assumptions

At the core of our strategy, there is a propensity score matching by which we account for the unconfoundedness (3.5), where we condition the treatment status on observable covariates. Since conditioning on all relevant covariates could lead to a high dimensional vector $X$, Rosenbaum & Rubin (1983) propose the use of propensity scores as balancing scores. Unconfoundedness requires no possible evasion from being treated, especially when it is known that an installation is treated based on specific measures. Hence, we assume that the installations did not have the chance to evade the treatment, for example, they were unable to reduce the thermal input to shift from being above the threshold and the policy did not cause any prior effects in installations' behaviour, such as reducing the production output.

SUTVA is not directly testable nor unconfoundedness is; hence, it is difficult to rule out the possibility that spillover effects happened between the treated and untreated installations. An analysis at the company level could internalize those effects because the impact on an installation is most likely shifted within the same company. Alternatively, a spillover effect can take place when the ETS installations adopt better, more efficient technology thanks to investment incentives resulting from the policy and consequently non-ETS installations can learn from installations subjected to the EU ETS and adopt a similar strategy without ever being treated. In this case, SUTVA violation would occur most likely within a sector. Löschel et al. (2019) aim to overcome the second case by estimating the effect within two-digit NACE subsamples thanks to a rich data sample. The limited number of regulated companies or installations within each sector separately does not allow us to analyse the effect of the EU ETS like that. But in an additional model, we estimate the treatment effect considering only installations within companies that own solely ETS installations or solely non-ETS installations.

We conduct a difference-in-differences (DID) to estimate the average treatment effect on a sample that follows the assumption of common support, and thus, the treatment and control group are as similar as possible. Weaker conditions concerning the propensity scores are assumed (described in the following section by equations 3.9 and 3.10). The main idea of DID declares that in the absence of treatment, the treatment group's outcome would evolve in parallel with the control group. Angrist & Pischke (2008) call it the assumption of common trends. Violation of parallel or common trends would mean biased estimates of the effect. The non-regulated installations would not serve as valid controls, because their reaction to economic influences and their development would differ.

## 3.3 Propensity score

Propensity score (PS) will be used to construct a control group of non-ETS installations and move closer to the unconfoundedness without a present selection bias. Rosenbaum & Rubin (1983) shows propensity score as a possible balancing score. PS stands for the probability of an installation being treated given its observed covariates $X$, expressed as

$$p(X) = P(ETS = 1|X). \tag{3.7}$$

Therefore, if unconfoundedness holds, by conditioning on the PS all biases due to observable components can be removed (Imbens 2004).

It is possible to use any discrete choice model to estimate the propensity score, in our case we will use logit model and propensity score will be estimated by following equation

$$e(x) = P(ETS = 1|X) = \Lambda(\beta_0 + \mathbf{X}\beta) = \frac{\beta_0 + \mathbf{X}\beta}{1 + exp(\beta_0 + \beta\mathbf{X})}, \tag{3.8}$$

where $\Lambda$ represents the logit function. As Caliendo & Kopeinig (2008) point out, the choice between logit and probit is not too critical because both models usually yield similar results in a binary treatment.

Propensity score estimation changes our identifying assumptions 3.5 and 3.6 and conditionals each unit on the propensity score rather than on separate covariates. The assumptions of unconfoundedness and common support are, respectively, in the following form

$$E(Y_{0i}|p(x_i), ETS) = E(Y_{0i}|p(x_i)), \tag{3.9}$$

$$P(ETS = 1|p(y) \in [0, 1], \forall x_i \in \chi, \tag{3.10}$$

while leaving SUTVA unchanged.

Propensity scores will bring another uncertainty into our regression, and resulting estimators are asymptotically less efficient compared to using covariates themselves. On the other hand, additional information about the treatment can be implemented, resulting in better finite-sample results (Angrist & Pischke 2008).

## Matching

There are various approaches on how to pair treated and untreated installations based on estimated propensity scores to create the required control group. The most straightforward and frequently used in causal studies (e.g. Petrick & Wagner (2014); Klemetsen et al. (2016)) is Nearest Neighbour (NN) matching which we prefer among other approaches such as radius or kernel matching. There are several possibilities, how to restrict the matching procedure if we want to be careful about the similarity between those groups[1].

Firstly, we have to set the number of untreated installations which will be matched to each treated installation. It can be implemented with or without replacement of the untreated installations, bearing in mind that allowing for replacement involves a trade-off between variance and bias (Caliendo & Kopeinig 2008). Next, it is possible to restrict the absolute difference in the estimated propensity scores, called a calliper distance. It does not allow two installations to be matched when their PS differ substantially (Austin 2011). They are not similar enough, and their matching would increase the sample size at the price of less similar treatment and control groups.

A comparison study of best matching approaches by Austin (2014) concludes that NN caliper matching without replacement performed the best among others. Contrary, when an installation is once matched without replacement, it cannot be used anymore. So in the case of a high number of treated firms and a low number of untreated firms with highly different PS, it is more feasible to allow for replacement.

During the process of matching the treated and untreated installations, only

---

[1] Instead of introducing additional uncertainty into the model, coarsened exact matching allows matching based on bounding the degree of imbalance (Iacus et al. 2009). However, this method did not prove suitable in our case because it left us with an undesirably small data sample.

those within the common interval of PS will be matched. Caliendo & Kopeinig (2008) argues that additional problems arise when observations at the bound are discarded even though they are very close. Since NN calliper matching imposes an additional restriction on the distance, this approach handles common support well.

## Matching requirements

Since we need observations before and after treatment for the DID approach, only installations that satisfy this condition will be eligible for the matching process. Next, we define a regulated installation (a candidate for the treatment group) as an installation that is regulated within all three phases of the system, implying $\mathrm{ets\_phase_p} = 1$ for $\mathrm{p} \in \langle 1, 3\rangle$ ($ets\_phase_{ip} = 1$ if the installation $i$ was regulated at least once in a given phase $p$). Otherwise, we could introduce a spillover effect to the groups by allowing to switch between the control and treatment group. For example, an installation regulated from phase III would be assigned to control group during phases I and II, but behaved as a treated one in the pre-treatment period (matching procedure period) and in phase III. Alternatively, an installation whose regulation was cancelled in phase II would switch to the control group in phase III. Finished treatment may influence the installation's behaviour even in the following phases, although the installation would not be officially treated anymore, leading to a flawed control group. On the other side, the specification of DID states that in the absence of treatment, the regulated installations would behave as the control units. We include additional specification in section 5.2.4, where we include installations whose regulation status changed between phases to explore how the effect changes.

To avoid matching on endogenous variables, we use for the propensity score estimation the average values of variables from 2003 and 2004. The Directive of the EU ETS was adopted in autumn (European Commission 2015), but due to the missing values in 2003 we choose to broaden the data sample by including also 2004. For the nearest neighbour matching, we require an exact match of sector code, because the installations in the same sector are more likely to face similar market conditions. Next, we allow for up to 10 closest neighbours with the calliper distance of 0.5, preventing to match together installations that might be the closest neighbours, but their probability of treatment is very dissimilar. We allow for replacement.

### Inverse probability treatment weighting

Instead of decreasing the sample size by matching procedure, we introduce a weighted regression by the PS. Inverse probability of treatment weighting (IPTW) creates a pseudo-population synthetic sample allowing us to use more observations and obtain unbiased estimates of ATT. The objective of IPTW is to create a weighted sample in which treated and control subjects' distributions of covariates are the same. Several possible forms of weights can be constructed from the PS. We will use the treated group of installations as a reference group since we estimate the ATT. The propensity score for a treated installation is thus set to 1, untreated installations are assigned with the following weights

$$w(x|ETS = 0) = \frac{\widehat{p}(x)}{1 - \widehat{p}(x)}. \tag{3.11}$$

In simple terms, the regression puts more weight on non-treated installations that are more similar to the treated ones, based on the estimated propensity score. The consistent estimate of ATT is obtained under unconfoundedness (3.9) and common support of probabilities (3.10) (Austin & Stuart 2015).

## 3.4 Empirical model

We estimate the average treatment effect on treated by regressing the logarithm of emissions or emission intensities on an interaction term of treatment status and other covariates. The DID does not substitute the randomized experiments perfectly. However, it provides a feasible way to assess the causal relationship when the parallel trends assumption holds in the period before the introduction of the EU ETS. The DID will be applied on a matched sample to meet the assumptions and to make the treated and control group as similar as possible, which can also control for time-invariant residual biases (Abadie 2005). And hence, under similar trends and sufficient resemblance of ETS and non-ETS installations, common shocks are averaged out by DID, and only causal effect is captured.

Let $Y_{it}$ be the outcome for installation $i$ in year $t$, where $t \in \langle 2002, 2019 \rangle$ and subscript $p$ be denoting phase $p$, where $p = 0$ when $t < 2005$, $p = 1$ when $t \in \langle 2005, 2007 \rangle$, $p = 2$ when $t \in \langle 2008, 2012 \rangle$ and $t = 3$ when $p \geq 2013$. For all three outcome variables (described in the following subsection), we estimate the difference-in-differences by linear regression (Angrist & Pischke 2008):

$$
\begin{aligned}
log(Y_{it}) = \beta_0 + \beta_1 ETS_{ip} + \beta_2 Year_t + \beta_3 ETS_{ip} * Phase_p \\
+ \beta_4 X_{it} + \gamma_i + \epsilon_{it}, \quad (3.12)
\end{aligned}
$$

where an installation $i$ is or is not subject to the EU ETS, and the outcome variable of installation $i$ in year $t$ is expressed in logarithm to be able to interpret the impact in relative terms. Coefficient $\beta_1$ captures the effect of assigned treatment; binary variable $ETS_{ip}$ is equal to 1 if the installation is treated in a given phase and zero otherwise. The year-fixed effect is captured by $\beta_2$ describing common yearly trends. We are interested in the interaction term's coefficient $\beta_3$, which captures the causal effect of ETS in phase $p$. Covariates of revenues, number of employees and the amount of assets are expressed as $X_{it}$, sector dummy variables control for its fixed effect by $\gamma_i$, and the equation ends with the error term $e_{it}$.

Secondly, instead of matching regulated installations by the EU ETS and non-regulated installations together, we expand the assessed data sample to the whole common support and weight the non-regulated installations in the regression by the inverse propensity scores.

The last estimation approach that we use to assess the ATT includes fixed effects of units $\eta_i$. As Angrist & Pischke (2008) point out, the fixed effect model accounts for the unobserved heterogeneity and hence, it is suitable when we suspect the model from omitting an important variable. Since the unconfoundedness seems demanding in our case, an endogenous problem could occur under the presence of unobserved variables affecting the dependent and treatment variables. Angrist & Pischke (2008) suggest solving this issue by using a proxy variable. Instead, we add a fixed effect model where we control for heterogeneous effects of installations because we are not aware of any suitable proxy variable. Furthermore, including the heterogeneous effects relaxes the assumption of common trends in a limited way. Clear common trends add, in this case, more robustness to the model. The regression equation includes now also a fixed effect of an installation $\eta_i$:

$$\begin{split} log(Y_{it}) = \beta_0 + \beta_1 ETS_{ip} + \beta_2 Year_t + \beta_3 ETS_{ip} * Phase_p \\ + \beta_4 X_{it} + \gamma_i + \eta_i + \epsilon_{it}. \end{split} \quad (3.13)$$

Incorporating propensity scores by matching the sample or weighting the sample means that additional uncertainty enters our model, and we should adjust the statistical inference. Moreover, correlation is probable in unobserved components in outcomes within clusters across several dimensions, Abadie et al. (2017) declare. They conclude that standard errors should be clustered at the level of treatment assignment. Given the rules of treatment assignment of the EU ETS, clustering at sector level appears appropriate. However, we end up in the analysis with a small number of sectors, and since we estimate the effect at the installation level, we choose to cluster the standard errors at the company level to account for any within-company correlation across installations.

## Hypotheses

Considering the target of the policy of the EU ETS and all the effort of the policy makers, we expect the causal effect to be in favour of reducing the outcome variables also in the Czech Republic, which will support the estimated effects in manufacturing sector in France (Wagner et al. 2014) or in Germany (Petrick & Wagner 2014). And hence, each of our main three hypotheses follows the same direction.

### Hypothesis 1

The EU ETS caused a reduction of $CO_2$ emissions of regulated installations since the beginning of the policy, especially during phases II and III.

**Hypothesis 2**

The EU ETS influenced positively the energy mix in the regulated installations, and thus, the carbon-fuel intensity, expressed as $CO_2$/fuel consumption, fell during the time period.

**Hypothesis 3**

The EU ETS caused a reduction of carbon intensity of production (measured by revenues), implying less carbon emissions per unit of revenues.

# Chapter 4

# Data

To estimate the causal effect of the EU ETS on regulated installations, we combined data from three data sources to have as much information as possible. The energy data comes from the REZZO database, financial data was obtained from the Magnus database, and the EUTL database offered us data about installations' participation in the EU ETS. Our variable in focus, $CO_2$ emissions, is estimated from fuel consumption of each installation, as reported in REZZO database. The next sections present thoroughly the process of compiling data together, detailed information about the sources of data, how the estimation of $CO_2$ emissions was done and descriptive statistics of the dataset.

## 4.1 Sources of data

### REZZO

To be able to estimate the $CO_2$ emissions from fuel consumption, we gathered data from the Air Pollution Emission Source Register[1] (REZZO) which the Czech Hydrometeorological Institute (CHMI) administers. The specific air pollutants available are carbon monoxide (CO), nitrous oxides ($NO_x$), sulphur dioxide ($SO_2$), total organic carbon (TOC) and solid pollutants (TZL). The $CO_2$ emissions are not recorded in REZZO database. However, companies

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[1] Registr emisí a zdrojů znečišťování ovzduší

are obliged to report annual fuel consumption figures of each installation to CHMI in compliance with act no. 86/2002 Sb. as the sources of air pollution. REZZO divides data into four categories of emitters. We focus only on the category REZZO 1, which is represented by large stationary installations defined by thermal output greater than 5MW, because only the greatest air pollutant emitters are regulated (e.g. installations in the energy sectors are regulated when their thermal input exceeds 20 MW), and we need to compare similar entities. Medium-sized emitters are comprised in REZZO 2 (thermal input lower than 5MW), REZZO 3 and 4 include either local units emitters such as area sources or households and mobile sources, respectively. Data is obtained at the installation level from both fuel combustion processes and their chemical reactions during technological processes.

The reported figures of fuel consumed had to be firstly joined from multiple files from each year and consolidated to correct the errors and typos made by the companies as much as possible, such as figures stated in different units or aggregating the NACE codes due to inconsistency before and after 2007 when the NACE revision took place and no exact conversion for each class was set. Data cleaning and preprocessing is an essential part of every analysis, and thus a lot of time was dedicated to this part; afterwards, the data is valid and can be used in the next part of the analysis. However, the measurement error may be present, and its magnitude is discussed in section 4.3. Empirical papers chose a similar strategy, for example, Jaraitė & Di Maria (2016) used data about fuel purchase to estimate the $CO_2$ emissions. Considering that the fuel purchases face greater measurement error because there is a probability that the fuel was not all consumed or its consumption was postponed to following years, our data has better quality.

## EUTL

The information about the regulation of an installation by the EU ETS is available from the official registry European Union Transaction Log (EUTL) (European Commission 2020b). The EUTL lists all regulated installations, past and present for every year. An operator holding account is owned by each installation where they receive EUA to be used for a given year. At first, we dropped aircraft operators that have been also regulated from phase

III since only immovable installations are in our interest. In addition to the duration of participation of each installation in the policy, also data about verified emissions, the number of allowances received, units surrendered and company's registration information is available for each year. The data from ETS is paired to REZZO, using unique ID of an installation.

### Magnus

The financial and operational data was gathered from the Magnus database, which comprises quarterly information about companies. Companies are obliged to report their financial performance each year. This information will be used to approximate the size of a company, specifically to approximate the size of an installation. Because of the small number of installations eligible for the analysis in our sample, we decided not to aggregate the emission data by installation to the firm level. Instead, we attribute the firm-level financial data among installations.

## 4.2 Emission data

As REZZO provides emission data only for the main air quality pollutants, we estimate the $CO_2$ emissions by following the approach presented in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2006) by using the energy data and emission factors.

The most common and simple approach is to apply emission factors and oxidation factors to the fuels consumed. The following equation was used to get the $CO_2$ emissions of each installation:

$$CO_2\ Emissions = AD * NCV * EF * OF, \tag{4.1}$$

where $AD$ stands for activity data, meaning the amount of fuel consumed by an installation in kilo tonnes unit for solid fuels, in mill. Nm3 for liquid fuels, $EF$ is the corresponding emission factor (coefficient which converts AD into GHG emissions), and since its units are t $CO_2$ / TJ, the fuel has to be expressed as released energy in the form of heat, which is achieved by $NCV$ (net calorific value) in TJ/ kt units. $OF$ stands for oxidation factor. The emission factors used for the estimation were obtained from the National Greenhouse Gas Inventory Report of the Czech Republic (CHMI 2020) and IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2006). Emission and oxidation factors applied can be found in the Appendix. Values of NCV used were already available in REZZO.

## 4.3 Data cleaning and measurement error

There are few limitations that we had to face and deal with. We are aware that the unverified estimated $CO_2$ emissions depend on energy data, and wrongly reported figures would have led to biased $CO_2$ emissions. The cleaned consumption of fuels at the beginning of our time period from the REZZO database is available to us only in the form of 11 groups of fuels, and hence, we could not use the emission factors for each specific fuel to get more accurate carbon emission estimates (the original data sample consists of 30 fuel types, available uncleaned from 2008). To check the validity of our estimates, a correlation coefficient between estimates of $CO_2$ emissions and verified $CO_2$ emissions was calculated, considering regulated installations because the EUTL records verified emissions only from installations that are regulated by the EU ETS. Estimates calculated from the 11 groups of fuels show a correlation coefficient equal to 0.901.

The data from later years in our sample was cleaned in the same procedure to have a consistent data sample. To compare how much noise we introduced to the emission estimates by working with the fuels grouped in 11 categories, we tried to rescale proportionally the original 30 types of fuels (instead of trying to clean it, it would not be manageable). The value of total energy released was kept for each installation in each year from the cleaned 11 group-fuel sample. The original ratio ($\text{fuel}_\text{j}$/fuel_total from uncleaned 30 fuel sample) was applied to the new cleaned total sum of fuel consumption of a given installation in a given year for each $\text{fuel}_\text{j}$. Hence, we preserved the original ratio between the specific fuel and total fuel consumption while having the cleaned total fuel consumption present. The figures could remain the same in case no data cleaning was needed for the given installation. The coefficient correlation rose to 0.94 when comparing $CO_2$ estimates from 30 rescaled specific fuels and verified $CO_2$ emissions from EUTL for regulated installations (after 2008).

Nevertheless, both of the approaches have limitations. Either the consumption of fuels is cleaned, and less accurate emission factors are used (11 groups of fuels), or consumption of fuels is not cleaned, only rescaled, but we can use more accurate emission factors (original 30 types of fuels). Since we need data before the EU ETS came into force, we decide to work with the $CO_2$ emissions calculated from 11 groups of fuels (for which fuel data was stored before 2008). According to annual averages and plots, while comparing those two possibilities, it can be shown that our preferred dataset rather undervalues $CO_2$ emissions from regulated installations, and it follows a similar trend.

## 4.4 Description of variables

The final unbalanced panel dataset includes annual information about installations and their $CO_2$ emissions, namely identification number of an installation, company registration number, a dummy variable if the installation was regulated by the EU ETS in a given year and other primary air pollutant emissions. Additionally, energy data of each fuel consumed (eleven groups of fuels, e.g. brown and hard coal or natural gas), the NACE classification (in level 2), financial data such as revenues, total assets and costs and the number of employees are present as well. Revenues, costs and assets were deflated by the PPI index with 2019 as a base year. Financial and operational data was attributed among the installations if a company owns more than one installation since we observe those data only at the firm level. All main variables are listed in table 4.1.

Additionally to the absolute volume of carbon emissions, we define two relative dependent variables. The carbon-fuel intensity presents how many kilogrammes of $CO_2$ emissions are emitted per one GJ of energy. The higher the ratio, the more fuel, which has high carbon content, was combusted. Thus, to achieve lower emissions and accelerate the transition to a low-carbon economy, it is important to observe decreasing figures.

Then, the carbon intensity of production examine the effect of the EU ETS from the production side. It would be preferable to calculate $CO_2$ emissions intensity as emissions relative to output produced by an installation, for example, emissions per ton of glass. However, rarely was data about production output reported by the companies and it would be challenging to compare output quantities in specific units across different industries. Under the assumption that more output produced means higher sales, we choose to replace the amount of output by revenues of an installation. We compute the carbon intensity of production as carbon emissions relative to the revenues of an installation, thus how many kilo tonnes of $CO_2$ emissions are emitted per billion Czech koruna. Since the production and $CO_2$ emissions are clearly correlated[2], it would be expected to see decreasing $CO_2$ intensity of production.

We observe whether an installation was regulated in a given year. Besides that, the regulation can be assessed in phases (an installation is considered as regulated during a given phase if the installation was regulated at least once during the phase - *ets_phase*) or during the whole time period (an installation is regulated if the installation was regulated at least once at all - *ets_ever*). Verified carbon emissions from the EUTL were used to validate our carbon estimates for regulated installations. Lastly, the first and last year of regulation is included. When an ETS installation is mentioned in the following sections, and nothing else is specified, it means that the installation was regulated at least once during 2005 - 2019 by the EU ETS.

## 4.5 Sample statistics

After having dropped sectors that are not in our interest, such as agriculture, universities and other sectors, we end up with an initial unbalanced panel data sample that consists of 2 632 unique Czech installations and 27 106 installation-year observations within the period 2000 - 2019.

On average, there are 1387 installations each year in the sample, out of which almost 20% of installations are regulated by the EU ETS. The average presence of an installation in our sample is 10.3 years, and almost 25% of installations are in the sample for at least 17 years.

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[2] When the first wave of pandemic hit the world in 2020, and the first strict measures were adopted, it also influenced industries and behavioural patterns of people resulting in approximately 17% of daily global emission reduction compared to the previous year (Le Quéré et al. 2020).

Table 4.1: List of variables

| Variable | Source | Description |
|---|---|---|
| id_prov | REZZO | ID of an installation |
| f_ico | REZZO | company registration number |
| nace | REZZO | NACE classification |
| co2 | own estimation | estimated $CO_2$ emissions from energy data (REZZO) using emission factors |
| carbon-fuel intensity | own estimation | $CO_2$ emissions relative to fuel used |
| carbon intensity of production | own estimation | $CO_2$ emissions relative to revenues |
| fuel | REZZO | total fuel consumed [GJ] |
| $\text{fuel}_\text{j}$ | REZZO | fuel consumption in 11 categories [GJ] |
| permit_id | EUTL | matched ETS ID of an installation |
| ets | EUTL | indicator if an installation is regulated in a given year |
| ets_phase | EUTL | indicator if an installation is regulated in a given phase |
| ets_ever | EUTL | indicator if an installation is regulated at least once |
| allowances | EUTL | number of allowances |
| verified | EUTL | verified $CO_2$ emissions of regulated inst. |
| entry | EUTL | first year of ETS regulation |
| last | EUTL | last year of ETS regulation |
| employees | Magnus | number of employees |
| revenues | Magnus | revenues in bil Kč |
| costs | Magnus | costs in bil Kč |
| assets | Magnus | assets in bil Kč |

There are 369 installations that were at least once regulated by the EU ETS. Most of the installations regulated by the EU ETS entered the system in 2005 and the last year of their regulation dates to 2019 (57%). Others were regulated either from 2005, but they stopped to be regulated before 2019, or they have been subject to the EU ETS later than from 2005. Our dataset ends in 2019. The majority of ETS installations were regulated from phase I. Only 30 installations (8%) were regulated from 2008 or later. Thus, even though phase III set rules for additional sectors, it did not add many new installations. We refer to those installations, whose treatment status has changed during 2005 - 2019, as switchers. They were included in the system later, or their regulation was cancelled either before phase III. There are 104 switchers out of the ETS installations where it is more common to leave the system and still be present in the data sample afterwards as unregulated installation.

Since we decided to analyse the data at installation-level rather than firm-level a short description of firms that operate installations in our sample is necessary. There are 1581 installations (50,4%) with no other installations belonging to the same company's authority. 274 companies own two installations (17,5% of installations) and the rest of the companies own three or more installations. There are 82 companies that own both a regulated installation and, in the same year, an unregulated installation which involves 469 installations. There is no noticeable increase of unregulated installations within those companies over time.

From table 4.2, it is visible that the regulated installations are mainly in the energy sector. On the other hand, the majority of the non-regulated installations are in the sector of manufacture of machinery and metal products, followed by the energy sector. As the energy sector accounts in the Czech Republic for the majority of $CO_2$ emissions (CHMI 2020), the same rule applies in our sample with almost three-quarters of total $CO_2$ emissions, which suggests that regulated installations in the energy sector cover the majority of $CO_2$ emissions. Contrary, the manufacture of machinery and metal products is the second greatest sector, though only one per cent of overall $CO_2$ emissions can be ascribed to it and thus, this sector is represented by small emitters. The percentage of $CO_2$ emissions that a given sector is responsible for is shown in the last two columns.

Table 4.2: Share of installation-year observations by sectors and share of $CO_2$ (2000-2019), in percentage

| | Installations | | $CO_2$ | |
|---|---|---|---|---|
| Sector | ETS | non-ETS | ETS | non-ETS |
| Energy sector | 45.87 | 21.58 | 78.7 | 59.68 |
| Man. of basic metals | 3.91 | 7.11 | 3.92 | 19.17 |
| Man. of basic pharm. products | 0.55 | 0.83 | 0.04 | 0.1 |
| Man. of coke and refined petroleum prod. | 1.57 | 0.04 | 0.91 | 0.28 |
| Man. of electronics | 0.8 | 5.31 | 0.02 | 0.46 |
| Man. of food products and beverages | 6.47 | 10.09 | 0.71 | 1.67 |
| Man. of chemic. prod. | 5.18 | 2.8 | 3.96 | 13.2 |
| Man. of machinery and metal products | 7.65 | 26.68 | 0.28 | 2.43 |
| Man. of non-metallic mineral products | 16.68 | 9.96 | 2.17 | 1.14 |
| Man. of paper and paper products | 3.55 | 1.18 | 1.93 | 0.34 |
| Man. of rubber and plastic products | 0.75 | 4.58 | 0.06 | 0.37 |
| Man. of textiles and wearing apparel | 1.64 | 4.37 | 0.09 | 0.61 |
| Man. of wood | 1.48 | 2.79 | 0.05 | 0.12 |
| Mining | 1.23 | 0.57 | 6.98 | 0.14 |
| Transportation and storage | 2.64 | 2.11 | 0.19 | 0.29 |

The difference between an average (median) ETS and an average (median) non-ETS installation is shown in table 4.3. From the first sight, the ETS installations are greater consumers of fuels, which goes hand in hand with greater size of an installation (represented by the approximate number of employees and higher revenues, costs and assets). On average, ETS installations emit ten times more $CO_2$ emissions and consume ten times more fuel. The non-ETS installation generates about 60% of ETS installation's revenues, similarly for the costs and possess only just under 40% of total ETS installations' assets. The number of employees show small difference. If we compare those two groups in terms of median, it is evident that small installations predominate in the sample, yet still, $CO_2$ emissions differ a lot.

The detailed data sample allow us to compare the installations in terms of consumption of fuel types. Almost 84% of all $CO_2$ emissions are caused by coal in our sample. Considering emissions in 2017, the share decreases to 82.2%, which is still more than the value of 62% that was reported by IEA (2019) in their annual report of $CO_2$ emissions by fuels for that year. Thus, it appears that our sample focuses mainly on sectors heavily dependant on fossil fuels. Table 4.4 sheds some light on the average fuel consumption per fuel type

Table 4.3: Summary statistics of initial sample, 2000 - 2019, before matching

| Variable | ETS installations Mean | ETS installations Median | Non-ETS installations Mean | Non-ETS installations Median |
|---|---|---|---|---|
| $CO_2$ emissions [kt] | 184.801 | 10.705 | 17.782 | 0.985 |
| Total fuel used [PJ] | 2.166 | 0.176 | 0.217 | 0.019 |
| Employees | 342 | 124 | 302 | 117 |
| Revenues [bil Kč] | 2.412 | 0.619 | 1.527 | 0.367 |
| Costs [bil Kč] | 2.144 | 0.578 | 1.431 | 0.349 |
| Assets [bil Kč] | 3.363 | 0.767 | 1.269 | 0.327 |
| Number of installations | 369 | | 2 263 | |
| Number of inst.-year obs. | 5 598 | | 21 508 | |

per ETS or non-ETS installation. In both groups, the most consumed fuel on average is brown coal in different ratios (49.6% for non-ETS ins. and 62.9% for ETS ins.), followed by hard coal. Non-ETS installations' average consumption is next represented by natural gas by 16%, while its contribution to the average fuel consumption of ETS installations is only 9%.

Table 4.4: Comparison of an average fuel consumption, 2000 - 2019

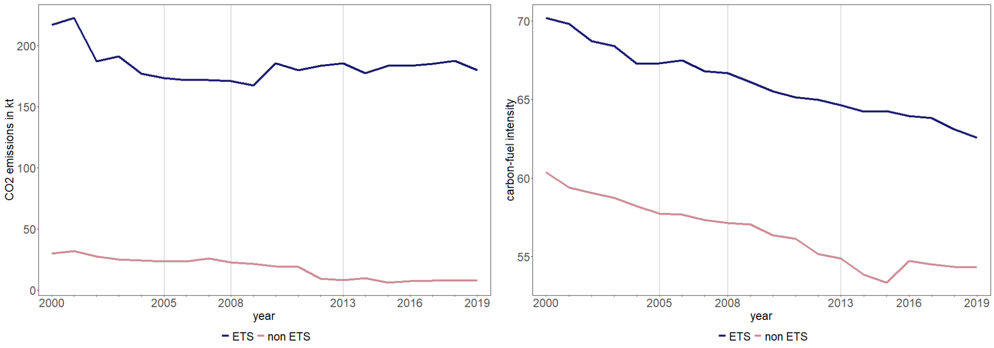
| Fuel type | Non-ETS GJ used | Non-ETS % share | ETS GJ used | ETS % share |
|---|---|---|---|---|
| Brown coal | 107 863 | 49.6% | 1 363 178 | 62.9% |
| Biogas | 987 | 0.5% | 476 | 0.0% |
| Biomass | 6 529 | 3.0% | 50 439 | 2.3% |
| $H_2$ | 147 | 0.1% | 4 561 | 0.2% |
| Hard coal | 43 125 | 19.8% | 273 525 | 12.6% |
| Hard oils | 2 956 | 1.4% | 13 643 | 0.6% |
| Light oils | 2 260 | 1.0% | 10 394 | 0.5% |
| Natural gas | 34 075 | 15.7% | 191 090 | 8.8% |
| LPG | 17 807 | 8.2% | 193 470 | 8.9% |
| Other gases | 467 | 0.2% | 29 699 | 1.4% |
| Bitumen | 1 433 | 0.7% | 36 196 | 1.7% |
| Total | 217 649 | 100% | 2 166 671 | 100% |

A description of development of selected variables in time closes this chapter. The overall average $CO_2$ emissions decrease over the years from 65 kt $CO_2$ in 2000 to 50 kt $CO_2$ in 2019. However, the first graph of figure A.3 indicates a steady decrease only for installations never subjected to the EU ETS. ETS installations reduced $CO_2$ emissions primarily at the beginning of the millennia. $CO_2$ emissions increased again at the beginning of the second decade and remained plateaued for the rest of the period. As can be seen from the graph, the treatment and control groups differ in the average amount of emitted $CO_2$ extensively.

Considering the carbon-fuel intensity (kg $CO_2$/GJ), ETS installations show a higher ratio, but the gap between the trends of average carbon-fuel intensity of ETS and non-ETS group is smaller. The carbon-fuel intensity decreases steadily for both ETS and non-ETS installations with a slump for non-ETS installations in 2013 and 2014 which we can see in the second graph of figure A.3.

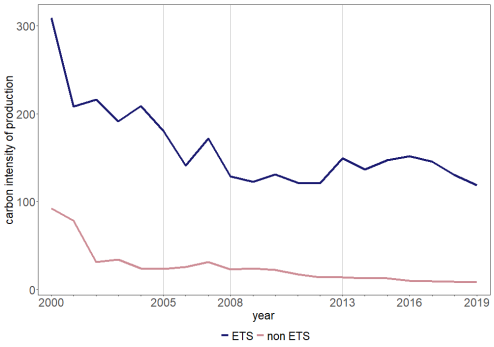
The last graph of figure A.3 illustrates the trend of carbon intensity of production (kt $CO_2$/bil. Kč) that is decreasing over time as well. Contrary to the other graphs, the ETS installations' carbon intensity of production is bumpier. The sharpest fall happened at the beginning of millennia. The decreasing trend for the ETS group has stopped at the beginning of phase II while the non-ETS group has continued to slowly decrease its instensity. On the other hand, the second part of phase III for the ETS group shows a decrease in the intensity which can be assigned to the rising revenues. Both trends of average fuel consumption and trends of average revenues can be found in Appendix section A.1.

Figure 4.1: Mean annual emissions and emission intensities, 2000 - 2019



(a) $CO_2$ emissions (kt)

(b) Carbon-fuel intensity (kg $CO_2$/GJ)



(c) Carbon intensity of production (kt $CO_2$/bil Kč)

# Chapter 5

# Results

In this chapter, we present results coming from empirical research of this thesis. We account for the different characteristics of ETS and non-ETS installations and possible selection bias by propensity score matching. Moreover, our chosen method of difference-in-differences assumes parallel trends in the pretreatment period. Thus, the results of propensity score matching are not negligible and the reader is provided with its description together with plots of trends. To analyse all three hypothesis, we perform also DID with inverse probability treatment weighting and DID where we account for fixed effects of installations (propensity score matching included again). In addition to the main models, we impose stricter conditions during the matching process to control the robustness of the results. Since there are various possibilities for constructing the study design, results from different two settings are included. Next to the $CO_2$ emissions, we study the effect of the EU ETS also on emissions relative to fuel consumption, and revenues respectively. This gives us an idea about installations' behaviour and transition to low-carbon fuel mix. The effect on absolute emissions and emission intensities is presented separately in subsections, followed by subsections of robustness checks that group all the dependent variables by the specific study design settings. The discussion of results completes this chapter.

## 5.1 PS Matching

The propensity score was estimated by the logit model, as described in section 3.3. Given the available data, we regressed the treatment status of installation on logarithm of $CO_2$ emissions, consumption of coal, natural gas and other fuels grouped together (the greatest part of fuel consumption of ETS installations, on average, pertain to coal, non-ETS installations consume, on average, a higher share of natural gas (see data section 4.4). Next we used the number of employees, revenues and total assets to approximate the size of an installation. $CO_2$ emissions and total assets of an installation proved significant and increase the probability of being treated. Table A.2 in the Appendix presents the logit results.

The restrictions to match the treated and non-treated installations were chosen to obtain as rich data set as possible, bearing in mind to make the control and treatment groups as close and similar as possible, and they are described in detail in the subsection 3.3. In brief, we required exact match of sector code, we allowed for up to 10 nearest neighbours and replacement, calliper was set to 0.5. Propensity scores outside the common support were discarded.

We are left with 78 treated installations that matched to 173 untreated installations. Figure 5.1 describes the distribution of propensity scores for each group before and after the process of matching. Treatment group in blue colour, control group in red colour, sample before matching on the left, sample after matching on the right. It is clear that tails were discarded and the groups' distributions narrowed. The number of sectors shrunk because there were no appropriate candidates to be matched together within some sectors. Allowing for replacement caused different numbers of ETS and non-ETS units in each sector. To give an idea, 30 out of 78 treated installations received 10 untreated neighbours, whereas 10 of them received only one nearest neighbour. The majority of installations operate in the energy sector, followed by the sector of manufacture of food products and beverages. The distribution of total $CO_2$ emissions and of installations among sectors mimics a similar pattern as the initial sample. There are 8.8% of companies that own both ETS and non-ETS installations, which accounts for 25% of installations.

Figure 5.1: Distribution of propensity scores

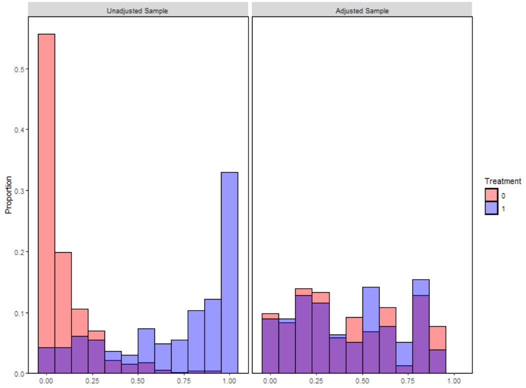


Table 5.1: Share of installation-year observations by sectors and share of $CO_2$ (2002-2019), common support and after matching

| | Common support | | | | Matched sample | | | |
|---|---|---|---|---|---|---|---|---|
| | Installations | | $CO_2$ | | Installations | | $CO_2$ | |
| Sector | ETS | non-ETS | ETS | non-ETS | ETS | non-ETS | ETS | non-ETS |
| Energy sector | 55.50 | 25.10 | 52.10 | 30.50 | 69.10 | 42.00 | 76.50 | 47.30 |
| Man. of basic metals | 2.10 | 5.00 | 2.80 | 4.70 | | | | |
| Man. of basic pharm. prod. | 1.10 | 1.40 | 1.80 | 1.40 | | | | |
| Man. of electronics | 1.70 | 5.30 | 0.70 | 4.40 | 2.20 | 4.20 | 1.10 | 4.30 |
| Man. of food prod. and beverages | 11.60 | 12.70 | 14.80 | 16.60 | 10.40 | 17.20 | 8.90 | 17.70 |
| Man. of chemical products | 2.00 | 2.70 | 2.00 | 6.30 | | | | |
| Man. of machinery and metal prod. | 6.70 | 27.30 | 5.50 | 16.10 | 6.80 | 16.90 | 6.20 | 14.40 |
| Man. of non-metallic mineral prod. | 6.30 | 7.20 | 5.10 | 8.40 | 6.30 | 10.10 | 4.50 | 9.80 |
| Man. of paper and paper products | 2.20 | 0.70 | 2.40 | 1.00 | 1.40 | 1.10 | 0.50 | 0.70 |
| Man. of rubber and plastic prod. | 1.10 | 4.30 | 2.20 | 2.50 | | | | |
| Man. of textiles | 3.20 | 4.70 | 2.30 | 5.80 | 1.40 | 2.40 | 0.90 | 4.50 |
| Man. of wood | 2.20 | 0.70 | 2.90 | 0.30 | | | | |
| Mining | 2.10 | 0.40 | 4.10 | 0.50 | | | | |
| Transportation and storage | 2.20 | 2.50 | 1.30 | 1.50 | 2.40 | 6.10 | 1.40 | 1.30 |

The smallest and the greatest installations were discarded or remained unmatched. ETS installations are now only two times greater emitters of $CO_2$, on average, than before matching when the ETS and non-ETS installations differed ten times. Almost the same holds true for the total fuel consumption, especially the consumption of natural gas became balanced. Fossil fuels still dominate among ETS installations. Interestingly, the difference in the number of employees has even widened; otherwise, the values of financial indicators have decreased for the ETS group and increased for the non-ETS group.

Table 5.2: Mean values of selected variables, 2002 - 2019

| | Before matching | | Common support | | After matching | |
|---|---|---|---|---|---|---|
| Variable | non-ETS | ETS | non-ETS | ETS | non-ETS | ETS |
| $CO_2$ emissions [t] | 16 498.22 | 181 905.46 | 2 377.67 | 9 369.29 | 3 406.85 | 8 177.71 |
| Total fuel [GJ] | 202 437.09 | 2 140 918.09 | 41 175.94 | 167 409.35 | 59 002.51 | 135 479.20 |
| Coal [GJ] | 141 014.18 | 1 606 298.47 | 2 121.22 | 27 886.15 | 2 786.42 | 28 702.53 |
| Natural gas [GJ] | 32 881.64 | 192 464.21 | 36 431.28 | 100 413.94 | 53 157.22 | 81 852.45 |
| Other fuel types [GJ] | 28 541.27 | 342 155.42 | 2 593.43 | 39 109.25 | 3 058.86 | 24 924.21 |
| Employees | 296 | 336 | 304 | 421 | 287 | 391 |
| Revenues [bil Kč] | 1.555 | 2.429 | 1.595 | 2.287 | 2.094 | 2.036 |
| Costs [bil Kč] | 1.452 | 2.145 | 1.493 | 1.987 | 1.943 | 1.724 |
| Assets [bil Kč] | 1.282 | 3.407 | 1.176 | 2.174 | 1.430 | 2.025 |
| Number of inst. | 2137 | 369 | 453 | 96 | 173 | 78 |

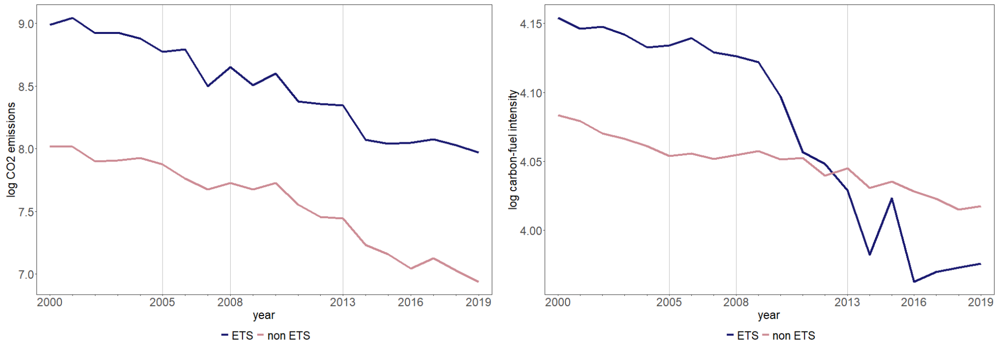
Most importantly, the trends of chosen variables follow a fairly parallel path necessary for the difference-in-differences estimator. Figure 5.2 depicts the development of the mean logarithm of $CO_2$ emissions, carbon-fuel intensity and carbon intensity of production for the matched sample. The changes in $CO_2$ emissions follow the same direction, especially in the pretreatment period. Except for greater magnitude of the changes in $CO_2$ emissions of treatment group, the parallel trend holds true even during phases I and II. The reduction of $CO_2$ emissions is faster for non-ETS installations during phase III.

The trend of average carbon-fuel intensity did not differ much during the pre-treatment period. The plot of mean values of logged carbon-fuel intensity shows slightly decreasing development before 2005. A great change occured at the beginning of phase II, where the ETS installations decreased their values of carbon-fuel intensity and they achieved even lower values than non-ETS installations then.

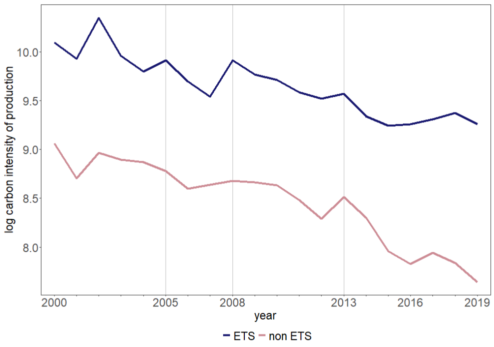
The emission-revenues ratio is bumpier, with a lagged development in the pretreatment period, it would appear. The parallel trend is not so clear as in the case of previous variables. Although, when we consider only the closest years (2002 - 2004) before the treatment which will be used in the estimation, the trend is decreasing for both groups. We have to be more cautious when interpreting the DID model.

We also present the data on common support, which we use for the DID model with inverse probability treatment weighting. The reader can compare how installations on common support and matched installations differ. On aver-

Figure 5.2: Mean annual emissions and emission intensities (in logarithm), after matching, 2000 - 2019



(a) $CO_2$ emissions (b) Carbon-fuel intensity (kg $CO_2$/GJ)

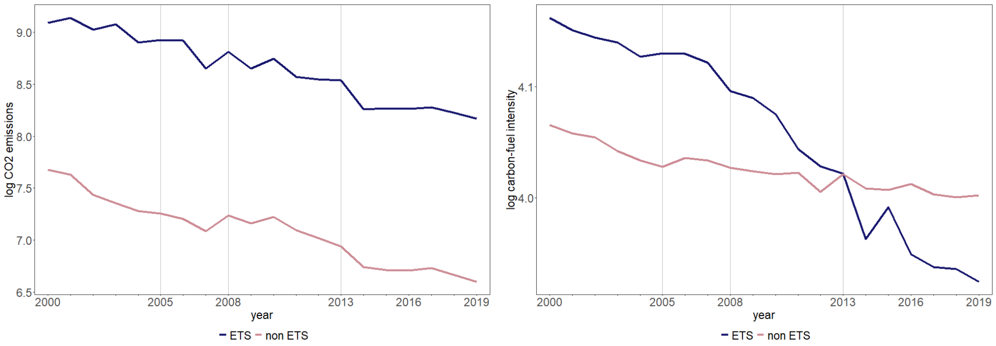


(c) Carbon intensity of production (t $CO_2$/bil Kč)

age, the ETS and non-ETS installations are more similar after matching rather than only on the common support. Data on common support still includes side installations that make the ETS group greater in chosen variables and non-ETS group smaller, on average. Specifically, there are 453 non-regulated and 96 regulated installations. Because we do not impose any additional restrictions as in the matching procedure, more sectors are kept in the sample (table 5.1), and the estimated effect comes from broader evidence. The mean values of emissions and emission intensities mimic the mean values of the matched sample (table 5.2). The gap between an average ETS and non-ETS installation in development of dependent variables has widened as shown in figure 5.3.

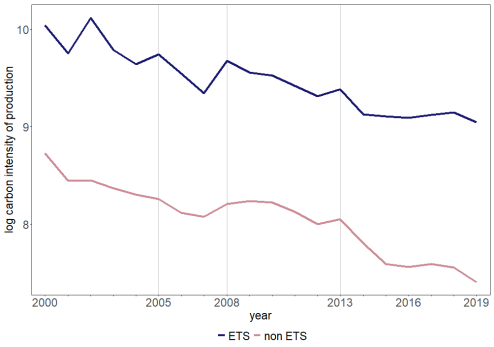
In addition to the visual evaluation of trends, we also present a placebo test of pre-treatment values (2000 - 2004). We regress each variable in our interest on interaction term of year dummy variable and treatment status (if the installation is treated after 2005). The joint hypothesis of equality of pre-treatment common trends cannot be rejected. The p-values of joint tests for

Figure 5.3: Mean annual emissions and emission intensities (in logarithm), common support, 2000 - 2019



(a) $CO_2$ emissions

(b) Carbon-fuel intensity (kg $CO_2$/GJ)



(c) Carbon intensity of production (t $CO_2$/bil Kč)

each variable can be found in section A.3.2 in the Appendix.

## 5.2 The effect of the EU ETS

### 5.2.1 $CO_2$ emissions

The estimated ATT of the EU ETS on $CO_2$ emissions are available in table 5.3. We present three main models. Classic difference-in-differences with propensity score matching, a DID model with inverse probability treatment weighting and a DID model including installations' fixed effects. The results of the DID model on matched sample with no covariates are in column (1), column (2) describes DID with industy dummies and all covariates included (employees, revenues, total assets) and the model in column (3) leaves out phase I. Column

(4) presents the results of DID model with IPTW, while column (5) reports the results for DID with installations' fixed effects. In each model, we accounted for year fixed effects and standard errors were clustered at the company level.

Overall, none of the estimated impacts is statistically significant at any convenient level with absolute value of the coefficients close to zero. The coefficient for phase II appears negative in each model. The coefficients for phases I and III in model (1) and (5) are negative, still statistically not distinguishable from zero, whilst it turns to be positive, still non-significant, for models (2) and (4). Since phase I was rather a pilot phase, we expect that the effect of the EU ETS in phases II and III would get stronger after excluding phase I. However, model (3) almost copies the results from model (2). While the DID specifications (1) - (4) show similar results, model (5) states a greater negative impact for all the phases. Inclusion of installations' fixed effects did not make the effects significant, even though the standard errors are smaller.

Table 5.3: The effect of the EU ETS on $CO_2$ emissions

| Dependant var.: | | | DID | | IPTW | FE |
|---|---|---|---|---|---|---|
| log of $CO_2$ em. | Coef. | (1) | (2) | (3) | (4) | (5) |
| ETS group | $\beta_1$ | 0.944$^{***}$ | 0.731$^{***}$ | 0.745$^{***}$ | -0.058 | |
| | | (0.164) | (0.149) | (0.156) | (0.250) | |
| ETS Phase I | $\beta_3$ | -0.026 | 0.018 | | 0.072 | -0.058 |
| | | (0.081) | (0.082) | | (0.155) | (0.082) |
| ETS Phase II | $\beta_3$ | -0.074 | -0.013 | -0.022 | -0.075 | -0.143 |
| | | (0.141) | (0.144) | (0.145) | (0.116) | (0.127) |
| ETS Phase III | $\beta_3$ | -0.008 | 0.032 | 0.038 | 0.043 | -0.092 |
| | | (0.221) | (0.228) | (0.228) | (0.237) | (0.189) |
| Year fixed effects | | Yes | Yes | Yes | Yes | Yes |
| Industry dummies | $\gamma_i$ | No | Yes | Yes | Yes | Yes |
| Control variables | | No | Yes | Yes | Yes | Yes |
| Phase I included | | Yes | Yes | No | Yes | Yes |
| Weighted reg. | | No | No | No | Yes | No |
| Inst. fixed effects | $\eta_i$ | No | No | No | No | Yes |
| Observations | | 4150 | 3978 | 3268 | 8713 | 3978 |

$^{*}$p<0.1; $^{**}$p<0.05; $^{***}$p<0.01

Note: Clustered standard errors at company level in parentheses. Financial variables corrected by PPI index. Examined period of 2002 - 2019. Columns (1) - (3) represent classic DID model with PS matching, column (4) reports DID model with inverse probability treatment weighting and the model in column (5) adds to the DID model with PS matching fixed effects of installations.

We are not surprised that the effect of the EU ETS did not appear significant in phase I and that the effect on $CO_2$ reduction of regulated firms is close to zero because the functioning of the the EU ETS were rather tested in the pilot phase. However, although we have the data available for a long time period, we find no effect on emissions during phases II and III either. Instead, it appears that the emission reduction happened independently of the EU ETS as all of the year effects proved negative and significant. Possible explanations of no effect of the EU ETS on $CO_2$ emissions are provided later.

### 5.2.2 Carbon-fuel intensity

We focus next on the estimated ATT of the EU ETS on carbon intensity expressed as $CO_2$ emissions relative to fuel consumption. The models are specified identically as in the previous section. The estimation results are presented in table 5.4.

The effect of the EU ETS on carbon intensity is more stable than the estimates of the effect on absolute emission volumes; however, none of the coefficients is statistically significant. The effects of phases II and III show the same signs in all models; even the magnitude remains similar. The clustered standard errors are much smaller now, but not enough to make the estimates statistically significant. The exclusion of phase I or additional covariates did not change the results either.

Again, the effect of the EU ETS during phase I is not distinguishable from zero and the installations did not react immediately to the policy by changing the fuel mix since it takes time to adapt. The reduction is visible for phases II (approx. 3%) and III (approx. 11%); however, none of these coefficients is statistically significant at any convenient level (standard clustered errors at the company level removed the significance at 1% level). The downward sloping trend is essential to observe the change from a high-carbon mix to a low-carbon mix of fuels. And thus, the incentives coming from the EU ETS to choose other type of fuel than fossil fuel were not sufficiently strong. The year effects suggest significant reduction of carbon-fuel intensity during phases II and III varying from approximately 4% to 8%.

Table 5.4: The effect of the EU ETS on carbon-fuel intensity

| Dependant var.:<br>log of carbon int. | Coef. | (1) | DID<br>(2) | (3) | IPTW<br>(4) | FE<br>(5) |
|---|---|---|---|---|---|---|
| ETS group | $\beta_1$ | 0.075*** | 0.075*** | 0.076*** | 0.007 | |
| | | (0.027) | (0.028) | (0.028) | (0.040) | |
| ETS Phase I | $\beta_3$ | 0.006 | 0.004 | | -0.001 | -0.008 |
| | | (0.013) | (0.013) | | (0.017) | (0.026) |
| ETS Phase II | $\beta_3$ | -0.036 | -0.033 | -0.033 | -0.030 | -0.031 |
| | | (0.037) | (0.039) | (0.039) | (0.041) | (0.055) |
| ETS Phase III | $\beta_3$ | -0.114 | -0.113 | -0.112 | -0.094 | -0.121 |
| | | (0.068) | (0.070) | (0.071) | (0.064) | (0.076) |
| Year fixed effects | | Yes | Yes | Yes | Yes | Yes |
| Industry dummies | $\gamma_i$ | No | Yes | Yes | Yes | Yes |
| Control variables | | No | Yes | Yes | Yes | Yes |
| Phase I included | | Yes | Yes | No | Yes | Yes |
| Weighted reg. | | No | No | No | Yes | No |
| Inst. fixed effects | $\eta_i$ | No | No | No | No | Yes |
| Observations | | 4151 | 3978 | 3268 | 8713 | 3978 |

*p<0.1; **p<0.05; ***p<0.01

Note: Clustered standard errors at company level in parentheses. Financial variables corrected by PPI index. Examined period of 2002 - 2019. Columns (1) - (3) represent classic DID model with PS matching, column (4) reports DID model with inverse probability treatment weighting and the model in column (5) adds to the DID model with PS matching fixed effects of installations.

### 5.2.3 Carbon intensity of production

The models estimating the ATT of the EU ETS on carbon intensity of production in the form of t $CO_2$ emitted per billion of Czech koruna follow the same specifications as the previous subsections, and results are available in table 5.5. All phases of the EU ETS appear to have a positive non-significant effect on the carbon intensity of production with different magnitude of estimates, depending on the given model.

During phase I, the effect of the EU ETS suggests a positive impact in 3 out of 4 estimated models. The great recession occurred at the beginning of phase II, which could have also influenced installations' production. The average revenues slow down their increasing trend from previous phase during that period (plotted in figure A.3). The treated installations appear to be hit harder by a slump in 2008, the control installations do not show such an apparent reaction. Phase III indicates again increasing average revenues and decreasing average emissions. The estimates are close to zero in models (2) - (5) and non-significant for each specification. Hence, we do not observe any effect of the EU ETS distinguishable from zero on carbon intensity of production.

Table 5.5: The effect of the EU ETS on carbon intensity of production

| Dependant var.:<br>log of carbon int. | Coef. | DID<br>(1) | <br>(2) | <br>(3) | IPTW<br>(4) | FE<br>(5) |
|---|---|---|---|---|---|---|
| ETS group | $\beta_1$ | 1.102*** | 0.512** | 0.523** | -0.143 | |
| | | (0.418) | (0.226) | (0.229) | (0.240) | |
| ETS Phase I | $\beta_3$ | -0.063 | 0.040 | | 0.083 | 0.057 |
| | | (0.203) | (0.163) | | (0.195) | (0.101) |
| ETS Phase II | $\beta_3$ | 0.046 | 0.159 | 0.143 | 0.086 | 0.051 |
| | | (0.286) | (0.259) | (0.260) | (0.202) | (0.187) |
| ETS Phase III | $\beta_3$ | 0.226 | 0.088 | 0.096 | 0.004 | 0.002 |
| | | (0.352) | (0.313) | (0.312) | (0.270) | (0.208) |
| Year fixed effects | | Yes | Yes | Yes | Yes | Yes |
| Industry dummies | $\gamma_i$ | No | Yes | Yes | Yes | Yes |
| Control variables | | No | Yes | Yes | Yes | Yes |
| Phase I included | | Yes | Yes | No | Yes | Yes |
| Weighted regression | | No | No | No | Yes | No |
| Inst. fixed effects | $\eta_i$ | No | No | No | No | Yes |
| Observations | | 4015 | 3978 | 3268 | 8713 | 3978 |

*p<0.1; **p<0.05; ***p<0.01

Note: Clustered standard errors at company level in parentheses. Financial variables corrected by PPI index. Examined period of 2002 - 2019. Columns (1) - (3) represent classic DID model with PS matching, column (4) reports DID model with inverse probability treatment weighting and the model in column (5) adds to the DID model with PS matching fixed effects of installations.

### 5.2.4 Robustness checks

We also perform models with different settings and restrictions to explore how robust the results are and if we find possibly slightly distinct results for the EU ETS' effect. In brief, we allow for only three nearest neighbours during the matching process, keep only companies that own solely ETS installations or solely non-ETS installations, or we also include regulated installations that entered the system or exited from the system without any time restrictions.

#### Smaller number of nearest neighbours

Firstly, we explore how the models change when stricter requirements during the matching process are set. We allow only for three nearest neighbours, instead of ten nearest neighbours, by which we diminish the sample size, but the installations will be more alike. Table 5.6 presents the results for DID, together with the DID model that includes installations' fixed effect. We disregard the exclusion of phase I since it did not change previous findings and we do not include the model without the covariates either. Since the common support data sample did not change, the results of DID with IPTW can be found in the previous section.

The composition of treatment and control groups is similar to the dataset in the previous section. Moreover, the non-ETS group is more similar, on average, to the ETS group and thus, we disregarded mainly the minor installations that are further neighbours. Specifically, we compare 78 ETS installations to 97 non-ETS installations. The number of installation-year observations decreased by 30%. The distribution of installation-year observations by sectors and plots of parallel trends can be found in Appendix section A.4 as well as the p-values of joint hypothesis of equality of pre-treatment common trends.

Table 5.6: The effect of the EU ETS on emissions and emission intensities, 3 neighbours

| | Dependant variable | | | | | |
|---|---|---|---|---|---|---|
| | $CO_2$ | | $CO_2$ / fuel | | $CO_2$ / revenues | |
| | (1) | (2) | (3) | (4) | (5) | (6) |
| ETS group | 0.555*** | | 0.066** | | 0.453* | |
| | (0.157) | | (0.031) | | (0.239) | |
| ETS Phase I | 0.049 | -0.028 | -0.001 | -0.010 | 0.030 | 0.029 |
| | (0.097) | (0.090) | (0.013) | (0.027) | (0.172) | (0.105) |
| ETS Phase II | -0.025 | -0.155 | -0.034 | -0.029 | 0.111 | -0.052 |
| | (0.162) | (0.135) | (0.040) | (0.055) | (0.286) | (0.218) |
| ETS Phase III | 0.126 | -0.051 | -0.101 | -0.099 | 0.027 | -0.104 |
| | (0.274) | (0.205) | (0.073) | (0.079) | (0.376) | (0.221) |
| Inst. fixed effects | No | Yes | No | Yes | No | Yes |
| Observations | 2794 | 2794 | 2794 | 2794 | 2794 | 2794 |

*p<0.1; **p<0.05; ***p<0.01

Note: Clustered standard errors at company level in parentheses. Financial variables corrected by PPI index. Examined period of 2002 - 2019. All covariates included. Columns (1), (3) and (5) represent classic DID model with PS matching, models in columns (2), (4) and (6) add to the DID model fixed effects of installations.

The estimates remained non-significant and we do not find any deviation from the results in the main section. The effect of the EU ETS on carbon-fuel intensity seems to be the most stable one again. The estimates for all phases are negative with small standard errors but not sufficiently small to show significance on any level. The coefficients of the effect on absolute $CO_2$

emissions became only greater, the insignificance is still present. We see a minor change in the effect on carbon intensity of production, where the fixed effect model suggests a negative impact during phases II and III. However, standard errors are still large and we cannot reject that the estimates are different from zero.

### Companies owning solely ETS installations or solely non-ETS installations

An internal spillover effect among regulated and non-regulated installations owned by the same company could serve as a possible explanation of no effect of the EU ETS. This would lead to a violation of the SUTVA assumption. It is not possible to test the SUTVA assumption empirically. However, we tried to mitigate the possible internal spillover by removing those companies from our data sample and perform the regression at the price of a very small data sample. We could be even stricter and remove all companies that own more than one installation, but we try to get rid of a potential spillover between regulated and non-regulated installations and thus, it is not necessary.

The matching variables remain the same as well as matching restrictions. Pre-treatment $CO_2$ emissions and total assets are statistically significant determinants of the treatment status. Unfortunately, many installations were discarded due to their position out of the common support, and we are left with only 22 treated and 93 untreated installations. Also, the number of main sectors shrunk to 5 sectors. The majority of installations are again in the energy sector, followed by the sector of manufacturing of machinery and metal products. Installations became balanced on average (all figures in Appendix section A.4.2), parallel trends are very bumpy. We have to be cautious about making any conclusions.

The results are similar to the results in the main part. However, the effect of the EU ETS on absolute $CO_2$ emissions in phase III appears significant in models in columns (2) and (3) at 5% and 10% significance levels with a positive effect of approximately 45% ($e^{0.37}$ - 1 = 0.45) and 39%, respectively. This suggests that the EU ETS made ETS installations increase their $CO_2$ emissions by more than one third compared to the control group. From the plot of parallel trends, it is visible that the average emissions of ETS installations has increased while the non-ETS installations managed to decrease their emissions. We cannot generalize this impact beyond this small sample. The coefficients of the effect of the EU ETS on carbon-fuel intensity is close to zero and model that also includes FE of installations presents significant effects of approximately 1.6% for phase I and 4% for phase II, both at a 10% significance level. Again, we stress that this is mainly a local effect, yet it appears that for this group, the installations' reaction was not in favour of green economy. No significant impacts were found for the dependent variable of carbon intensity of production even though the plots show vast gap between trends of groups for phase III for the matched sample.

Table 5.7: The effect of the EU ETS on emissions and emission intensities, companies that own solely ETS installations or solely non-ETS installations

| | Dependant variable | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | $CO_2$ | | | $CO_2$ / fuel | | | $CO_2$ / revenues | | |
| | DID<br>(1) | IPTW<br>(2) | FE<br>(3) | DID<br>(4) | IPTW<br>(5) | FE<br>(6) | DID<br>(7) | IPTW<br>(8) | FE<br>(9) |
| ETS group | 0.295** | 0.210 | | 0.016 | 0.082 | | -0.314 | -0.269 | |
| | (0.146) | (0.184) | | (0.042) | (0.070) | | (0.334) | (0.271) | |
| ETS Phase I | 0.029 | 0.100 | -0.047 | 0.016 | -0.014 | 0.016* | -0.187 | 0.092 | -0.094 |
| | (0.030) | (0.082) | (0.118) | (0.013) | (0.030) | (0.009) | (0.124) | (0.112) | (0.140) |
| ETS Phase II | 0.030 | 0.180 | 0.041 | 0.009 | -0.037 | 0.024 | -0.160 | 0.136 | -0.098 |
| | (0.153) | (0.110) | (0.163) | (0.028) | (0.058) | (0.022) | (0.312) | (0.176) | (0.176) |
| ETS Phase III | 0.443 | 0.373** | 0.334* | 0.047 | -0.005 | 0.040* | 0.164 | 0.208 | 0.107 |
| | (0.233) | (0.161) | (0.192) | (0.024) | (0.073) | (0.022) | (0.386) | (0.209) | (0.190) |
| Weighted reg. | No | Yes | No | No | Yes | No | No | Yes | No |
| Inst. FE | No | No | Yes | No | No | Yes | No | No | Yes |
| Observations | 1838 | 5380 | 1838 | 1835 | 5380 | 1838 | 1838 | 5380 | 1838 |

$^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

Note: Clustered standard errors at company level in parentheses. Financial variables corrected by PPI index. Examined period of 2002 - 2019. All covariates included. Columns (1), (4) and (7) represent classic DID models with PS matching, columns (2), (5) and (8) present DID models with inverse probability treatment weighting and models in columns (3), (6) and (9) add to the DID model with PS matching fixed effects of installations.

### Switchers included

As discussed in subsection 3.3, the choice of ETS installations was limited only to installations regulated during each phase. Table 5.8 summarizes findings when we allow the installations to enter the system also after phase I or exit from the system before phase III. The main idea of DID, which says that in the absence of treatment, the ETS installations would behave as non-regulated ones, should account for those changes. Nonetheless, we expect that the treatment behaviour spills over to subsequent years for installations that used to be treated. Possibly, they adjusted their emissions thanks to the EU ETS by investing in better technology or their behavioural patterns have changed.

The propensity score matching settings were not changed. This time, in addition to pre-treatment values of $CO_2$ and total assets, also the consumption of coal appears significant. The data sample increased and after matching, it consists of 95 installations regulated at least once during one of the phases and 205 installations never subjected to the EU ETS. Their average values are reported in Appendix section A.4.3. The energy sector still accounts for most of the installations and $CO_2$ emissions; on the other side, the number of sectors increased to ten. Instead of year fixed effects, we include phase group fixed effects to account for specific characteristics among installations regulated during different phases.

Table 5.8: The effect of the EU ETS on emissions and emission intensities, switchers included

| | Dependant variable | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | $CO_2$ | | | $CO_2$ / fuel | | | $CO_2$ / revenues | | |
| | DID (1) | IPTW (2) | FE (3) | DID (4) | IPTW (5) | FE (6) | DID (7) | IPTW (8) | FE (9) |
| ETS phase FE | 0.719*** | 0.086 | 0.699* | 0.039 | 0.006 | 0.093 | 0.581*** | 0.023 | 0.603* |
| | (0.142) | (0.194) | (0.280) | (0.030) | (0.034) | (0.089) | (0.185) | (0.210) | (0.286) |
| ETS Phase I | 0.100 | 0.123 | -0.002 | 0.021 | 0.013 | -0.011 | 0.102 | 0.148 | 0.045 |
| | (0.104) | (0.111) | (0.099) | (0.022) | (0.014) | (0.030) | (0.137) | (0.140) | (0.108) |
| ETS Phase II | -0.098 | -0.026 | -0.253* | 0.002 | -0.0005 | -0.053 | -0.007 | 0.116 | -0.170 |
| | (0.156) | (0.116) | (0.126) | (0.038) | (0.024) | (0.040) | (0.224) | (0.190) | (0.164) |
| ETS Phase III | 0.083 | 0.040 | -0.133 | 0.015 | 0.007 | -0.084 | 0.114 | -0.010 | -0.064 |
| | (0.210) | (0.199) | (0.188) | (0.056) | (0.033) | (0.060) | (0.260) | (0.242) | (0.195) |
| Weighted reg. | No | Yes | No | No | Yes | No | No | Yes | No |
| Ins. FE | No | No | Yes | No | No | Yes | No | No | Yes |
| Observations | 4749 | 9087 | 4749 | 4749 | 9087 | 4749 | 4749 | 9087 | 4749 |

*p<0.1; **p<0.05; ***p<0.01

Note: Clustered standard errors at company level in parentheses. Financial variables corrected by PPI index. Examined period of 2002 - 2019. All covariates included. Columns (1), (4) and (7) represent classic DID models with PS matching, columns (2), (5) and (8) present DID models with inverse probability treatment weighting and models in columns (3), (6) and (9) add to the DID model with PS matching fixed effects of installations.

We do not see any explicit changes. The effect of the EU ETS on emissions copies the results from section 5.2 except that the emission reduction of 22% caused by the EU ETS during phase II estimated by model that includes fixed effects of installations appears significant at 10% level. As the main results follow also a negative (non-significant) effect of the EU ETS during phase II, it suggests that it could be the only period where the installations managed to reduce the emissions partly due to the EU ETS. Also the recession may have contributed to the abatement. The effect of the EU ETS on both carbon-fuel intensity and carbon intensity of production do not show any significant estimates and we cannot reject that they are different from zero.

## 5.3 Discussion

According to our results, we conclude that the policy of the EU ETS had no significant impact on $CO_2$ emissions of regulated installations in the Czech Republic. We examine the effect of the EU ETS by estimating various models and their specifications and still, the effect of the EU ETS has remained not significant at any convenient level for DID with propensity score matching as well as for DID model, where we account for installation-specific heterogeneity. The replacement of propensity score matching by IPTW in the DID model shows non-significant effect either. We note that the results found hold for the models that were feasible to estimate due to small data sample and only for a subset of regulated installations due to difficulties to find suitable unregulated installations that will match with the treated ones. Our results should be therefore interpreted with a caution.

We are not surprised that we find no effect of the EU ETS in phase I in the Czech Republic. Several schollars (Convery et al. (2008), Abrell et al. (2011), Ellerman & Buchner (2008)) have pointed out that the volume of emission allowances allocated (for free) exceeded the actual emissions and thus, the incentives to lower the emissions were low. Low motivation for the abatement resulted in increased accumulation of EUA that continued until the MSR went into force, as shown in figure 2.2. The over-allocation went hand in hand with very low prices of EUA at the end of phase I making trading unnecessary. However, the exclusion of phase I from our analysis did not improve our findings for phases II and III. Larger effect of the EU ETS might be expected in the phase IV, which has just started, since the EUA price that is now exceeding 50 EUR, is making carbon emissions more expensive. For instance, Best et al. (2020) estimate a 0.3% emission reduction in a subsequent year when the price of a tonne of $CO_2$ rises by one euro.

The EU ETS has come into force more than 15 years ago, which means that this regulation also coincided with the recession happening during phase II. In fact, we find a negative effect on $CO_2$ emissions and carbon-fuel intensity and a positive effect on carbon intensity of production, in all cases not significant at any convenient level, during phase II. Since economic recession covered phase II almost entirely, it is difficult to disentangle the effect of the EU ETS from the effect of the recession and involved economic sector restructuralization and possible input substitutions. A 22% abatement significant at 10% level (estimated by only one FE model (3) in table 5.8 that includes also switchers) during phase II suggests that the EU ETS could be the cause.

Phase III did not result in significant effect either (except additional models based on a very small sample) for any of the dependent variables. This is the most surprising outcome of our analysis. The system has undergone several changes, the pilot phase was long ago, and stricter measures were applied. Especially, the free allocation of EUA diminished being replaced by auctioning. Despite Abrell et al. (2011) and Dechezleprêtre et al. (2018) stress that a greater abatement might occur without free allocation of allowances, this did not happen in the Czech Republic, at least among the installations that comprised our subset of regulated units that was possible to use in our analysis.

From the plots, we can see that non-regulated installations reduced emissions at a quicker pace. Carbon-fuel intensity decreases very convincingly for the ETS group too, mainly due to shifting their energy mix in the direction towards the low-carbon fuels. However, the effect of the EU ETS has remained still non-significant. And the no-effect persists also when we investigate the effect of the EU ETS on the carbon intensity of production. The development of trends is similar as in the case of emission levels.

Nonetheless, we estimate only a local effect. Due to PS matching, the installations from eight main sectors were present in our dataset only, with a great share of installations in the energy sector. Moreover, uncertainty enters the data sample through companies' self-reporting of fuel used and our estimation of $CO_2$ emissions relying on fuel-specification emission factors. Furthermore, we compare environmental performance during all phases to pre-treatment levels that cover 2003-2004, making phase III far away from the pre-treatment period. Installations matched together on pretreatment levels could have deviated a lot during the ten years and would not appear like a good match just before phase III. Studying only phase III seems convenient, but it would mean matching installations on endogenous variables (e.g. 2010-2012 considered as a pre-treatment period which overlaps with phase II), which will bias the estimates. Considering only ETS installations that enter the system during phase III only is not possible due to a minimal number of regulated installations.

Given all the circumstances and data limitations of our study, we believe that we accounted for most of the difficulties that we might encounter. Although our time period covered the whole three phases (2020 could not be included due to the global pandemic and a one-year delay in data reporting), we did not find any effect of the EU ETS on $CO_2$ emissions or carbon intensities, and we cannot support any of our three hypotheses. As the effect of the EU ETS on carbon-fuel intensity appeared consistent among all phases with rather small standard errors, but still non-significant, the next analysis could focus on fuel switching within this period to confirm the hypothesis of changing the fuel type from fossil fuels to less carbon-intense fuels. Or, if there is some effect of the EU ETS on other non-carbon emissions (i.e. ancillary effect). Besides the environmental effect, even though the carbon intensity of production showed no reaction to the EU ETS, one could explore if the EU ETS had any effect on the economic performance of installations or companies.

# Chapter 6

# Conclusion

In this thesis, we explored the effect of the EU Emissions Trading System, the main tool of the European Union to combat global climate warming, on $CO_2$ emissions, carbon-fuel intensity and carbon intensity of production in the Czech Republic (2005 - 2019). Installation-level data allowed us to analyse the effect of a cap-and-trade system, which should motivate regulated installations to reduce the emissions cost-efficiently and innovate their technology.

However, we conclude that the EU ETS had no impact on the regulated installations in the Czech Republic. We used a difference-in-differences approach with propensity score matching without and with installations' fixed effects as well as DID with inverse probability treatment weighting to estimate what would have happened had not the EU ETS been introduced. No significant estimates are in favour of our three hypotheses of reduction of emissions or emission intensities. It appears that non-ETS installations managed to reduce $CO_2$ emissions regardless of the policy. The trend of carbon intensity of production ($CO_2$ emissions relative to revenues) suggests a very similar result. And even though the ETS installations were successful in reducing the carbon-fuel intensity ($CO_2$ emissions relative to fuel consumption), it was not enough to assign the causal effect to the EU ETS. All these findings hold for the average effect of the EU ETS on regulated installations, although, we acknowledge a heterogeneity in response is possible.

The incentives by the EU ETS to reduce emissions have been in fact small to encourage emission abatement. While phase I was criticized for the over-allocation of allowances making the price of EUA very low, the second phase coincided with economic recession and downturn. One might expect some effect of the EU ETS in phase III when the allocation of allowances changed and the system has been working for many years, yet we find no effect. Contrary, we cannot deny the limitations of our study. There is only a fraction of ETS installations in the Czech Republic compared to the whole EU. Having more data would be beneficial during the matching process leading to more observations for the regressions.

Still, our findings are in line with previous studies of the effect of the EU ETS based on data from other small countries like Lithuania by Jaraitė & Di Maria (2016) who find no effect on $CO_2$ emissions and a slight improvement in carbon intensity of production, or Norway where Klemetsen et al. (2016) estimate only a weak tendency to abatement. Since the negative, still not significant, effect of the EU ETS on carbon-fuel intensity remains stable across model specifications, an analysis of a relationship between fuel switching from high- to low-carbon energy mix and the policy of the EU ETS shows a logical next step of research.

# References

Abadie, A. (2005). Semiparametric Difference-in-Differences Estimators. *The Review of Economic Studies*, *72*(1), 1–19. doi: 10.1111/0034-6527.00321

Abadie, A., Athey, S., Imbens, G. W., & Wooldridge, J. (2017). *When Should You Adjust Standard Errors for Clustering?* (Tech. Rep. No. 24003). National Bureau of Economic Research. doi: 10.3386/w24003

Abrell, J., Faye, A. N., & Zachmann, G. (2011). *Assessing the impact of the EU ETS using firm level data* (Tech. Rep.). Bruegel.

Anderson, B., & Di Maria, C. (2011). Abatement and Allocation in the Pilot Phase of the EU ETS. *Environmental and Resource Economics*, *48*(1), 83–103. doi: 10.1007/s10640-010-9399-9

Angrist, J. D., Imbens, G. W., & Rubin, D. B. (1996). Identification of Causal Effects Using Instrumental Variables. *Journal of the American Statistical Association*, *91*(434), 444–455. doi: 10.2307/2291629

Angrist, J. D., & Pischke, J.-S. (2008). *Mostly Harmless Econometrics.* Princeton University Press.

Austin, P. C. (2011). An Introduction to Propensity Score Methods for Reducing the Effects of Confounding in Observational Studies. *Multivariate Behavioral Research*, *46*(3), 399–424. doi: 10.1080/00273171.2011.568786

Austin, P. C. (2014). A comparison of 12 algorithms for matching on the propensity score. *Statistics in Medicine*, *33*(6), 1057–1069. doi: https://doi.org/10.1002/sim.6004

Austin, P. C., & Stuart, E. A. (2015). Moving towards best practice when using inverse probability of treatment weighting (IPTW) using the propensity score to estimate causal treatment effects in observational studies. *Statistics in Medicine*, *34*(28), 3661–3679. doi: 10.1002/sim.6607

Bayer, P., & Aklin, M. (2020). The European Union Emissions Trading System reduced CO2 emissions despite low prices. *Proceedings of the National Academy of Sciences of the United States of America*, *117*(16), 8804–8812. doi: 10.1073/pnas.1918128117

Bel, G., & Joseph, S. (2015). Emission abatement: Untangling the impacts of the EU ETS and the economic crisis. *Energy Economics*, *49*, 531–539. doi: 10.1016/j.eneco.2015.03.014

Best, R., Burke, P. J., & Jotzo, F. (2020). Carbon Pricing Efficacy: Cross-Country Evidence. *Environmental and Resource Economics*, *77*(1), 69–94. doi: 10.1007/s10640-020-00436-x

Bruninx, K., Ovaere, M., & Delarue, E. (2019). The Long-Term Impact of the Market Stability Reserve on the EU Emission Trading System. KULeuven Energy Institute.

Brzobohatý, T., & Janský, P. (2010). Impact of CO2 Emissions Reductions on Firms' Finance in an Emerging Economy: The Case of the Czech Republic. *Transition Studies Review*, *17*(4), 725. doi: 10.1007/s11300-010-0168-9

Caliendo, M., & Kopeinig, S. (2008). Some practical guidance for the implementation of propensity score matching. *Journal of Economic Surveys*, *22*(1), 31–72. doi: 10.1111/j.1467-6419.2007.00527.x

Carbon Dioxide Information Analysis Center. (2021). *CO2 emissions (kg per PPP $ of GDP).* Retrieved 2021-07-02, from https://data.worldbank.org/indicator/EN.ATM.CO2E.PP.GD?end=2018&locations=CZ&start=1990&view=chart

CHMI. (2020). *National Greenhouse Gas Inventory Report of the Czech Republic (reported inventories 1990 - 2018)* (Tech. Rep.). Prague: Czech Hydrometeorological Institute.

CHMI. (2021). *National Greenhouse Gas Inventory Report of the Czech Republic (reported inventories 1990 - 2019)* (Tech. Rep.). Prague: Czech Hydrometeorological Institute.

Chvalkovská, J. (2006). Assessing impacts of the implementation of EU ETS with special focus on the position of Czech Republic. Prague: Charles University.

Chèze, B., Chevallier, J., Berghmans, N., & Alberola, E. (2020). On the CO2 emissions determinants during the EU ETS Phases I and II: a plant-level analysis merging the EUTL and Platts power data. , *41*(4).

Colmer, J., Martin, R., Muûls, M., & Wagner, U. J. (2020). *Does Pricing Carbon Mitigate Climate Change? Firm-Level Evidence from the European Union Emissions Trading Scheme* (SSRN Scholarly Paper No. ID 3725482). Rochester, NY: Social Science Research Network.

Convery, F., Perthuis, C. D., & Ellerman, D. (2008). The European Carbon Market In Action: Lessons From The First Trading Period. Interim Report. Massachusetts Institute of Technology, Center for Energy and Environmental Policy Research.

Cui, J., Liu, X., Sun, Y., & Yu, H. (2020). Can CDM projects trigger host countries' innovation in renewable energy? Evidence of firm-level dataset from China. *Energy Policy*, *139*, 111349. doi: 10.1016/j.enpol.2020.111349

Dechezleprêtre, A., Nachtigall, D., & Venmans, F. (2018). The joint impact of the European Union emissions trading system on carbon emissions and economic performance. OECD. doi: https://doi.org/10.1787/4819b016-en

Earnhart, D., & Lizal, L. (2008). Pollution reductions in the Czech Republic. *Post-Communist Economies*, *20*(2), 231–252. doi: 10.1080/14631370802018999

Ellerman, A. D., & Buchner, B. K. (2008). Over-Allocation or Abatement? A Preliminary Analysis of the EU ETS Based on the 2005–06 Emissions Data. *Environmental and Resource Economics*, *41*(2), 267–287. doi: 10.1007/s10640-008-9191-2

EPA. (2014). *Acid Rain Program* [Overviews and Factsheets]. Retrieved 2020-11-08, from https://www.epa.gov/acidrain/acid-rain-program

European Commission. (2015). *EU ETS Handbook.* European Union.

European Commission. (2016). *Causes of climate change.* Retrieved 2021-02-27, from https://ec.europa.eu/clima/change/causes_en

European Commission. (2020a). *EU Emissions Trading System (EU ETS)* [Text]. Retrieved 2020-11-15, from https://ec.europa.eu/clima/policies/ets_en

European Commission. (2020b). *European Union Transaction Log.* Retrieved 2021-02-12, from https://ec.europa.eu/clima/ets/welcome.do?languageCode=en

European Commission. (2020c). *Report from the Commission to the European Parliament and the Council: Report on the functioning of the European carbon market* (Tech. Rep. No. 740). Brussels: European Commission.

European Commission. (2021). *2030 Climate Target Plan* [Text]. Retrieved 2021-07-18, from https://ec.europa.eu/clima/policies/eu-climate-action/2030_ctp_en

Eurostat. (2021). *Greenhouse gas emissions intensity of energy consumption.* Retrieved 2021-07-02, from https://ec.europa.eu/eurostat/databrowser/view/sdg_13_20/default/table?lang=en

Höhne, N., Elzen, M. d., Rogelj, J., Metz, B., Fransen, T., Kuramochi, T., ... Dubash, N. K. (2020). Emissions: world has four times the work or one-third of the time. *Nature*, *579*(7797), 25–28. doi: 10.1038/d41586-020-00571-x

Iacus, S., King, G., Porro, G., Battistin, E., Beck, N., Blackwell, M., ... Winship, C. (2009). Causal inference without balance checking: Coarsened exact matching.

IEA. (2019). *CO2 emissions from fuel combustion - Highlights* (Tech. Rep.). International Energy Agency.

Imbens, G. W. (2004). Nonparametric Estimation of Average Treatment Effects under Exogeneity: A Review. *The Review of Economics and Statistics*, *86*(1), 4–29.

IPCC. (2006). *2006 IPCC Guidelines for National Greenhouse Gas Inventories.* IGES.

IPCC. (2018). *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the* *global response to the threat of climate change, sustainable development, and efforts to eradicate poverty* (Tech. Rep.). (Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.))

Jaraitė, J., & Di Maria, C. (2016). Did the EU ETS Make a Difference? An Empirical Assessment Using Lithuanian Firm-Level Data. In (Vol. 37, p. 1). CERE - the Center for Environmental and Resource Economics.

Klemetsen, M. E., Rosendahl, K. E., & Jakobsen, A. L. (2016). The impacts of the EU ETS on Norwegian plants' environmental and economic performance. Statistics Norway.

Laing, T., & Sato, M. (2013). Assessing the effectiveness of the EU Emissions Trading System. In *Grantham Research Institute on climate change and the environment.*

Le Quéré, C., Jackson, R. B., Jones, M. W., Smith, A. J. P., Abernethy, S., Andrew, R. M., … Peters, G. P. (2020). Temporary reduction in daily global CO 2 emissions during the COVID-19 forced confinement. *Nature Climate Change*, *10*(7), 647–653. doi: 10.1038/s41558-020-0797-x

Löschel, A., Lutz, B. J., & Managi, S. (2019). The impacts of the EU ETS on efficiency and economic performance – An empirical analyses for German manufacturing firms. *Resource and Energy Economics*, *56*, 71–95. doi: 10.1016/j.reseneeco.2018.03.001

Marcantonini, C., Teixido-Figueras, J., Verde, S. F., & Labandeira, X. (2017). *Low-carbon innovation and investment in the EU ETS* (Tech. Rep.). (doi: 10.2870/402517)

Ministry of the Environment of the Czech Republic. (2017). *Climate Change Policy of the Czech Republic: Executive Summary* (Executive Summary). Prague: Ministry of the Environment of the Czech Republic.

NAO. (2004). *The UK Emissions Trading Scheme: A New Way to Combat Climate Change* (Tech. Rep.).

Nissen, C., Cludius, J., Graichen, V., & Gores, S. (2020). *ETC/CME Report 3/2020: Trends and projections in the EU ETS in 2020.* (Tech. Rep.). ETC/CME.

Němcová, I., Vondrušková, B., & Horák, J. (2010). Carbon Trading under the EU ETS and Energy Prices: a Case of the Czech Republic. *Politické vedy / Political Sciences*, *13*(4), 130–144.

Olivier, J., & Peters, J. (2020). *Trends in Global CO2 and Total Greenhouse Gas Emissions: 2019 Report* (Tech. Rep. No. 4068). The Hague: PBL Netherlands Environmental Assessment Agency.

Petrick, S., & Wagner, U. (2014). *The impact of carbon trading on industry: Evidence from German manufacturing firms* (Kiel Working Paper No. 1912). Kiel Institute for the World Economy (IfW).

Reuters. (2021). *EU carbon price hits record 50 euros per tonne on route to climate target.* Retrieved 2021-07-02, from https://www.reuters.com/business/energy/eu-carbon-price-tops-50-euros-first-time-2021-05-04/

Rizkova, M. (2009). *Emission trading: evaluation of the European experience* (Unpublished doctoral dissertation).

Rosenbaum, P. R., & Rubin, D. B. (1983). The central role of the propensity score in observational studies for causal effects. *Biometrika*, *70*(1), 41–55. (Publisher: Oxford Academic) doi: 10.1093/biomet/70.1.41

Spiesová, D. (2014). Modeling of the Impacts of Revenue from Emission Allowances Trading on Selected Macroeconomic Indicators in the Czech Republic. *Littera Scripta*(2), 34–46.

Tauchmannová, B. (2017). *Evropský systém obchodování s emisními povolenkami (EU ETS), jeho fungování a úspěšnost* (Unpublished master's thesis). Charles University, Praha.

UNFCCC. (2008). *Kyoto Protocol Reference Manual on Accounting of Emissions and Assigned Amounts.*

UNFCCC. (2020a). *The Doha Climate Gateway.* Retrieved 2020-11-08, from https://unfccc.int/process/conferences/the-big-picture/milestones/the-doha-climate-gateway

UNFCCC. (2020b). *The Katowice climate package: Making The Paris Agreement Work For All.* Retrieved 2020-12-29, from https://unfccc.int/process-and-meetings/the-paris-agreement/katowice-climate-package

UNFCCC. (2020c). *Mechanisms under the Kyoto Protocol.* Retrieved 2020-11-11, from https://unfccc.int/process/the-kyoto-protocol/mechanisms

UNFCCC. (2020d). *Nationally Determined Contributions (NDCs).* Retrieved 2020-12-29, from https://unfccc.int/process-and-meetings/the-paris-agreement/nationally-determined-contributions-ndcs/nationally-determined-contributions-ndcs

United Nations. (1992). *United Nations Framework Convention on Climate Change.*

United Nations. (2016). *Report of the Conference of the Parties on its twenty-first session, held in Paris from 30 November to 11 December 2015.*

Wagner, U., Muûls, M., Martin, R., & Colmer, J. (2014). The Causal Effects of the European Union Emissions Trading Scheme: Evidence from French Manufacturing Plants..

Wood, J. (2018). The Pros and Cons of Carbon Taxes and Cap-and-Trade Systems. *The School of Public Policy Publications*, *11*. doi: 10.11575/sppp.v11i0.52974

Zimmermannová, J. (2015). Pilot Analysis of the Behaviour of Companies Within the 3rd Trading Period of the EU ETS in the Czech Republic. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis*, *63*(6), 2213–2220. doi: 10.11118/actaun201563062213

Zimmermannova, J., & Cermak, P. (2015). Emission allowances trading vs. environmental taxation: The case study of Czech Republic. *Actual Problems of Economics*, *163*(1), 328–337.

# Appendix A

# Appended tables and figures

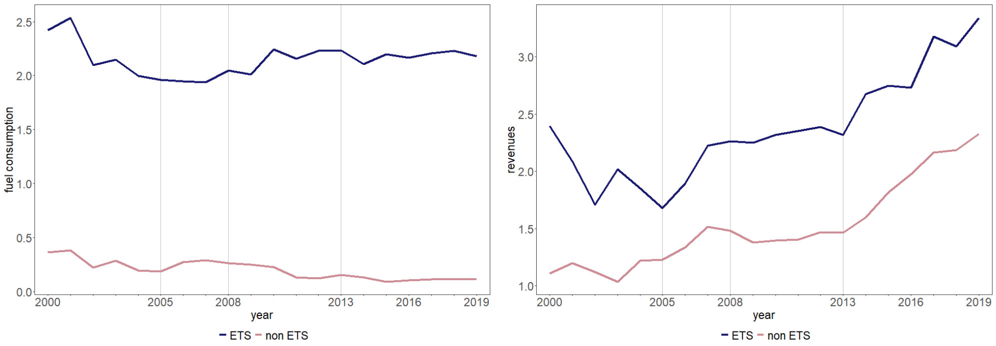
## A.1 $CO_2$ emissions estimation

Table A.1: Emission and oxidation factors

| Fuel type | Emission factor | Oxidation factor |
|---|---|---|
| Brown coal | 99.34 | 0.9707 |
| Hard coal | 94.56 | 0.9707 |
| Biomass | 0 | - |
| Bitumen | 80.7 | 1 |
| Hard oils | 77.4 | 1 |
| Light oils | 74.1 | 1 |
| Other gases | 73.3 | 1 |
| Natural gas | 55.44 | 1 |
| LPG | 55.44 | 1 |
| Biogas | 0 | - |
| $H_2$ | 0 | - |

## A.2 Initial sample

Figure A.1: Mean annual fuel consumption and revenues, initial sample, 2000 - 2019



(a) Fuel consumption (PJ)

(b) Revenues (bil Kč)

# A.3 PS Matching

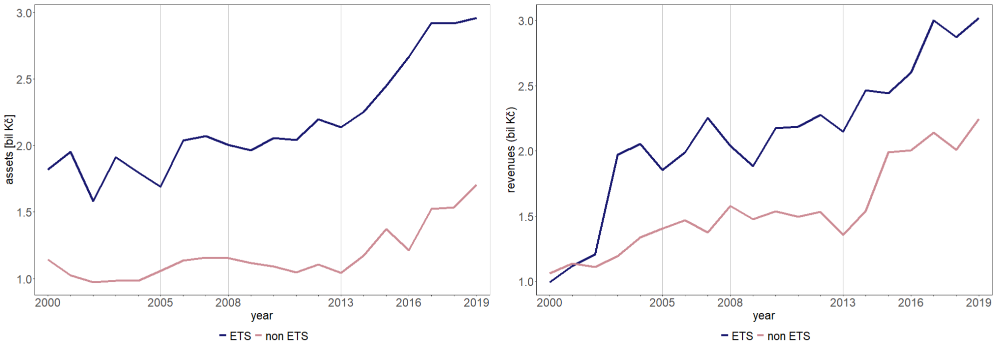
## A.3.1 Logit model

Table A.2: Propensity score estimation

| | *Dependent variable:* |
|---|---|
| | ETS |
| $CO_2$ emissions | 1.531$^{***}$ |
| | (0.180) |
| Other fuel used [GJ] | 0.019 |
| | (0.027) |
| Coal [GJ] | 0.050 |
| | (0.044) |
| Natural gas [GJ] | 0.010 |
| | (0.041) |
| Employees | −0.080 |
| | (0.112) |
| Revenues | −0.128 |
| | (0.221) |
| Assets | 0.417$^{**}$ |
| | (0.213) |
| Constant | −13.377$^{***}$ |
| | (1.710) |
| Observations | 683 |
| Log Likelihood | −170.163 |
| Akaike Inf. Crit. | 356.327 |
| *Note:* | $^{*}$p<0.1; $^{**}$p<0.05; $^{***}$p<0.01 |

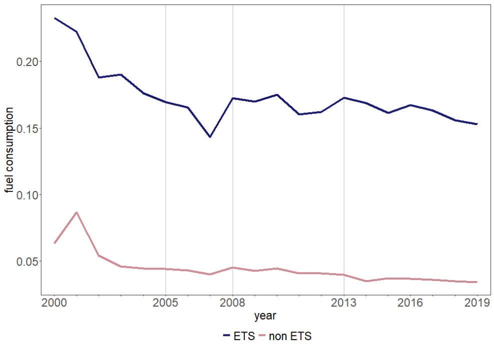
### A.3.2 Trends of selected variables

Figure A.2: Mean annual assets, revenues and fuel consumption, common support, 2000 - 2019



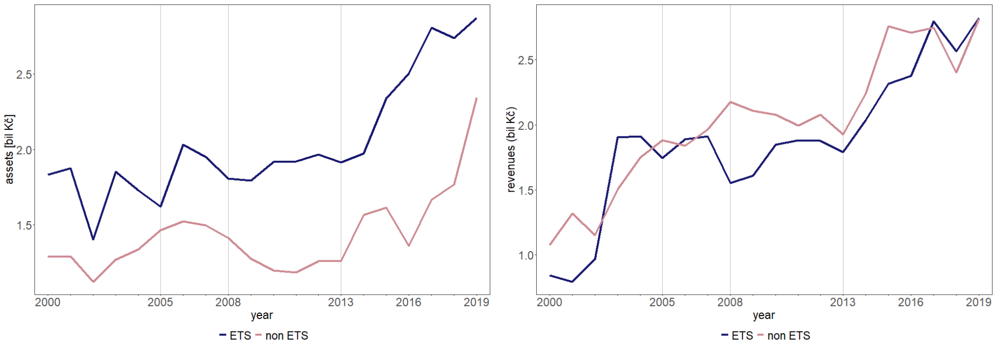
(a) Assets (bil Kč)

(b) Revenues (bil Kč)

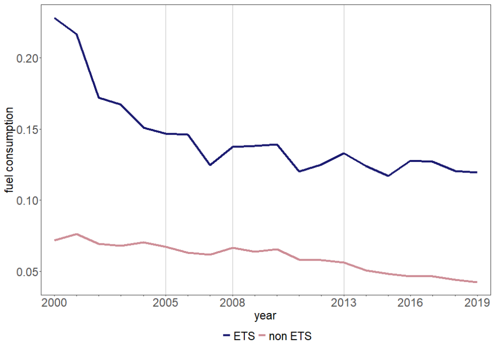


(c) Fuel consumption (PJ)

Figure A.3: Mean annual assets, revenues and fuel consumption, after matching, 2000 - 2019



(a) Assets (bil Kč) (b) Revenues (bil Kč)



(c) Fuel consumption (PJ)

Table A.3: Parallel trends tests

| | Common support | | Matched sample | |
|---|---|---|---|---|
| Variable | P-value | No. of obser. | P-value | No. of obser. |
| $CO_2$ emissions | 0.887 | 2302 | 0.768 | 1126 |
| Carbon-fuel intensity | 0.999 | 2302 | 0.999 | 1126 |
| Carbon intensity of production | 0.502 | 1922 | 0.883 | 950 |
| Fuel consumption | 0.883 | 2302 | 0.746 | 1126 |
| Revenues | 0.632 | 1922 | 0.844 | 950 |
| Employees | 0.745 | 1917 | 0.908 | 947 |
| Assets | 0.979 | 1919 | 0.906 | 950 |

## A.4 Robustness checks

### A.4.1 Smaller number of nearest neighbours

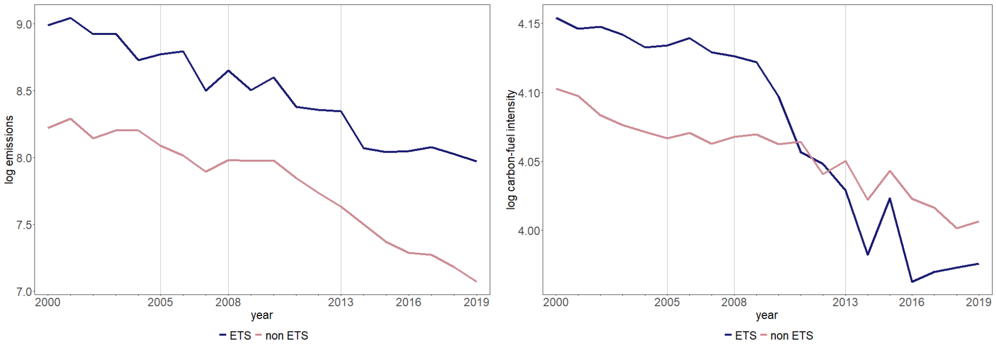
Table A.4: Mean values of selected variables, 3 neighbours, 2002 - 2019

| | Before matching | | After matching | |
|---|---|---|---|---|
| Variable | non-ETS | ETS | non-ETS | ETS |
| $CO_2$ emissions | 16 498.22 | 181 905.46 | 4 082.669 | 8 177.711 |
| Fuel [GJ] | 202 437.09 | 2 140 918.09 | 70 034.450 | 135 479.200 |
| Coal [GJ] | 141 014.18 | 1 606 298.47 | 4 199.835 | 28 702.540 |
| Natural gas [GJ] | 32 881.64 | 192 464.21 | 61 144.490 | 81 852.450 |
| Other types of fuel [GJ] | 28 541.27 | 342 155.42 | 4 690.124 | 24 924.220 |
| Employees | 296.57 | 336.88 | 305.028 | 391.866 |
| Revenues [bil Kč] | 1.555 | 2.429 | 2.520 | 2.036 |
| Costs [bil Kč] | 1.452 | 2.145 | 2.302 | 1.725 |
| Assets [bil Kč] | 1.282 | 3.407 | 1.700 | 2.025 |
| Number of installations | 2 173 | 369 | 97 | 78 |

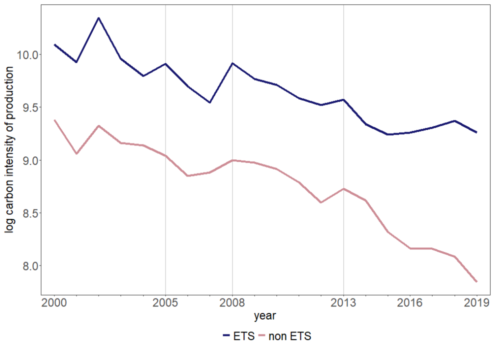
Table A.5: Share of installation-year observations by sectors and share of $CO_2$ (2002-2019), 3 neighbours, after matching

| | Installations | | CO2 | |
|---|---|---|---|---|
| Sector | ETS | non-ETS | ETS | non-ETS |
| Energy sector | 69.1 | 47.6 | 76.5 | 51.2 |
| Man. of electronics | 2.2 | 5.5 | 1 | 5 |
| Man. of food products and beverages | 10.5 | 14.7 | 8.9 | 15.4 |
| Man. of machinery and metal products | 6.8 | 13.1 | 6.2 | 13.2 |
| Man. of non-metallic mineral products | 6.3 | 9.6 | 4.5 | 7.1 |
| Man. of paper and paper products | 1.4 | 1.9 | 0.5 | 1.1 |
| Man. of textiles and wearing apparel | 1.4 | 3.2 | 0.9 | 5.4 |
| Transportation and storage | 2.4 | 4.5 | 1.4 | 1.7 |

Figure A.4: Mean annual emissions and relative emissions (in logarithm), after matching, 3 neighbours, 2000 - 2019



(a) $CO_2$ emissions (b) Carbon-fuel intensity



(c) Carbon intensity of production

Table A.6: Parallel trends test, 3 neighbours

| Variable | P-value | No. of observations |
|---|---|---|
| $CO_2$ emissions | 0.420 | 782 |
| Carbon-fuel intensity | 0.992 | 782 |
| Carbon intensity of production | 0.625 | 667 |
| Fuel consumption | 0.338 | 782 |
| Revenues | 0.844 | 667 |
| Employees | 0.863 | 667 |
| Assets | 0.995 | 667 |

### A.4.2 Companies that own solely ETS installations or solely non-ETS installations

Table A.7: Propensity score estimation, logit model, companies that own solely ETS or solely non-ETS installations

| | *Dependent variable:* |
|---|---|
| | ETS |
| $CO_2$ emissions | 2.493$^{***}$ |
| | (0.372) |
| Other fuel used [GJ] | −0.020 |
| | (0.041) |
| Coal [GJ] | −0.039 |
| | (0.061) |
| Natural gas [GJ] | −0.012 |
| | (0.054) |
| Employees | −0.079 |
| | (0.179) |
| Revenues | −0.514 |
| | (0.325) |
| Assets | 0.617$^{**}$ |
| | (0.314) |
| Constant | −22.165$^{***}$ |
| | (3.468) |
| Observations | 503 |
| Log Likelihood | −79.785 |
| Akaike Inf. Crit. | 175.569 |
| *Note:* | $^{*}$p<0.1; $^{**}$p<0.05; $^{***}$p<0.01 |

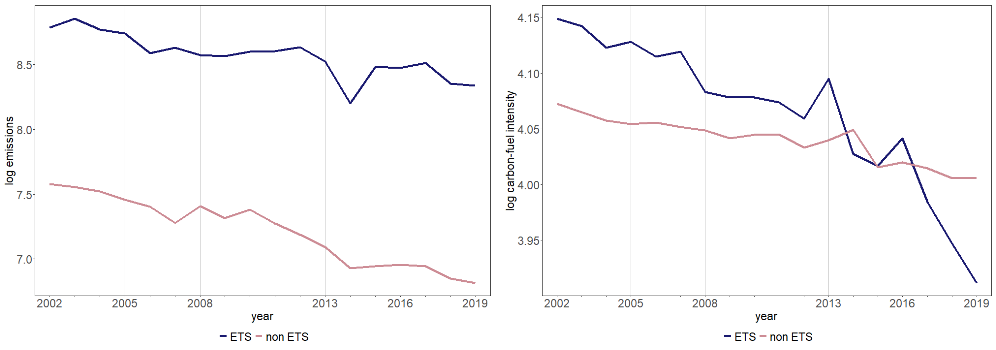
Table A.8: Mean values of selected variables, companies that own solely ETS or solely non-ETS installations, 2002 - 2019

| | Before matching | | Common support | | After matching | |
|---|---|---|---|---|---|---|
| Variable | non-ETS | ETS | non-ETS | ETS | non-ETS | ETS |
| $CO_2$ emissions | 16 498.22 | 181 905.46 | 2 267.10 | 7 214.33 | 2 996.33 | 5 267.32 |
| Fuel [GJ] | 202 437.09 | 2 140 918.09 | 38 626.89 | 146 054.16 | 50 628.32 | 86 642.04 |
| Coal [GJ] | 141 014.18 | 1 606 298.47 | 3 095.02 | 22 624.34 | 3 948.05 | 8 250.82 |
| Natural gas [GJ] | 32 881.64 | 192 464.21 | 33 742.56 | 78 027.37 | 43 553.34 | 71 915.09 |
| Other fuel types [GJ] | 28 541.27 | 342 155.42 | 1 789.32 | 45 402.45 | 3 126.93 | 6 476.13 |
| Employees | 296.57 | 336.88 | 343.07 | 279.05 | 259.85 | 248.57 |
| Revenues [bil Kč] | 1.555 | 2.429 | 1.547 | 1.219 | 1.006 | 0.958 |
| Costs [bil Kč] | 1.452 | 2.145 | 1.444 | 1.145 | 0.963 | 0.893 |
| Assets [bil Kč] | 1.282 | 3.407 | 1.106 | 0.987 | 0.847 | 0.882 |
| No. of installations | 2 173 | 369 | 298 | 36 | 93 | 22 |

Table A.9: Share of installation-year observations by sectors and share of $CO_2$ (2002-2019), in percentage, companies that own solely ETS or solely non-ETS installations, common support and after matching

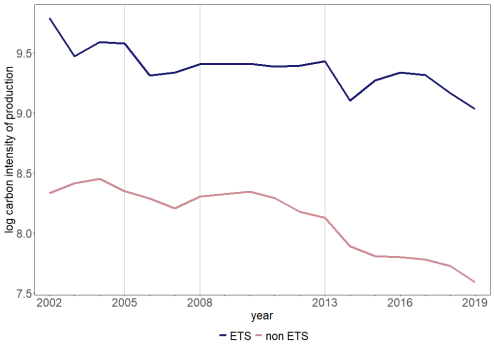
| | Common support | | | After matching | | |
|---|---|---|---|---|---|---|
| Sector | ETS | non-ETS | $CO_2$ | ETS | non-ETS | $CO_2$ |
| Energy sector | 44.8 | 19.1 | 30.1 | 59.8 | 43 | 43.8 |
| Man. of basic metals | | 5.1 | 5.7 | | | |
| Man. of basic pharm. prod. | | 1.8 | 1.8 | | | |
| Man. of electronics | | 6.5 | 5.3 | | | |
| Man. of food prod. and beverages | 17.4 | 17.3 | 24.4 | 19.3 | 17.5 | 25.8 |
| Man. of chemicals and chem. prod. | 3 | 2.5 | 4.1 | | | |
| Man. of machinery and metal prod. | 12 | 29.2 | 19.5 | 6.8 | 22.1 | 11.7 |
| Man. of non-metallic mineral prod. | 5.6 | 4.9 | 6.6 | 9.3 | 14.2 | 12 |
| Man. of paper and paper prod. | 3 | 0.7 | 1.4 | | | |
| Man. of rubber and plastic prod. | | 3.7 | 2.8 | | | |
| Man. of textiles and wearing apparel | 8.7 | 7.1 | 10.5 | 4.9 | 3.2 | 6.7 |
| Man. of wood | 5.6 | 0.8 | 3.4 | | | |
| Mining | | 0.3 | 0.7 | | | |
| Transportation and storage | | 1.1 | 1.5 | | | |

Figure A.5: Mean annual emissions and emission intensities (in logarithm), common support, companies that own solely ETS or solely non-ETS installations, 2002 - 2019



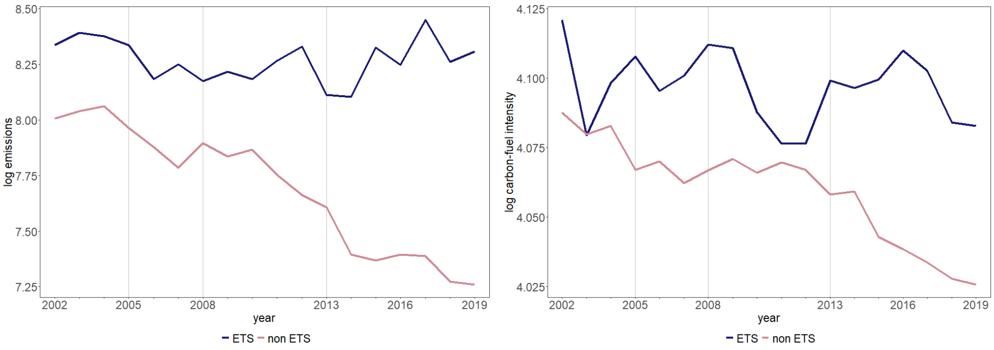
(a) $CO_2$ emissions

(b) Carbon-fuel intensity

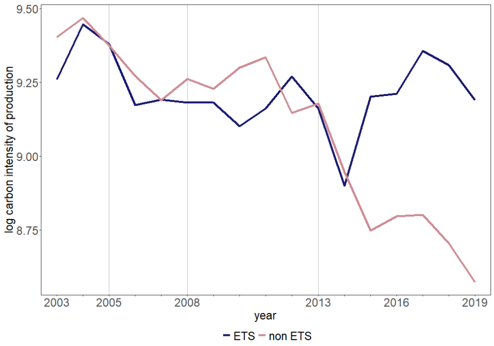


(c) Carbon intensity of production

Figure A.6: Mean annual emissions and emission intensities (in logarithm), after matching, companies that own solely ETS or solely non-ETS installations, 2002 - 2019



(a) $CO_2$ emissions (b) Carbon-fuel intensity



(c) Carbon intensity of production

Table A.10: Parallel trends test, companies that own solely ETS or solely non-ETS installations

| | Common support | | Matched sample | |
|---|---|---|---|---|
| Variable | P-value | No. of obser. | P-value | No. of obser. |
| $CO_2$ emissions | 0.991 | 1454 | 0.956 | 524 |
| Carbon-fuel intensity | 0.979 | 1454 | 0.98 | 524 |
| Carbon intensity of production | 0.937 | 1165 | 0.913 | 405 |
| Fuel consumption | 0.986 | 1454 | 0.814 | 524 |
| Revenues | 0.996 | 1165 | 0.963 | 405 |
| Employees | 0.482 | 1162 | 0.786 | 404 |
| Assets | 0.998 | 1165 | 0.971 | 405 |

### A.4.3 Switchers included

Table A.11: Propensity score estimation

| | *Dependent variable:* |
|---|---|
| | ETS_PHASE |
| $CO_2$ emissions | $1.295^{***}$ |
| | (0.149) |
| Coal | $0.043^{*}$ |
| | (0.025) |
| Natural gas | 0.065 |
| | (0.041) |
| Other fuel used | 0.032 |
| | (0.038) |
| Employees | 0.060 |
| | (0.103) |
| Revenues | −0.268 |
| | (0.202) |
| Assets | $0.455^{**}$ |
| | (0.195) |
| Constant | $-11.917^{***}$ |
| | (1.477) |
| Observations | 705 |
| Log Likelihood | −208.157 |
| Akaike Inf. Crit. | 432.315 |
| *Note:* | $^{*}$p<0.1; $^{**}$p<0.05; $^{***}$p<0.01 |

Table A.12: Mean values of selected variables, switchers included, 2002 - 2019

| | Before matching | | Common support | | After matching | |
|---|---|---|---|---|---|---|
| Variable | non-ETS | ETS | non-ETS | ETS | non-ETS | ETS |
| $CO_2$ emissions [t] | 16 498.22 | 181 905.46 | 2 387.82 | 9 399.99 | 3 452.11 | 8 023.53 |
| Fuel [GJ] | 202 437.09 | 2 140 918.09 | 41 349.46 | 169 404.06 | 59 950.24 | 133 965.29 |
| Coal [GJ] | 141 014.18 | 1 606 298.47 | 2 132.53 | 21 576.44 | 2 353.17 | 22 262.30 |
| Natural gas [GJ] | 32 881.64 | 192 464.21 | 36 602.71 | 112 978.68 | 53 089.07 | 94 416.52 |
| Other fuel types [GJ] | 28 541.27 | 342 155.42 | 2 614.23 | 34 848.94 | 4 508.00 | 17 286.46 |
| Employees | 296.57 | 336.88 | 309.07 | 407.79 | 270.43 | 370.56 |
| Revenues [bil Kč] | 1.555 | 2.429 | 1.613 | 2.151 | 1.916 | 1.869 |
| Costs [bil Kč] | 1.452 | 2.145 | 1.509 | 1.872 | 1.780 | 1.610 |
| Assets [bil Kč] | 1.282 | 3.407 | 1.187 | 2.230 | 1.233 | 1.736 |
| No. of installations | 2 173 | 369 | 450 | 122 | 205 | 95 |

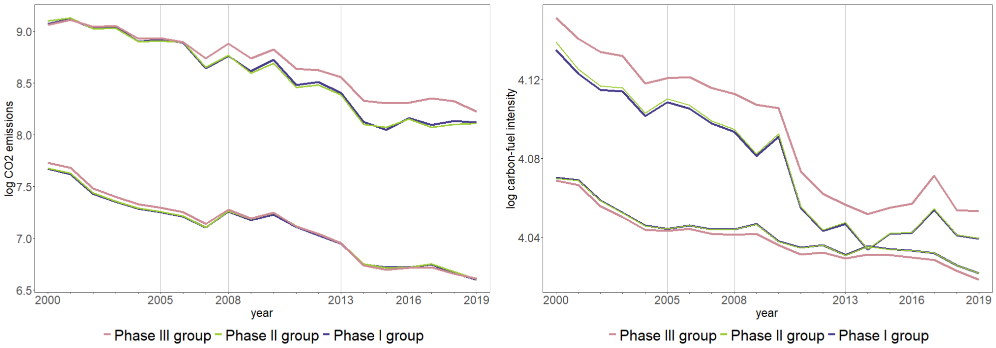
Table A.13: Share of installation-year observations by sectors and share of $CO_2$ (2002-2019), in percentage, common support and after matching, switchers included

| | Common Supoort | | | After matching | | |
|---|---|---|---|---|---|---|
| Sector | ETS | non-ETS | $CO_2$ | ETS | non-ETS | $CO_2$ |
| Energy sector | 48.6 | 26.3 | 40.9 | 60.8 | 36.7 | 55.3 |
| Man. of basic metals | 2.5 | 4.8 | 3.7 | | | |
| Man. of basic pharm. products | 0.9 | 1.4 | 1.3 | | | |
| Man. of coke and refined petrol. prod. | 0.9 | | 1.2 | | | |
| Man. of electronics | 1.4 | 5.3 | 2.2 | 1.8 | 2.6 | 1.7 |
| Man. of food products and beverages | 11.8 | 12.9 | 15.2 | 9.7 | 15.9 | 12.9 |
| Man. of chemicals and chemical prod. | 3.1 | 2.6 | 6.8 | 3.1 | 3.4 | 8.9 |
| Man. of machinery and metal prod. | 10 | 26.6 | 10 | 11.9 | 19.4 | 10.9 |
| Man. of non-metallic mineral prod. | 6.6 | 6.6 | 5.5 | 7.4 | 13.9 | 7.3 |
| Man. of paper and paper products | 2.6 | 0.7 | 2.8 | 1.1 | 0.9 | 0.5 |
| Man. of rubber and plastic products | 0.9 | 4.1 | 2 | | | |
| Man. of textiles and wearing apparel | 2.6 | 4.8 | 3.8 | 1.1 | 1 | 1.6 |
| Man. of wood | 3.3 | 0.7 | 1.4 | 2.1 | 1.6 | 0.4 |
| Mining | 1.6 | 0.4 | 1.8 | | | |
| Transportation and storage | 3.2 | 2.6 | 2.7 | 1 | 4.6 | 0.4 |

Table A.14: Parallel trends test, switchers included

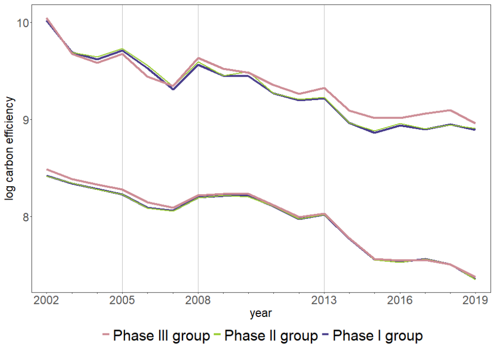
| | Common support | | Matched sample | |
|---|---|---|---|---|
| Variable | P-value | No. of obser. | P-value | No. of obser. |
| CO2 emissions | 0.933 | 2407 | 0.943 | 1319 |
| Carbon-fuel intensity | 0.995 | 2407 | 0.998 | 1319 |
| Carbon intensity of production | 0.498 | 2028 | 0.669 | 1129 |
| Fuel consumption | 0.906 | 2407 | 0.900 | 1319 |
| Revenues | 0.652 | 2028 | 0.555 | 1129 |
| Employees | 0.727 | 2022 | 0.803 | 1125 |
| Assets | 0.990 | 2025 | 0.926 | 1129 |

Figure A.7: Mean annual emissions and relative emissions (in logarithm), common support, switchers included, 2000 - 2019



(a) $CO_2$ emissions

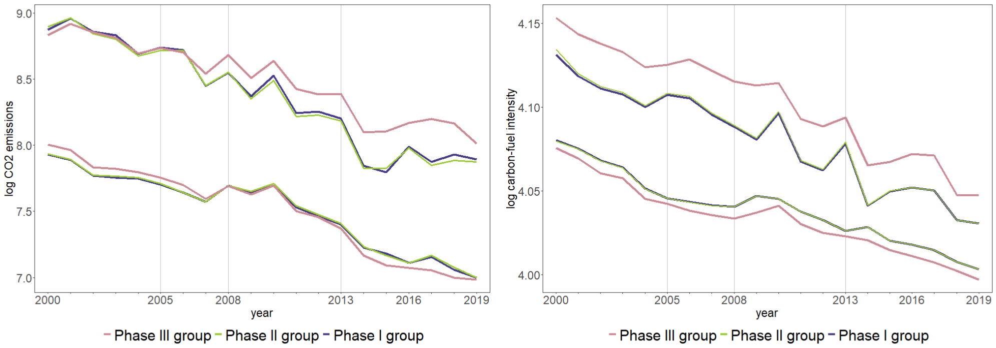
(b) Carbon-fuel intensity



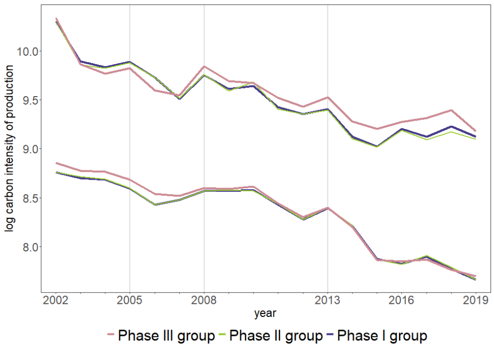
(c) Carbon intensity of production

*Note:* Each phase group shows installations regulated (upper line) and non-regulated (lower line) during that phase.

Figure A.8: Mean annual emissions and relative emissions (in logarithm), after matching, switchers included, 2000 - 2019



(a) $CO_2$ emissions (b) Carbon-fuel intensity



(c) Carbon intensity of production

*Note:* Each phase group shows installations regulated (upper line) and non-regulated (lower line) during that phase.