Universität Basel

Wirtschaftswissenschaftliche Fakultät

WWZ

May 2020

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WWZ Working Paper 2020/05

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A publication of the Center of Business and Economics (WWZ), University of Basel.

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A carbon horse race: Abatement subsidies vs. permit trading in Switzerland*

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May 15, 2020

Abstract

Swiss climate policy consists of three regulatory instruments for greenhouse gas emissions reduction: A CO_2 levy, the Swiss Emissions Trading System (CH EHS), and an additional "nonEHS" program for medium-sized plants that consists of command-and-control elements plus a sizeable abatement subsidy. Our paper informs about this tripartite climate policy, which is unique in the international context. Second, we estimate the differential impact of the CH EHS and the nonEHS program on plants' emissions. Our empirical strategy exploits a policy change in 2013 that instituted a mandatory emissions trading system for a subset of previously regulated firms. We find that the nonEHS outperforms the CH EHS for a minority of plants, but that on average, the two programs result in similar abatement efforts despite very different financial incentives. Firms that previously engaged in abatement efforts continue to do so even after the financial incentives were reduced by an order of magnitude. Our results suggest the presence of preferences for abatement per se, above and beyond financial incentives. They further imply that expanding the nonEHS system at the expense of the CO_2 levy may be associated with significant costs but no additional emission reductions.

Policy insights

- We identify no difference between the emissions reductions of firms regulated by cap-and-trade vs. an abatement subsidy in Switzerland
- Exempting firms from paying an emissions tax can likely not be justified by a superior performance of a subsidy
- The costs of climate policy should not be concentrated on households and small firms

Keywords: Climate policy, emissions tax, carbon tax, emissions trading, subsidies, command-and-control, Switzerland.
JEL codes: D22, D62, H23, H25, H32, Q52, Q54, Q58.

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*This research has been supported by the WWZ Förderverein of the University of Basel. We are grateful to the Swiss Federal Office of the Environment for providing us with the required data and many helpful comments, in particular by Raphael Bucher and Silvan Aerni. We thank Armin Eberle for valuable insights and Lucas Zuckschwert and Nina Lustenberger for excellent research assistance. Any remaining errors are our own.

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1 Introduction

Switzerland uses a mix of policy instruments to reduce greenhouse gas emissions. In 2008, a CO_2 levy was introduced on fossil combustion fuels. This levy was gradually increased to the current level of CHF 96 per tCO_2 equivalents,[1] making it one of the highest carbon taxes worldwide. Not all greenhouse gas emissions from fossil fuels are subject to the CO_2 levy. Importantly, transportation fuels have been exempt. Furthermore, to protect the interests of energy-intensive firms, the Swiss government has established two programs that allow firms and individual plants to be exempt from the CO_2 levy. The first program was established in 2008 and can be described as a command-and-control instrument that is combined with generous abatement subsidy. To join, firms in certain subsectors that have sufficiently high annual emissions can develop abatement measures and emissions targets and submit these for approval to the federal government. This program is known today under the label nonEHS.[2]

In 2013, the federal government additionally introduced an emissions trading scheme, called the CH EHS. This system is identical to the EU Emissions Trading Scheme (EU ETS) in all relevant aspects and has been designed with a view to linking it with the EU system. The link was delayed for several years for political reasons but finally took place in January 2020. Plants subject to the CH EHS are also exempt from the CO_2 levy. Besides the threefold regulation of CO_2 on the federal level, there are also cantonal regulations that affect the energy use of plants and thus, indirectly, their emissions.

In this paper, we exploit the sequential introduction of the nonEHS and the EHS programs to measure their differential impact on plant emissions. More specifically, we focus on a set of plants that joined the nonEHS program in 2008. Among these, a subset was transferred to the CH EHS in 2013, whereas the others remained in the nonEHS program. This allows for the identification of the *differential* effect of these programs in a causal sense using a difference-in-differences framework.

Because the abatement subsidy in the nonEHS program has always been higher than

[1] The Swiss Franc is currently at parity with the US Dollar.

[2] EHS is the German acronym for Emissionshandelssystem, or emissions trading scheme (ETS).

the allowance price in the CH EHS, neoclassical economics predicts a negative treatment effect of the EHS on abatement, i.e., a positive effect on emissions. We do find such a positive effect, but only for about a quarter of the included plants that had both relatively low revenue and did not engage in significant emissions reduction during the pre-treatment period. For all other plants, the treatment effect is not statistically significantly different from zero. Our results suggest that financial incentives matter, but that other aspects (such as green preferences) may also be important drivers of firms' production and abatement decisions.

Empirically evaluating the effect of the different climate policy instruments is difficult. Since everyone is affected, either by the levy or one of the two exemption programs, no valid control group exists to cleanly identify the effect of a single policy. Furthermore, the fuel use of firms and households subject to the levy is only recorded on aggregate.[3] Betz et al. (2015) provide qualitative arguments as to why the multiplicity of policies makes it difficult to achieve Switzerland's overall emissions target, but without quantitatively assessing the effectiveness of the individual policies.

The previous empirical research about the effectiveness of Swiss climate policy is confined to before-vs-after studies (Ecoplan, 2015, 2017), surveys of the involved firms (TEP Energy, 2016) and engineering estimates (Ecoplan, 2015; EnAW, 2019). Both the levy and the nonEHS program were found to have significantly reduced emissions, whereas the same is not clear for the CH EHS (SFAO, 2017). However, these results may be driven by unobserved heterogeneity or self-selection into the nonEHS program, as larger firms were both more likely to reduce their emissions and to apply for an exemption via nonEHS.

Although a clean identification of the effect of each program would clearly be preferable, the differential impact is nevertheless interesting. There is an ongoing debate in Switzerland about whether the nonEHS program should be extended to include smaller plants. Because shifting plants to a subsidies program will result in higher costs, such a move would have to be justified by a superior performance of the nonEHS program in

[3]The levy is imposed on fossil fuels as they cross the border and thus simply becomes a part of the overall price. Individual purchases are only recorded if firms claim the exemption from the levy, which is then returned to them.

terms of emissions reductions relative to a tax. We cannot test for this directly. However, to the extent that an emissions levy of CHF 96 can be expected to achieve at least as much in terms of abatement as a cap-and-trade system with an allowance price of CHF 10, our results indicate that the nonEHS program is unlikely to outperform the levy.

Our analysis contributes to the political discussion about climate policy, in particular in Switzerland, but potentially also in other countries that use a combination of different climate policy instruments that provide different marginal incentives for abatement.

More broadly speaking, our paper contributes to the literature on overlapping instruments for climate change. Even though economists typically prescribe the use of a (single) Pigovian tax on emissions in order to internalize climate-related emission externalities, almost all countries use a range of instruments such that firms are subject to more than one emissions policy. This is usually viewed as problematic (see, e.g., Fankhauser et al., 2010), but it could be justified by market failures in addition to the climate externality (Fischer and Preonas, 2010), uncertainty about the future climate policy (Lecuyer and Quirion, 2013) or private information (Krysiak and Oberauner, 2010). Overlapping instruments are usually explained using political-economy considerations (Jenkins, 2014). For example, they can be the the result of interest groups successfully lobbying for subsidies in addition to, or instead of, carbon pricing (Brandt and Svendsen, 2004; Hieronymi and Schüller, 2015). Multiple policies may also be due to the interaction between different levels of government, which may result in the simultaneous pursuit of bottom-up and top-down approaches to regulation (Solorio and Jörgens, 2017). Our paper is also related to the literature that focuses on voluntary action against climate change on behalf of firms (e.g., Pizer et al., 2011; Gans and Hintermann, 2013; Hsueh, 2019).

In the next section, we provide more background information. Section 3 describes our identification strategy and the data and section 4 presents the results. Section 5 offers concluding remarks.

2 Background: Swiss climate policy

Swiss climate policy is based on the Federal Act on the Reduction of CO_2 Emissions ("CO_2 Act"),[4] which has been updated several times since its inception in 2000. Originally, the CO_2 Act focused on meeting the commitment made for the Kyoto Protocol of reducing overall GHG emissions by eight percent during the 2008 – 2012 period, relative to the 1990 baseline. It prescribes a variety of policy measures that were further specified in different of action plans, programs and policies. The latest revision of the CO_2 Act was implemented on 1. 1. 2013. It updated the emission targets and policy measures for the post-Kyoto period. More information about the revised CO_2 Act and Swiss climate policy can be found on the website of the Federal Office of the Environment (FOEN),[5] and in Hintermann and Zarkovic (2020). In what follows, we briefly describe those measures and policies that are relevant to our context: (1) The CO_2 levy for heating fuels, (2) the CH EHS, (3) the nonEHS program and (4) cantonal regulation.

2.1 The CO2 Levy

Since 2008, Switzerland has imposed a CO_2 levy on fossil heating and process fuels, such as heating oil, natural gas, coal or petroleum coke, in order to incentivize a more efficient use of fossil fuels and a transition to low-carbon energy sources. Transport fuels have been exempted from the CO_2 levy from the very beginning. Instead, a surcharge of one cent/liter was added to all gasoline and diesel imports and the revenue is used to finance GHG offsets in Switzerland and abroad.[6] The levy is collected at the border crossing (there are no fossil fuels produced in Switzerland). Two thirds of the collected revenue is redistributed to taxpayers and firms, whereas the remainder is used to fund a building energy efficiency program and a technology fund.

[4]This is known as "CO_2 Gesetz" in German. SR 641.71, enacted on 23. 12. 2011. Currently, the CO_2 Act is in the process of revision to shape climate policy for the years after 2020.

[5]`https://www.bafu.admin.ch/bafu/en/home/topics/climate/info-specialists/climate-policy.html` (last accessed in January 2019)

[6]The surcharge has been increased to 4.5 cents/liter, but is not allowed to exceed the maximum level of 5 cents per liter. At 2.3 kg of CO2 per liter of gasoline, the maximum surcharge translates to a CO_2 tax for transport fuels of 22 CHF/tCO_2, which is only a fraction of the CO_2 levy that applies to combustion fuels. The exclusion of transport fuels from the CO_2 levy was due to successful lobbying efforts (Brönnimann et al., 2014).

Table 1: CO_2 levy and fuel prices, 2008-2018

		Unit	2008	2009	2012	2014	2016	2018
CO_2 levy		[CHF/tCO2]	12	24	36	60	84	96
Heating oil EL	Market price	[CHF/kg]	0.990	0.560	0.894	0.766	0.385	0.612
	Surcharge		0.038	0.076	0.114	0.190	0.265	0.303
Natural gas	Market price	[CHF/kg]	0.519	0.240	0.394	0.334	0.201	0.347
	Surcharge		0.032	0.064	0.096	0.160	0.224	0.256
Hard coal	Market price	[CHF/kg]	0.158	0.076	0.087	0.069	0.058	0.090
	Surcharge		0.028	0.057	0.085	0.142	0.198	0.227
Propane	Market price	[CHF/kg]	0.836	0.510	0.811	0.617	0.286	0.532
	Surcharge		0.036	0.072	0.108	0.179	0.251	0.287

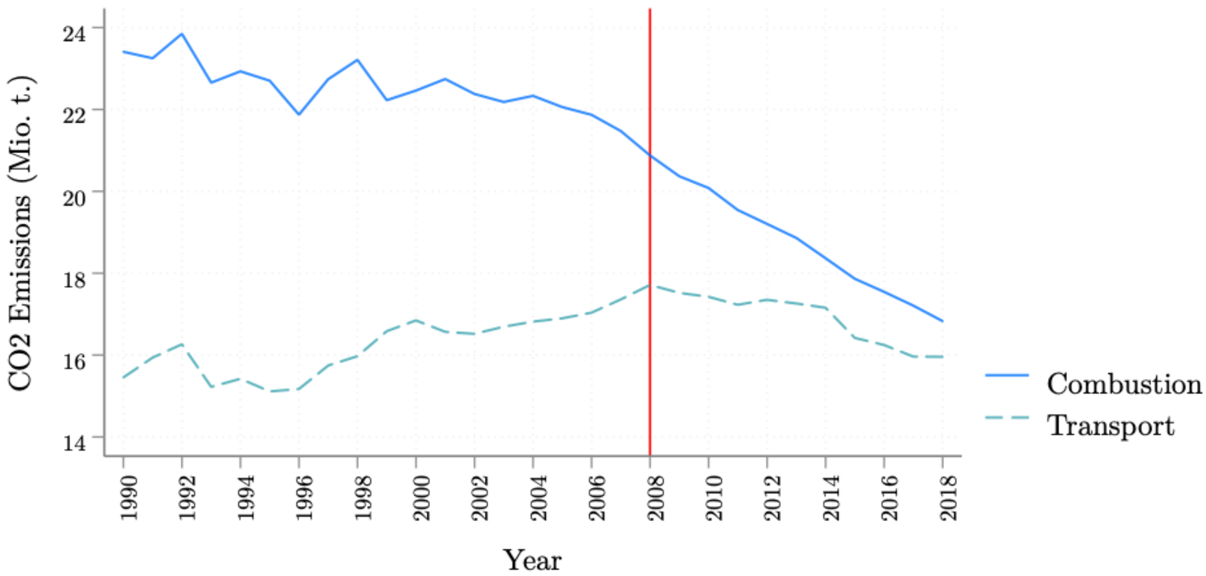
Sources: Thomson Reuters and FOEN (2019b)

In order to provide firms and households with planning and investment security, the CO_2 Act defined interim reduction targets for emissions from thermal fuels, upon which the rate of the levy was defined in advance. Non-attainment of the targets triggers an automatic increase in the CO_2 levy in multiples of CHF 12 per metric ton of CO_2 equivalents. Table 1 shows the levy since its introduction, along with the (international) exchange prices for four types of fuels and the corresponding surcharges due to the levy. The current levy is CHF 96/tCO_2. The existing CO_2 Act defines a maximum level of CHF 120/tCO_2.

Figure 1 indicates that, unlike transport emissions, aggregate combustion emissions have significantly decreased in Switzerland, suggesting that the CO_2 Act has had some effect. However, it is not clear to what extent each instrument of the Act has contributed to the emissions reduction, including the effect of the subsidies that are financed with the proceeds of the CO_2 levy. Furthermore, a part of the decrease may have been due to general technological progress, as the decrease in emissions started well before 2008.

A series of reports commissioned by FOEN (Ecoplan, 2015, 2017) estimate the effect of the CO_2 tax on firms and households by means of a time series analysis and a computable general equilibrium model. The time-series analysis implies that for the years 2008-2015, the levy led to a reduction of 6.9 million tons of CO_2, which corresponds to 4.4% of the

Figure 1: Aggregate emissions from combustion and transportation



Source: FOEN, Swiss greenhouse gas inventory

combustion emissions during that period.[7] The results from the CGE model are somewhat lower, but on a similar order of magnitude. Figure 2 presents the estimates from the time-series model, which imply that the CO_2 levy had a significant effect on emissions. This analysis relies on the assumption that the time trend of business-as-usual emissions before the introduction of the tax also applies to the trend after the introduction.

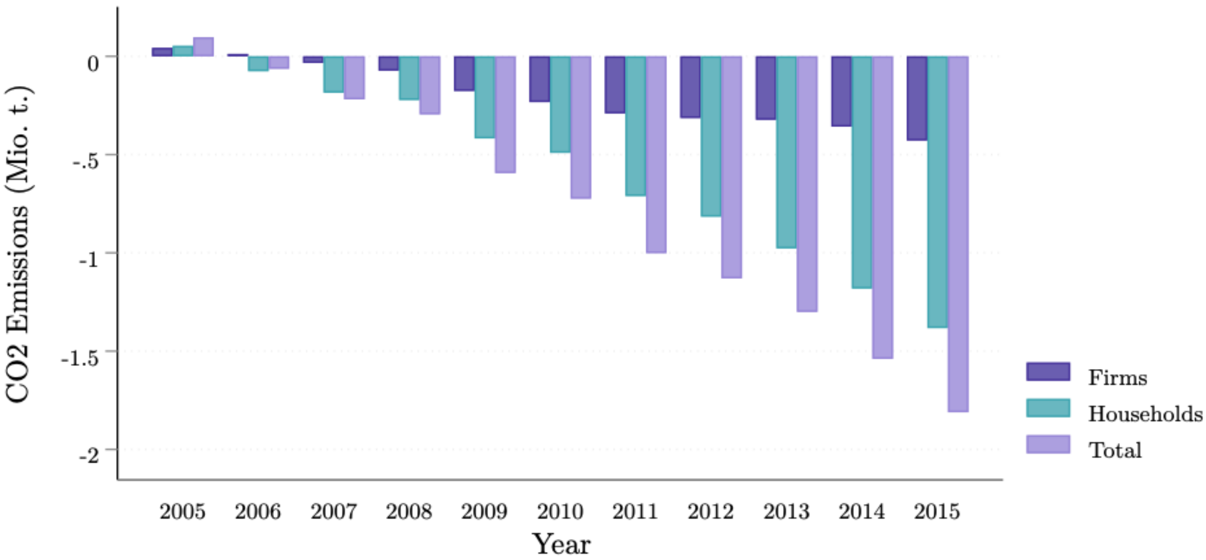
2.2 The nonEHS program

For the purposes of our analysis, we assume that the nonEHS program was instituted in 2008 with the start of the CO_2 Act.[8] Firms from sectors of the economy that have a high emissions tax burden in relation to their value, and whose international competitiveness would be significantly undermined as a result, can be exempted from paying the CO_2 levy by participating in the nonEHS program. The exemption takes place on the plant

[7]Total GHG emissions in Switzerland in the years 2008-2015 amounted to 411 million tons of CO_2, of which 155 million tons were subject to the CO2 tax. Source: Swiss greenhouse gas inventory, available at `https://www.bafu.admin.ch/bafu/en/home/topics/climate/state/data/greenhouse-gas-inventory.html`.

[8]Technically, the nonEHS program was instituted only in 2013, along with the "new" CH EHS. However, a program that was identical in all relevant aspects was introduced in 2008 by the CO_2 Act under the label "CH EHS". Despite its name, this "first-period" EHS was not a cap-and-trade system, as there was no fixed cap. Like the current nonEHS program, it was based on emission intensities. It also relied on mandatory abatement measures and contained an abatement subsidy. For these reasons, we label both the first-period EHS and the current nonEHS program as nonEHS and refer only to the post-2012 EHS as CH EHS.

Figure 2: Effect of the CO_2 levy on combustion emissions



Source: Ecoplan (2017); Translation by authors.

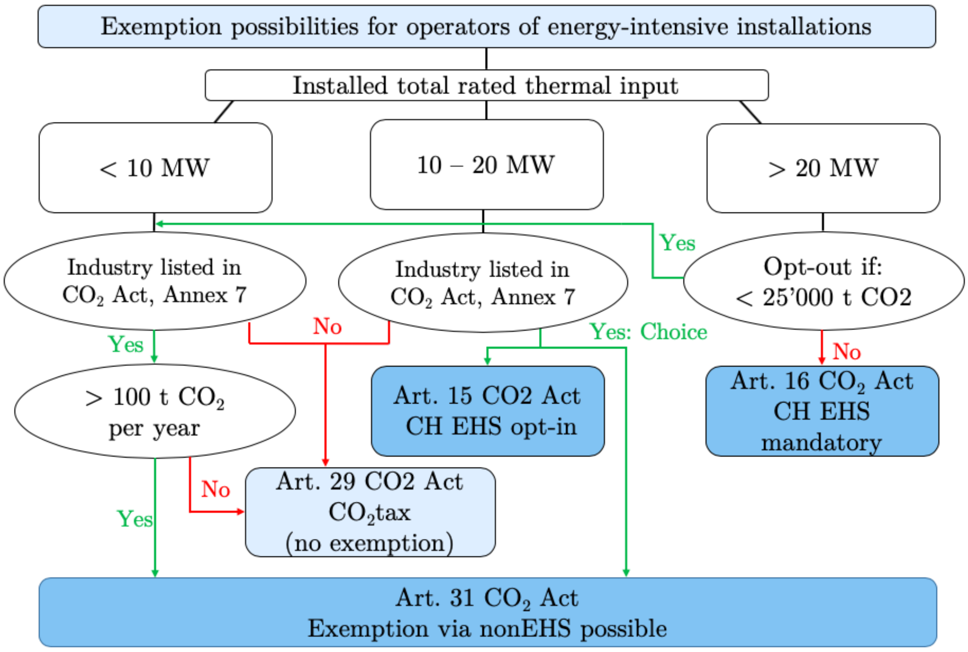
level. However, nonEHS participants can form groups, such that firms can aggregate their included plants and participate as a single entity. To be eligible for the nonEHS, a plant must be engaged in specific production activities and emit at least 100 tons CO_2eq. in one of the preceding two years. If the plant has an installed rated thermal input exceeding 20 MW, it is automatically included in the CH EHS. Figure 3 provides an overview of the eligibility rules from the CO_2 levy.

To initiate the application process, a firm develops a set of specific emissions measures and reduction goals in cooperation with one of two specialized business associations, the "Energie-Agentur der Wirtschaft" (EnAW) and "Cleantech Agentur Schweiz" (ACT).[9] Firms then submit this abatement plan to FOEN, along with an application for exemption from the CO_2 levy. If approved, the plan forms the basis for a formal target agreement between the firm and FOEN. Firms must comply with this agreement in order to become (and remain) exempt from the CO2 tax.

Only abatement measures that are deemed "economically viable" are included in the agreements. For production and processing facilities, this means that the investment

[9]There are two "flavors" of this program. The first is based on specific emissions goals along with abatement measures and applies to larger firms, whereas the second version only includes a definition of measures that a firm has to implement. The "abatement measures" version is reserved for firms with annual emissions of less than 1500 tonnes CO_2 eq. per year. In this paper, we focus on the larger firms.

Figure 3: Exemption from the CO_2 levy



Source: FOEN. Translation by authors.

should be recovered within four years, given the investment cost and the prevailing energy and emissions prices. For investments in building insulation and heating equipment, the required payback period is eight years (FOEN, 2018, p.80). The most popular measures are related to lighting, heating, process optimization and ventilation (EnAW, 2019).

If firms performed better than their defined abatement path, they could sell the surplus in the form of offsets to the Climate Cent Foundation (CCF) in 2008-2012, and to the Foundation for Climate Protection and Carbon Offset (KliK) since 2013. The two foundations used these "domestic" offsets, along with international Kyoto offsets, to compensate emissions from various sources, and in particular from transport. The price paid by CCF for offsets was determined in a series of auctions and ranged between 40 and 100 CHF per ton of over-abatement.[10] KliK pays a fixed price of CHF 100/tCO_2 for offsets that have been generated since 2013, and CHF 50/tCO_2 for banked offsets generated before 2013. CFC and KliK are financed by a fuel surcharge on transport fuels (see footnote 6). In theory, the system is symmetric in the sense that firms could also purchase these domestic offsets if they fall short of their goals. In practice, however, this never happens because

[10]The clearing prices paid per tCO_2 were CHF 70 in 2007, CHF 100 in 2009 and CHF 40 in 2012 (Climate Cent Foundation, 2013).

(i) the abatement goals are chosen such that they can be achieved with the mandatory measures, (ii) shocks in product demand (and thus emissions) are neutralized by benchmarking, (iii) firms were allowed to count a limited number of international offsets towards achieving their emission targets (FOEN, 2019a) and (iv) to transfer emissions over time such that a shortfall in one year can be offset by a surplus in the next. As a consequence, nonEHS firms exclusively act as suppliers of domestic offsets, rendering this an explicit abatement subsidy.[11]

A study commissioned by FOEN (TEP Energy, 2016) surveyed firms subject to the tax or one of the exemption mechanisms with respect to climate-relevant decision making. Exempt firms reported more abatement measures than firms paying the tax. However, since larger firms (in terms of employees) and firms with a higher emission intensity were both more likely to seek exemption and to engage in significant abatement measures, these results could be explained by self-selection. Firms that chose not to apply for an exemption explained this with the significant transaction costs associated with developing a target agreement. Krysiak and Oberauner (2010) report a similar result for the introduction of the nonEHS program, based on a theoretical model coupled with firm surveys: Firms with a high emission intensity found it optimal (and indeed tended to choose) the exemption, whereas firms with relatively low emissions paid the tax.

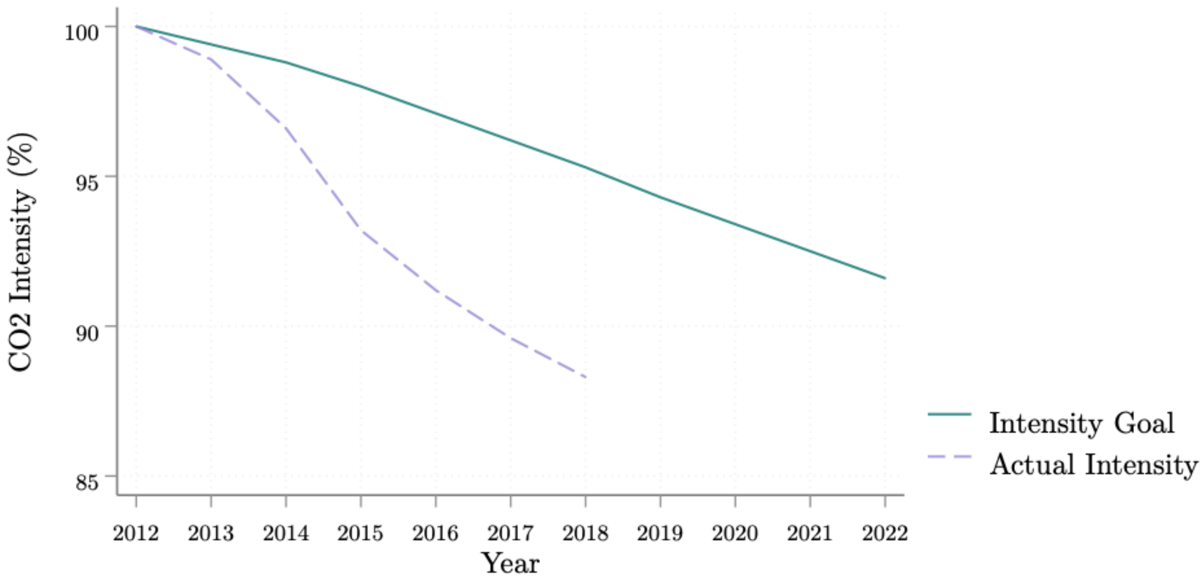
Based on the energy model that was used to identify the abatement targets, EnAW (2019) estimates that the emission goals imply an increase in emissions intensity, relative to the base year 2012, of 4.7% by 2018 and of 8.4% by 2022 (see Figure 4). However, firms over-achieved these reduction goals, such that by 2018, the actual emission intensity had been decreased by 11.7% (dashed line).

These numbers should be viewed with caution, however, as some of the involved abatement measures would have happened anyway. An external evaluation concluded that only 20%-40% of the emission reductions are caused by the agreement and the subsidies,

[11]In this section, we interpret the fuel surcharge as a tax that goes to the Federal government, which also happens to subsidize nonEHS firms for abatement that otherwise would not happen. Conversely, one could take the view that there is an emissions cap in the transport sector, and drivers pay with their surcharge for the offsets generated by nonEHS firms. In that interpretation, there is no subsidy paid (as it is a transfer from drivers to firms), but the offsets generated by nonEHS firms do not constitute additional emission reductions (as they simply replace abatement that would have happened in the transport sector).

whereas the remainder would have happened anyway (Ecoplan, 2016). EnAW (2019) argues that an important side effect of the target agreements is to increase the awareness for environmental efficiency within the firm, which leads to the establishment of processes and procedures to measure and reduce emissions.

Figure 4: Emission intensity for firms with emissions goals



Source: EnAW (2019)

Ecoplan (2016) estimated average abatement cost of the target agreement measures to be CHF 26-69 CHF per tCO_2. From 2008 to 2018, nonEHS firms emitted a total of 23.7 million tCO_2. Multiplied with the levy that applied at the time of the emission, this leads to a foregone tax revenue of CHF 1,017 million.[12] In addition, the federal government spent CHF 296 million to compensate firms for over-abatement. Besides these monetary costs, additional costs accrue in the process of working out target agreements and monitoring firms' compliance. Overall, we conclude that the nonEHS has significantly reduced emissions, but at a considerable cost.

[12]Because the revenue from the CO_2 levy is returned, the federal government does not actually have less money if another firm is exempt. However, returning the money is associated with a social benefit: A third of the revenue is used to fund energy efficiency programs in the building sector, and distributing the remaining two thirds to firms and households increases redistribution. The government thus loses the ability to subsidize and redistribute income as a consequence of exempting more firms.

2.3 The CH EHS

The CH EHS in its current form was introduced in 2013.[13] All relevant parameters of the revised system have been aligned with those in the EU. Participation in the CH EHS is mandatory for plants with a total rated thermal input above 20 MW. Additional thresholds apply to certain sectors based on production capacity. In sectors that tend to be dominated by large installations (e.g., refining of mineral oil or production of steel), no entry threshold is set, such that all plants are included. Due to the absence of fossil-based power generation in Switzerland, the number of plants that fulfill these criteria is quite low. Firms that have a an installed thermal input capacity between 10 and 20 MW are allowed to opt into the EHS. This led to the inclusion of four additional plants, all of which belong to firms that already had other plants in the CH EHS. Currently, the CH EHS includes 53 plants belonging to 36 different firms.

The CH EHS uses harmonized allocation rules, which are based on the benchmarks of emissions performance used in the EU ETS. These benchmarks depend on the physical quantity of goods produced in the past or on heat input. About 95% of the cap is allocated for free to EHS participants, whereas the remainder is retained as a reserve. Changes in free allocation due to adjustments in production capacity, entries or exits do not affect the overall cap, but are taken from (or added to) the reserve. Figure 5 shows the total emissions cap (solid line), along with emissions and free allocation (bars).

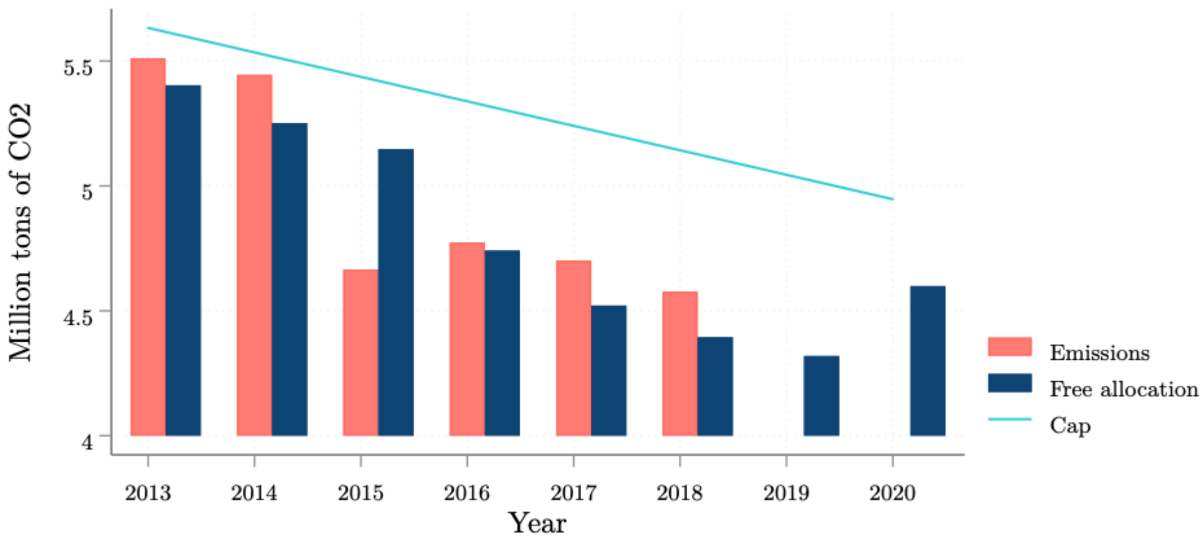
Most of the installations belonging to manufacturing industries have more allowances than they need to cover their emissions, whereas combined heat producers tend to be under-allocated. In addition, firms are allowed to use a limited number of international emissions reduction units.[14]

The unused allowance reserve is sold in the following year in bi-annual auctions. The auction in May 2014 established the first price for CH EHS emission allowances (CHUs).

[13] As noted above, a previous version of the CH EHS was instituted in 2008. Since this was indistinguishable from the current nonEHS system in terms of the main program parameters, we refer to this system as CH EHS only since its overhaul in 2013.

[14] Plants that were already exempt from the levy before 2013 were allowed to use a maximum of 11% of their emissions target in 2008- 2012 for compliance in both phases. Plants that only joined the CH EHS with the reform in 2013 are allowed to make use of 4,5% of their actual greenhouse gas emissions in period 2013- 2020. This is consistent with the rules in the EU ETS (Hintermann and Gronwald, 2019).

Figure 5: Overall cap, free allocation and emissions in the CH EHS



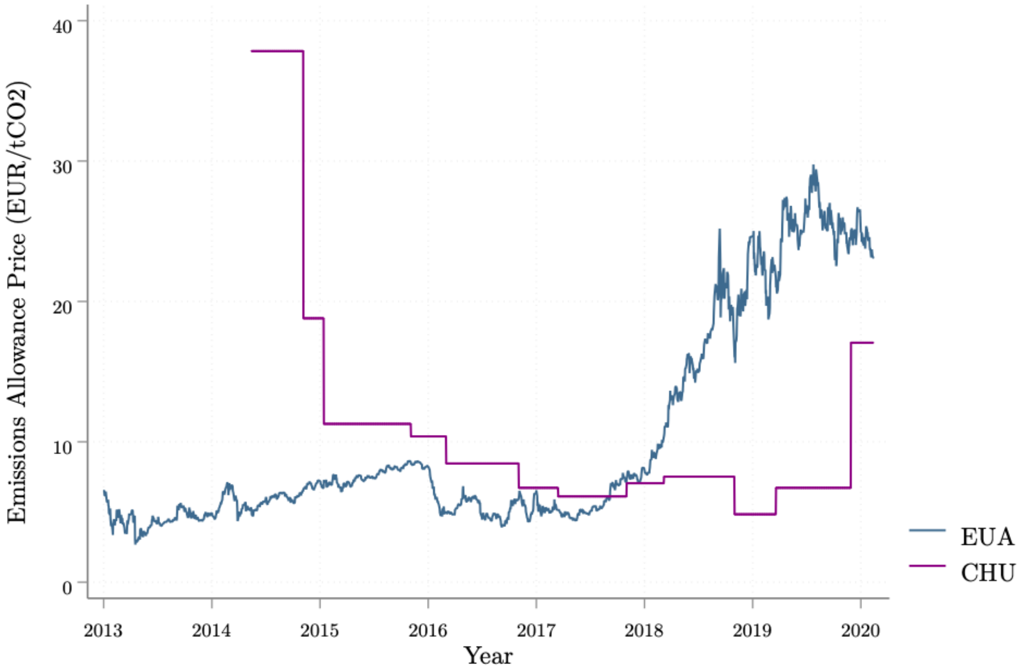
As no secondary allowance market has emerged, the auctions have remained the sole source of a price signal. Figure 6 shows the clearing prices for CHUs, along with the market price for allowances in the EU ETS. The prices were not visibly correlated until recently. This can likely be explained by the uncertainty surrounding the link, and by the absence of a secondary market, which resulted in significant transactions costs to exploit any price differences between CHUs and EUAs.

In 2017, the CH EHS was formally evaluated by the Swiss Federal Audit Office (SFAO, 2017) and found to be over-allocated in terms of emission allowances and plagued by low liquidity. The resulting allowance price was deemed too low to induce firms to engage in meaningful abatement activities. In addition, the report criticised the uncertainty of the eventual link to the EU ETS and the fact that the CH EHS was simply too small to remain in autarky. Despite these shortcomings, however, we note that emissions in the CH EHS did decrease over time, as can be seen in Fig 5. In 2018, the total emissions within the CH EHS were 17 % lower than in 2013.

2.4 Cantonal regulation

Swiss cantons have a far-reaching regulatory autonomy. However, to facilitate the processes that involve more than one canton (such as the planning of buildings and production

Figure 6: Evolution of the CHU and EUA prices; Source: https://www.emissionsregistry.admin.ch and Thomson Reuters Eikon.



processes), the cantonal governments have agreed on a "lowest common denominator" for energy policy. This basic compromise is known as the "large user model" (Grossverbrauchermodell in German, or GVM) and states that all cantons should regulate plants that use more than 5 GWh of heat input and/or 0.5 GWh of electricity per year.[15] Firms can choose one of three pathways to implement the GVM: (1) work out energy efficiency measures with EnAW or Swiss Cleantech, just like nonEHS plants (see above); (2) develop an agreement with the canton in which they operate; and (3) carry out an energy audit.

The GVM does not focus on emissions but on energy efficiency, and in particular on electricity use. The overlap with the CH EHS is therefore limited. Furthermore, most cantons do not require very stringent energy efficiency measures in order not to disadvantage "their" firms relative to competitors in other cantons and abroad. Nevertheless, it is possible that firms in the CH EHS have reduced emissions, among other reasons, due to the measures developed under the GVM. To control for a potential direct impact of cantonal regulation, we include a dummy that denotes active regulation subject to the GVM (and which is zero otherwise) in our regressions. This dummy only applies to EHS

[15] More information about the GVM can be found at https://www.endk.ch/de/energiepolitik-der-kantone/grossverbrauchermodell.

plants, as all nonEHS plants fulfill the GVM criterion by construction.

3 Methodology and data

In this section, we first describe our identification strategy and then present the data.

3.1 Research design

Our design exploits that despite the name change, the main parameters of the nonEHS program have remained stable since its introduction in 2008, and that many of the firms currently in the CH EHS used to be in the nonEHS program. We estimate the differential effect of these two programs using a difference-in-differences (DiD) approach. The control group consists of the firms that have remained in the nonEHS program throughout, whereas the treatment firms are those that were transferred from the nonEHS program to the CH EHS in the beginning of 2013. Since inclusion into the EHS was mandatory, the treatment is arguably exogenous.[16]

Comparing the emissions in the two groups allows for a causal identification of the *differential* effect. The individual effects of each program are not identified, but these can be approximated by means of the studies defined above. Furthermore, knowing the differential effect between a subsidy program and a cap-and-trade program is interesting in its own right. Based on the higher financial incentive for emissions reductions, we would expect the nonEHS to have a larger effect on emissions.

Our base specification consists of a difference-in-differences (DiD) analysis of the log of emissions, such that we measure which group reduced emissions by a larger proportion. We estimate the following equation:

$$e_{it} = c_i + c_t + \alpha \cdot DiD_{it} + \epsilon_{it}\,, \tag{1}$$

[16] As discussed above, four plants opted into the CH EHS even though they did not meet the mandatory inclusion requirement. However, these plants belong to firms that owned other plants for which inclusion in the EHS was mandatory. Presumably, the transactions costs of being part of two separate programs was deemed sufficiently large for these firms to opt all their plants into the system. This does not negate our assumption that, taken on its own, the nonEHS is the more attractive program due to the presence of the abatement subsidy.

where e_{it} refers to the natural logarithm of CO_2 emissions, c_i to a firm-level fixed effect, c_t to a vector of yearly dummies and ϵ_{it} is an i.i.d. error term. The coefficient of interest is α, which multiplies the difference-in-difference term $DiD_{it} \equiv D_t \cdot D_i$, where D_i refers to the treatment group dummy and D_t to the treatment period dummy. We allow the errors to be correlated within observations belonging to the same firm (which may own several plants), but not across firms.

To investigate a potential effect heterogeneity across plants, we allow the treatment effect to vary across pre-treatment characteristics Z_{0i}:

$$e_{it} = c_i + c_t + \alpha \cdot DiD_{it} + \gamma \cdot DiD_{it} \cdot Z_{0i} + \epsilon_{it} \tag{2}$$

In Z_{0i}, we include the same information that we use for matching, but also additional variables that could impact the effect of the treatment. Rather than continuous variables, we will use dummies denoting bins of the distribution, such that the treatment effect for a particular bin will be given by $\alpha + \gamma$.

In addition to a simple comparison of (log) means, we employ a matched-control analysis similar in spirit to Fowlie et al. (2012) and Wagner et al. (2014), where we compare treated firms to control firms that are similar with respect to pre-treatment characteristics. We match exactly on the 1-digit industry classification,[17] as well as parametrically on the pre-treatment level of revenue, employment and capital. To control for potentially different trajectories of abatement over time, even in the absence of any treatment, we also match on the proportional emissions reduction during the pre-treatment period. Because there may be anticipation effects, we only use information from the years 2008-2011 for matching, while excluding the year 2012 (more about this below).

We start by matching to the nearest neighbor without replacement, where we allow for error clustering on the matched pairs. To test for the robustness of the results, we also engage in matching with replacement, in which we vary the number of matched control plants per treated plant between 1 and 5 and bootstrap the standard errors.

[17] Exact matching on 2 digits would lead to very few matched observations, given our sample size.

3.2 Data

Total reported emissions from firms in the nonEHS and EHS programs in the period 2008-2012 are available from the public reports published in the Swiss Emissions Trading Registry.[18] However, emissions reported for the period 2008-2012 are not directly comparable with emissions reported since 2013, for the following reasons. First and foremost, the perimeter of the covered emissions has changed. During 2018-2012, only the emissions from eight "standard" fuels were considered,[19] but since 2013, a number of process emissions (e.g., in the production of cement and steel) and waste emissions have also been included. To make the data comparable, we computed plant emissions from the eight standard fuels for the entire sample period.

Second, emissions of CO_2 equivalents are not measured but calculated based on the fuel (or process) inputs. The emission factors applied to calculate the $CO_2eq.$ emissions were last updated in 2017, and we apply these for the entire sample period (EZV, 2018).

Third, emissions from purchased heat have been counted as the heat producers' emissions since 2013, but had been assigned to the buyer before that. To circumvent this problem, we identify the emissions associated with the heat purchases in 2008-2012 and associate them with the producers throughout our sample period.

Last, plants are allowed to participate in groups in both the CH EHS and the nonEHS program. Some of these groups dissolved with the policy change, whereas new groups were formed in 2013. To make a comparison possible, we aggregate the emissions to the largest group level before and after 2013. To make these adjustments, we had to rely on the expertise of FOEN staff. The adjusted dataset with the comparable emissions perimeter before and after 2013 is confidential information provided to us by FOEN.

We complement the emissions data with information on employment, capital and revenue from Bureau van Dijk's Orbis database. These data are used only for matching purposes, such that we focus on the pre-treatment period. The Orbis data are on the firm-level. To assign the quantities to individual plants, we used additional information

[18]For more information on allocation, surrendering obligation, surrendered units and issued attestations, visit `https://www.emissionsregistry.admin.ch`.

[19]These are lignite, hard coal, propane, butane, natural gas, gas-oil, extra light fuel oil, medium/heavy heating oil and coke.

from business reports. Where no such information is available, we simply divide the firm-level information equally among the number of plants.

Table 2: Summary statistics

	Observations (Nr.)	Emissions (Mt CO_2/y)	Revenue (million CHF/y)	Employees (Full-time eq.)	Capital (million CHF/y)	Offsets (Mt CO_2)
All plants	2,332	8.043	429.124	923	13.831	9.415
Treated	286					
2008-2012	130	51.398	2,343.757	5,586	67.517	48.907
2013-2018	156	41.593	2,398.359	5,485	76.306	-
Control	2,046					
2008-2012	930	2.929	131.137	252	4.819	3.895
2013-2018	1,116	2.406	135.489	223	4.861	-

Notes: Offsets correspond to the total amount of over-abatement sold to CCF and KliK generated during 2008-2012.

Table 2 presents summary statistics of our 26 treated and 186 control plants (or group of plants, if participating jointly) over the eleven-year period. The EHS plants are significantly larger in all dimensions. Constant differences are accounted for by the plant-level fixed effects and therefore pose no problem for identification, but we have to account for the possibility that very emission-intensive firms may have different abatement trajectories than firms for which emissions account for only a small share of total costs. This is the reason for including the proportional reduction of emissions during the pre-treatment years among our matching variables (see above).

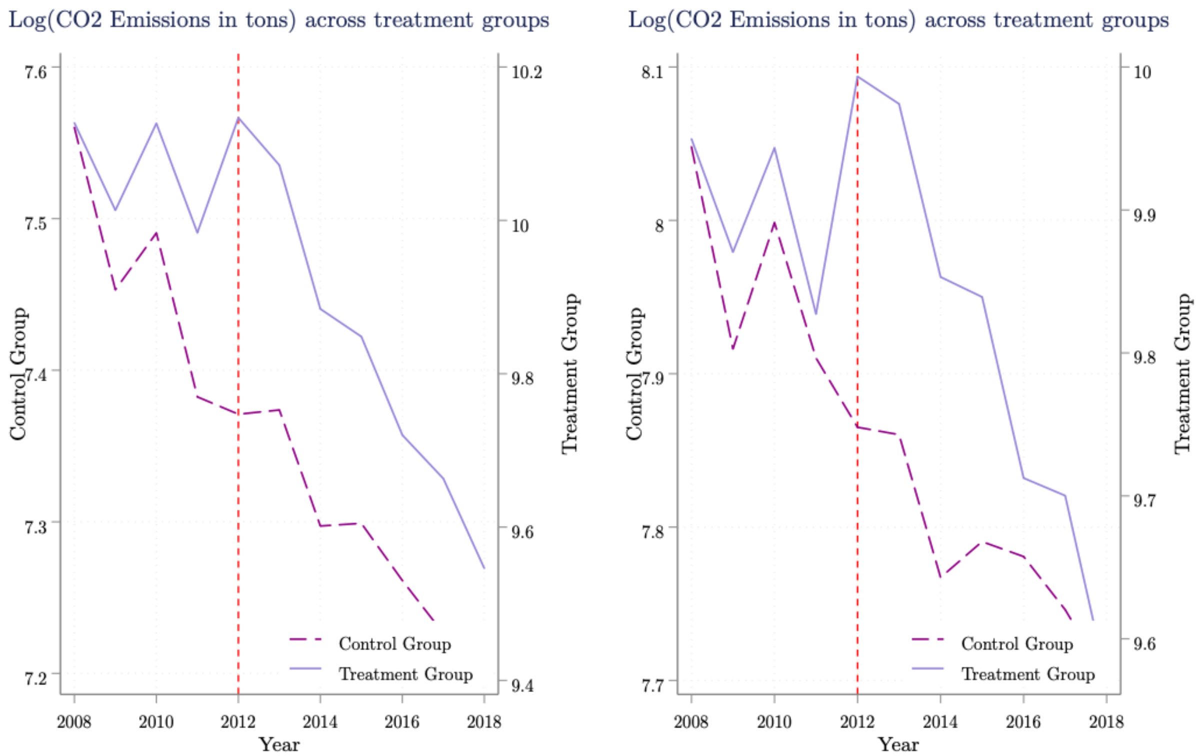
Average annual emissions of the treated and control plants are shown in Figure 7, with and without matching on observable characteristics. The treatment is denoted by a vertical line in the year 2013. Because the emission levels differ significantly between the two groups, we plot the emission trends on different axes.

The figure highlights two important facts. First, matching matters. The trends prior to 2013 are much more similar once we condition on pre-treatment characteristics. When interpreting our findings, we will therefore place more weight on the results from the matched analysis. Second, the year 2012 is special in the sense that the treatment group temporarily increased its emissions relative to the control plants.[20] To avoid creating

[20]This is confirmed in a regression analysis: Adding an interaction between the year-2012-dummy and the control group dummy leads to a positive and statistically significant coefficient. The temporary surge

a bias from such anticipation effects, we exclude the year 2012 from our analysis. The average treatment effect that we estimate will therefore be based on a comparison of the years 2008-2011 (pre-treatment) and the years 2013-2018 (post-treatment).

Figure 7: Emissions before (left) and after (right) matching



4 Results

Table 3 presents the results from estimating equation (1). In the first column, we do not include plant fixed-effects but instead control for pre-treatment observable characteristics and industry dummies. In addition to the variables used for matching, we also include the level of pre-treatment emissions and the number of offsets generated during 2008-2012. We also include a dummy denoting cantonal regulation.

in emissions for plants that joined the CH EHS in 2013 could be due to various reasons. For example, firms could have increased their emissions in order to obtain more free allocation, or to "use up" their surplus accumulated during the previous years in the belief that it could not be transferred into the treatment period. These hypotheses require an assumption of imperfect information, as free allocation was not based on emissions in 2012, and firms could in fact sell their over-abatement from 2008-2012 even in the post-treatment years. However, this may not have been clear for all firms.

Plant emissions increase with the average level of pre-treatment emissions and revenue, whereas the effect of the other variables is not significant at p<0.05. However, this regression may be influenced by omitted variables that drive emissions, and which are correlated with observed plant characteristics. To control for (constant) unobserved heterogeneity, we include plant-level fixed effects in all other regressions.

Table 3: Treatment effect (full sample and matched sample)

Dependent Variable:	Emissions in tons of CO2 in logs				
	(1) no matching	(2) no matching	(3) NN w./o. repl.	(4) N3N w. repl.	(5) N5N w.repl.
DiD	0.036 (0.797)	-0.071 (0.632)	0.108 (0.368)	0.157 (0.129)	0.114 (0.220)
Emissions ave.	0.962*** (0.000)				
Emissions trend	0.270** (0.045)				
Revenue	0.063*** (0.001)				
Capital	-0.019 (0.276)				
Employment	-0.059*** (0.007)				
Offsets	-0.005 (0.270)				
Cantonal regulation	0.115 (0.420)				
Industry dummies	✓	✗	✗	✗	✗
Year FE	✓	✓	✓	✓	✓
Firm FE	✗	✓	✓	✓	✓
Obs.	1515	2066	433	568	727

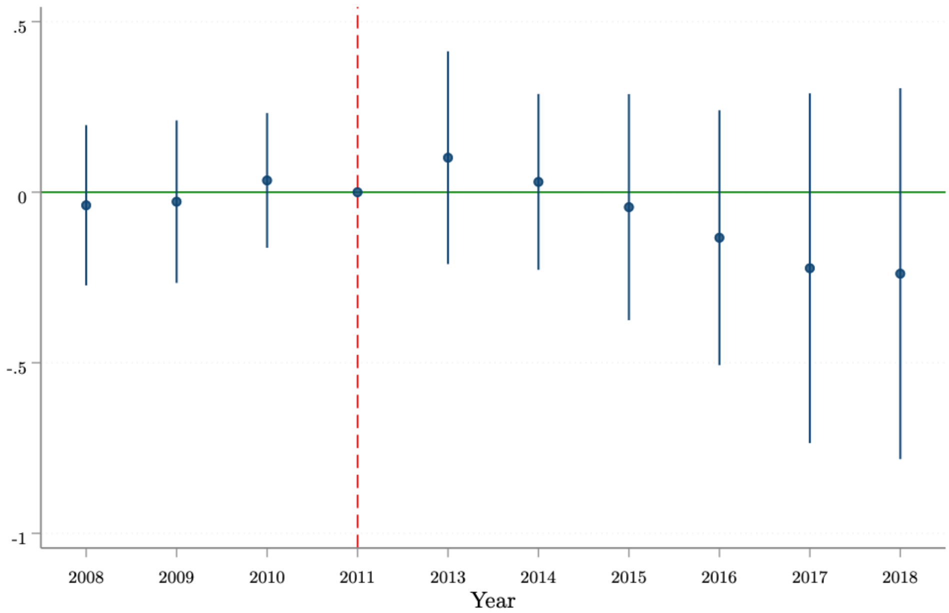
Note: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. (1) and (2): Standard errors (in parentheses) are clustered on the firm level. (3): Standard errors (in parentheses) are clustered on the matched-pair level. (4) and (5): Standard errors (in parentheses) are obtained through bootstrapping (500 replications). "Emissions trend" refers to the (log) difference of emissions in 2010-2011 and 2008-2009. "Offsets" refers to the ratio between the offsets generated by over-abatement and plants' total emissions during 2008-2012.

Column (2) presents the result from a difference-in-differences estimation involving all plants. In columns 3-6, we compare treated with matched control firms based on various forms of matching. In all regressions, the estimate for average treatment effect is not statistically significant from zero. This is surprising, given the very different financial incentives for abatement in these two programs.

Figure 8 shows the results in the format of an event study. We see that the average treatment effect is far from being significant in all years, and that there are no pre-treatment effects in the years 2008-2011.

To investigate whether the absence of an overall effect masks heterogeneous responses by different types of plants, we interact the DiD term with pre-treatment information

Figure 8: Event Study



as specified in eq. (2). We present the results from including dummies, rather than continuous variables, which facilitates the interpretation of the coefficients. Specifically, we create dummies that take the value of one if a plant exhibits an above-median value for a particular pre-treatment variable, and zero otherwise.

The results from this analysis are presented in Table 4. All regressions in this table are based on nearest-neighbor matching without replacement. The results for regressions based on different methods of matching (including no matching) are included in Tables A.1-A.4 in the appendix. The method of matching does affect the results. The appendix also contains the results from including continuous pre-treatment variables (rather than dummmies) in Table A.5.

Columns (1)-(6) individually include seven dummies corresponding to the six pre-treatment variables. For some specifications, the treatment effect is positive and significant for plants that exhibit below-median values for the respective pre-treatment variable (offsets, average emissions and revenue). The treatment effect for plants with above-median values is the sum of the coefficients on the DiD term and on the interaction term, which is not statistically significant for any column.

We also interact the DiD term with a dummy for (post-treatment) cantonal regulation (column 7). The results indicate that the treatment effect is not driven by the cantonal regulation, as both the coefficient on the DiD term and its sum with the interaction coefficient is not significant. This indicates that the abatement on behalf of CH EHS is not due to cantonal regulation.

Table 4: Treatment effect (matched sample)

Dependent Variable:	Emissions in tons of CO2 in logs								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Matching without replacement								
DiD	0.265**	0.237*	0.020	0.216*	0.177	0.085	0.068	0.379***	0.373***
	(0.035)	(0.053)	(0.872)	(0.081)	(0.122)	(0.438)	(0.668)	(0.001)	(0.001)
DiD x Offsets	-0.317**							-0.284*	-0.318**
	(0.030)							(0.060)	(0.020)
DiD x Emissions ave.		-0.285*						-0.090	
		(0.051)						(0.467)	
DiD x Emissions trend			0.173						
			(0.246)						
DiD x Revenue				-0.236				-0.197*	-0.237*
				(0.111)				(0.089)	(0.075)
DiD x Capital					-0.150				
					(0.335)				
DiD x Employment						0.046			
						(0.764)			
DiD x Cantonal regulation							0.084		
							(0.512)		
Year FE	✓	✓	✓	✓	✓	✓	✓	✓	✓
Firm FE	✓	✓	✓	✓	✓	✓	✓	✓	✓
Obs.	433	433	433	433	433	433	433	433	433

Note:* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Standard errors (in parentheses) are clustered on the matched-pair level. The interaction terms are dummies that take the value of one if a plant's value exceeds the median, and zero otherwise.

The individual inclusion of pre-treatment variables serves to identify potential effect modifiers, but the coefficients may reflect the effect of more than one determinant since the pre-treatment dummies are correlated. For example, plants with high pre-treatment emissions also tend to generate more offsets and generate more revenue. To address this, we jointly include those variables for which the interaction terms are individually significant at p<0.2 (which are also the ones for which the coefficient on the DiD term is significant at p<0.1). The results from this joint regression are shown in column (8). The coefficients imply that the treatment effect varies with the level of generated offsets (i.e., over-abatement) and revenue during the pre-treatment years. In contrast, the coefficient on the interaction term for pre-treatment emissions becomes insignificant.

In column (9), we re-estimate this model using only the significant interaction terms. This creates four groups within the treated plants, defined over their levels of over-abatement and revenue in the pre-treatment period: HH (high offsets and revenue); HL (high offsets, low revenue); LH (low offsets, high revenue); and LL (low offsets and revenue). As it turns out, the level of revenue and over-abatement are not strongly correlated, such that the treated plants are quite evenly distributed across these four groups.

We can now discuss the treatment effect for each of these four groups. The treatment effect for the LL group is given by the coefficient on the DiD term alone, which is positive and statistically significant. The treatment effect for the HL group consists of the sum of the coefficient on the DiD term and the coefficient on the offset interaction term; the treatment effect for the LH group is the sum of the coefficient on DiD and the interaction term with revenue; and the treatment effect on the HH group is formed by the sum of all three coefficients. The effect for none of the groups involving a high level of any variable is statistically significantly different from zero.[21]

One interpretation of our results is the following: Firms do respond to financial incentives for abatement, which is the reason for the positive treatment effect for group LL. However, there may be reasons other than money that induce firms to reduce their emissions. For example, some firms may want to develop (or maintain) a "green" image, which could lead them to value emission abatement in its own right. As a consequence, they engage in abatement in excess of equating their marginal abatement costs with the allowance price. The extent of offsets generated by over-abatement during the pre-treatment phase could proxy for such green preferences. In other words, firms that abated emissions above and beyond what they needed to do by law continue to do so under the EHS regime, whereas those that just did the minimum respond to the lower financial incentive in the EHS by reducing their abatement effort.

A possible explanation underlying the effect involving revenue could be that firms generating a lot of cash flow can afford to engage in more stringent abatement measures than firms that are more cash-constrained.

[21]For group HL, the treatment effect (with standard error in parenthesis) is 0.093 (0.132). For groups LH and HH, the corresponding values are 0.134 (0.132) and -0.169 (0.191), respectively.

5 Conclusions

We find that the nonEHS program leads to significant costs in terms of lost revenue and abatement subsidies payments, but it is not clear that it leads to a higher level of emissions reduction than a regular ETS. This raises the question of whether this money is well spent. Furthermore, one of the advantages of market-based instruments (such as taxes and cap-and-trade systems) is that they do not require individual information about firms' abatement costs, which tend to be private. The command-and-control component of the nonEHS program, on the other hand, very much relies on firm-specific information. The current system provides incentives for firms to over-state their abatement costs and thus under-state their abatement opportunities. If successful, such a strategy would enable firms to cheaply over-achieve their goals and be compensated for this at a rate of CHF 100/tCO_2. We have no way of measuring whether this is indeed the case; we merely note that the system is not robust to the strategic use of private information by firms.

There is an ongoing political discussion in Switzerland about whether the scope of the nonEHS program should be broadened to include more plants, e.g., by lowering the inclusion threshold in terms of annual emissions. To the extent that the current tax of CHF 96 per tCO_2 can be expected to have at least as strong an effect as an ETS with an allowance price on the order of CHF 10, we would not expect that moving firms from the CO_2 levy into the nonEHS program will result in additional emissions reductions. This is true *a fortiori* given that the tax is scheduled to increase further in the future.

Proponents of the nonEHS program argue that it some of its chief benefits lie in "bringing emissions into the boardroom", and that the collaboration with specialized agencies informs firms about possible abatement measures that they otherwise would not have identified. However, it is not clear why rational firm managers should care more about earning CHF 100 than about saving a tax of CHF 96 per per tCO_2. In fact, the concept of loss aversion would indicate that firms will do *more* to reduce losses than to realize gains (Kahneman et al., 1991). Furthermore, nothing stops a firm from using the advisory services of the specialized agencies even if it is not part of the nonEHS program, as the prospect of saving the CO_2 levy should be incentive enough to become informed about effective abatement measures. Many of the firms that have developed abatement measures in cooperation with EnAW and ACT are not exempt from the levy.

If Switzerland (along with other countries) is to significantly reduce its GHG emissions, the burden of this effort should be spread across many shoulders. Exempting additional firms from the CO_2 levy shifts the incidence of climate policy towards households and the remaining firms. This is not equitable, and our results imply that it may not lead to more abatement either.

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A Additional Tables and Figures

Figure A.1: Event study graph with the year 2012 included

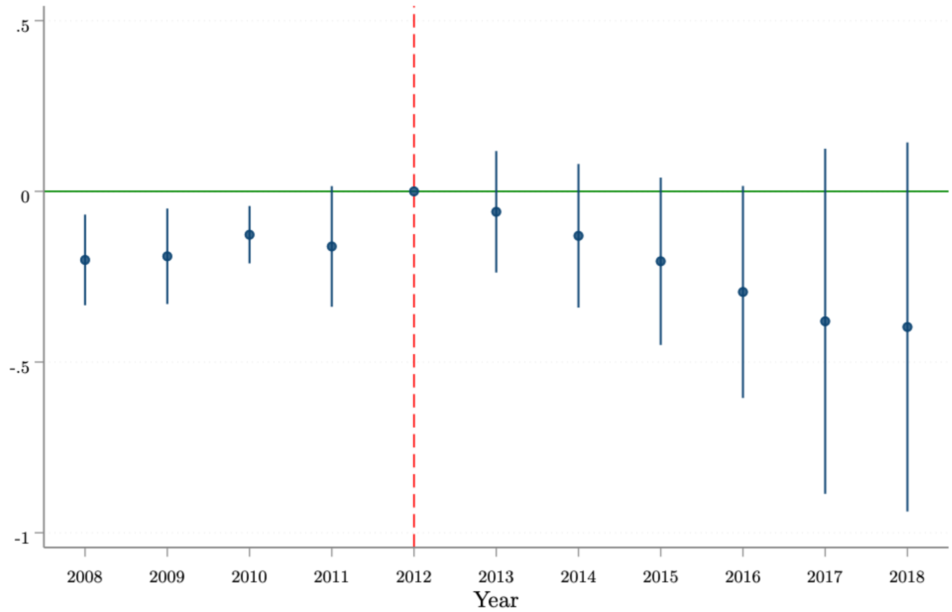

Table A.1: Heterogeneous treatment effects without matching

Dependent Variable:	Emissions in tons of CO2 in logs								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
				Matching without replacement					
DiD	-0.114	0.096	-0.210	0.213**	0.174*	0.070	-0.036	0.180	0.169
	(0.674)	(0.558)	(0.373)	(0.037)	(0.053)	(0.801)	(0.705)	(0.277)	(0.318)
DiD x Offsets	0.086							0.162	0.088
	(0.762)							(0.637)	(0.745)
DiD x Emissions ave.		-0.334						-0.191	
		(0.221)						(0.590)	
DiD x Emissions trend			0.275						
			(0.330)						
DiD x Revenue				-0.529**				-0.439*	-0.529**
				(0.040)				(0.068)	(0.042)
DiD x Capital					-0.456*				
					(0.080)				
DiD x Employment						-0.263			
						(0.317)			
DiD x Cantonal Regulation							-0.075		
							(0.758)		
Year FE	✓	✓	✓	✓	✓	✓	✓	✓	✓
Firm FE	✓	✓	✓	✓	✓	✓	✓	✓	✓
Obs.	2066	2066	2066	2066	2066	2066	2066	2066	2066

Note: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Standard errors (in parentheses) are clustered on the firm level.

Table A.2: Heterogeneous treatment effect with nearest 1-neighbor matching

Dependent Variable:	Emissions in tons of CO2 in logs								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Matching without replacement								
DiD	0.316***	0.288**	0.071	0.267**	0.228*	0.136	0.106	0.430***	0.424***
	(0.007)	(0.025)	(0.595)	(0.046)	(0.062)	(0.283)	(0.555)	(0.001)	(0.002)
DiD x Offsets	-0.317**							-0.284*	-0.318**
	(0.022)							(0.057)	(0.017)
DiD x Emissions ave.		-0.285*						-0.090	
		(0.043)						(0.523)	
DiD x Emissions trend			0.174						
			(0.233)						
DiD x Revenue				-0.236				-0.196	-0.237*
				(0.104)				(0.113)	(0.077)
DiD x Capital					-0.150				
					(0.346)				
DiD x Employment						0.046			
						(0.768)			
DiD x Cantonal Regulation							0.092		
							(0.464)		
Year FE	✓	✓	✓	✓	✓	✓	✓	✓	✓
Firm FE	✓	✓	✓	✓	✓	✓	✓	✓	✓
Obs.	383	383	383	383	383	383	383	383	383

Note: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Matching performed with replacement. Standard errors (in parentheses) are obtained through bootstrapping (500 replications).

Table A.3: Heterogeneous treatment effect with nearest 3-neighbor matching

Dependent Variable:	Emissions in tons of CO2 in logs								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Matching without replacement								
DiD	0.314***	0.286**	0.068	0.264**	0.225**	0.134	0.104	0.428***	0.422***
	(0.003)	(0.021)	(0.545)	(0.030)	(0.045)	(0.178)	(0.554)	(0.000)	(0.000)
DiD x Offsets	-0.318**							-0.285*	-0.319**
	(0.022)							(0.069)	(0.013)
DiD x Emissions ave.		-0.285*						-0.090	
		(0.050)						(0.526)	
DiD x Emissions trend			0.175						
			(0.218)						
DiD x Revenue				-0.235				-0.196	-0.236*
				(0.109)				(0.134)	(0.074)
DiD x Capital					-0.149				
					(0.345)				
DiD x Employment						0.047			
						(0.758)			
DiD x Cantonal Regulation							0.098		
							(0.440)		
Year FE	✓	✓	✓	✓	✓	✓	✓	✓	✓
Firm FE	✓	✓	✓	✓	✓	✓	✓	✓	✓
Obs.	568	568	568	568	568	568	568	568	568

Note: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Matching performed with replacement. Standard errors (in parentheses) are obtained through bootstrapping (500 replications).

Table A.4: Heterogeneous treatment effect with nearest 5-neighbor matching

Dependent Variable:	Emissions in tons of CO2 in logs								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Matching without replacement								
DiD	0.271***	0.243**	0.025	0.221**	0.182*	0.091	0.061	0.385***	0.379***
	(0.003)	(0.019)	(0.817)	(0.043)	(0.059)	(0.343)	(0.694)	(0.000)	(0.000)
DiD x Offsets	-0.317**							-0.285*	-0.318**
	(0.022)							(0.066)	(0.012)
DiD x Emissions ave.		-0.285**						-0.090	
		(0.050)						(0.519)	
DiD x Emissions trend			0.174						
			(0.255)						
DiD x Revenue				-0.235*				-0.197*	-0.237*
				(0.091)				(0.092)	(0.065)
DiD x Capital					-0.150				
					(0.351)				
DiD x Employment						0.046			
						(0.762)			
DiD x Cantonal Regulation							0.086		
							(0.489)		
Year FE	✓	✓	✓	✓	✓	✓	✓	✓	✓
Firm FE	✓	✓	✓	✓	✓	✓	✓	✓	✓
Obs.	727	727	727	727	727	727	727	727	727

Note: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Matching performed with replacement. Standard errors (in parentheses) are obtained through bootstrapping (500 replications).

Table A.5: Heterogeneous treatment effects with continuous variables

Dependent Variable:	Emissions in tons of CO2 in logs							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Matching without replacement							
DiD	0.265**	1.833***	0.108	1.163	0.510*	0.227	1.976***	1.307*
	(0.041)	(0.002)	(0.369)	(0.209)	(0.062)	(0.257)	(0.008)	(0.088)
DiD x Offsets_C	-0.029**						-0.022*	-0.029**
	(0.045)						(0.066)	(0.032)
DiD x Emissions_C		-0.174***					-0.122**	
		(0.006)					(0.037)	
DiD x EmissionsDiff_C			0.031					
			(0.940)					
DiD x Revenue_C				-0.088			-0.045	-0.087
				(0.243)			(0.476)	(0.166)
DiD x Capital_C					-0.049			
					(0.158)			
DiD x Employment_C						-0.022		
						(0.523)		
Year FE	✓	✓	✓	✓	✓	✓	✓	✓
Firm FE	✓	✓	✓	✓	✓	✓	✓	✓
Obs.	433	433	433	433	433	433	433	433

Note: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Nearest-neighbor matching without replacement, as in Table 4. Standard errors (in parentheses) are clustered on the matched-pair level.