Analyzing the Effects of the Swiss Carbon Tax on Carbon Emissions from the Energy Sector

Ansar Mirza

NYU Abu Dhabi, Class of 2022
am9311@nyu.edu

Abstract

Switzerland has shown to increase its carbon tax rate at a rapid speed. This paper evaluates the effect of the Swiss carbon tax on carbon emissions in the energy sector by using panel data of select countries in the OECD. My experiments consist of difference-in-difference (DiD) regressions and synthetic control methods (SCMs) to assess the causal effect of carbon tax on energy carbon emissions. The SCM method provides evidence that the tax implementation decreased emissions from less than 1% a year after treatment to a 20% decrease in emissions at the end of the post-treatment period. This evidence suggests a negative causality of carbon tax on carbon emissions in the energy sector. My paper contributes to the small pool of carbon tax ex-post literature.

Keywords: *Switzerland, carbon tax, synthetic control method, carbon emissions*

I. Introduction

The Paris Agreement is a nonbinding agreement between all nations of the world that serves to address the pressing issues of climate change. Many ideas have been put forth as to how to reduce CO_2 emissions in the most optimal manner. CO_2 is at the center of greenhouse gas emissions, and as such there is a consensus that it must be taxed (Klenert et al, 2018).

Sweden has shown to be a prime example of an excellent policymaker (Klenert et al, 2018). Sweden has public support for the levy, which is not seen anywhere else. The general lack of public support elsewhere is mainly due to doubts of its effectiveness to combat climate change through the means of carbon emission reductions. Because very few countries have implemented a carbon tax, even fewer empirical analyses of the causal effect of carbon tax on emissions have been published. In this paper, I will conduct an investigation into the relationship between carbon taxation and carbon emissions by using Switzerland as a case study. The analysis will focus on Switzerland's carbon tax on the buildings, manufacturing and construction, and industry sector, which was introduced in 2008. Switzerland initially priced the carbon tax at US$12 per tonne of CO_2, rising rapidly over the years to a rate of US$96 per tonne of CO_2 in 2019. At the time of writing, the Swiss carbon tax currently stands at US$130 per tonne of CO_2 (2022) - almost identical to Sweden's and effectively having the second highest carbon price in the world (World Bank, 2017). The carbon tax fully covers buildings, manufacturing and construction, and only covers around 40% of industry (Burkhardt, 2021). This is due to the exemption options in the industrial sector.

There are many debates about the effectiveness of the Swiss carbon tax on emission reduction.

Thalmann reports that the Swiss tax has been very effective in the construction sector and industry sector, with its high pricing contributing to the reduction (Jorio, 2021), whereas Luigis Jorio finds that Switzerland is a country of concern and its contribution to the Paris agreement is insufficient (Jorio, 2021) despite the high pricing. We also see that new revisions to the tax are being rejected by the public (Revill, 2021). There is no consensus as to whether the tax has been effective in reducing emissions in the taxed sectors. However, after a decade since its enactment, it is imperative to look at the carbon tax rate in Switzerland to conduct quantitative analyses. Thus, the goal of my study is to empirically evaluate the effects of the 2008 Swiss carbon tax on carbon emissions in the energy sector.

Switzerland's taxes are focused on depth – only certain emissions are taxed but at a high rate (whereas Finland and Sweden tax more sectors and achieve higher pricing over a longer course of time). The high tax rate does raise the possibility of spillover effects and can thus be useful in evaluating the efficacy of carbon tax on carbon emission reduction.

I will test whether the implementation of the Swiss carbon tax leads to a significant reduction in the amount of energy carbon emissions. In my method, I use data for 12 OECD countries to create country-level panel data from 1990 to 2019 and implement DiDs and SCM to study the effect of the Swiss carbon tax enacted in

2008. For both methods, the OECD countries form the control group, and are weighted (the amount differs between methods) to create a synthetic counterfactual. I first employ the DiD method. I use energy carbon emissions per capita as my dependent variable, allowing me to analyze the difference in the effect of the carbon tax on carbon emissions between Switzerland and the control group — providing the effect of the carbon tax. I also test for spillover by altering the dependent variable to another sector. Some results are suggestive of causality, however lack statistical significance.

Thus, I mainly rely on the SCM method to provide robust results. The panel data is used to form a counterfactual – a synthetic version of Switzerland that comprises a weighted combination of countries that had no carbon tax. This weighting is done through assigning different weights to key predictors of energy carbon emissions and to countries that exhibit a similar number of emissions to best resemble Switzerland's pre-treatment period (1990 to 2008). This method estimates a reduction in emissions for the energy sector by 0.52 CO_2 tonnes per capita by the end of the post-treatment period in 2019 (20% decrease). The results are robust and suggest a negative causal effect of the carbon tax on carbon emissions in the energy sector per capita.

II. Literature Review

There is a lack of empirical research on the causal effect of a carbon tax intervention. The primary methods that the available empirical research uses are simulation models, mainly equilibrium-based, to generate projections of potential impacts of a carbon tax (ex-ante analysis) (Gupta et al, 2019). However, there are even fewer empirical studies based on real data about countries that have implemented a carbon tax (Baranzini and Carattini, 2014). Studying the effects of carbon taxes through empirical research is vital, as credible studies of ex-post empirical analysis of climate change policies will ensure countries yet to adopt environmental mitigation policies have access to the lessons drawn from current climate policies employed worldwide (Carraro et al, 2015). Therefore, it is pivotal to have more ex-post analyses to study the true impact of carbon taxation upon carbon emissions.

The majority of the empirical literature is focused on the Nordic countries due to them being the first to implement an explicit carbon tax at the start of the 1990s (Riley, 2021; Lin and Li, 2011; Andersson, 2019; Alola and Nwulu, 2022).

Lin and Li (2011) use difference-in-difference (DiD) to test whether there is a present effect of CO_2 taxation on total CO_2 emissions per capita. Their regressions include the effect of carbon taxation across five European countries, concluding a significant effect in Finland, but not in the rest of the Nordic countries. The outcome variable used is total emissions, which comprises all sectors, regardless of whether they were treated with a carbon tax. This is likely to underestimate the actual impact of the CO_2 tax upon emissions.

However, Andersson (2019) was able to determine negative causality of carbon taxation on emissions per capita produced by the transport sector in Sweden. His findings were done through the use of synthetic control methods (SCMs). This paper was the first to find this negative causal effect, concluding a reduction of 11% in annual emissions as a result of the carbon tax. Similarly, Runst and Thonipara (2019) follow a similar methodology by using both a DiD and SCMs to study the effect of the size of the carbon taxation on carbon emissions in the Swedish residential sector. They were able to also find negative causality, concluding a reduction in annual CO_2 emissions per capita by 800kg as well evidence to support their theory of 'dosis facit effectum' (the size of a carbon tax determines its effect). Sweden's carbon price at the time was 100 euros per tonne of CO_2 in 2018 – the highest in the world. Criqui, Jaccard, and Sterner (2019) provide a comparative analysis of carbon taxation in three countries: Sweden, France, and Canada. The literature is primarily descriptive, focused on assessing the social and political conditions in relation to acceptance of carbon tax. It is interesting to note that this paper discusses the difficulty of drawing conclusions regarding effects from aggregate data. Criqui, Jaccard, and Sterner (2019) urge that there must be comprehensive research into each industry and sector to truly conclude any effects, a point that forms part of the inspiration for this paper. The need for sectoral study is met for some Swedish papers in the aforementioned papers (Andersson, 2019; Runst and Thonipara, 2020), however, there is still much missing for other countries and their respective sectors.

Current empirical scholarship surrounding Switzerland is ex-ante, generating projections of the potential effects if a tax were to be imposed (Bernard, Vielle and Viguier, 2005; Bahn and Frei, 2000; Imhof, 2012). The focus of these papers is primarily the economic impacts regarding equity and efficiency as well as revenue recycling. There has only been a single ex-post analysis of carbon tax in Switzerland. Ott and Weber (2018) review the short-term impact of the carbon tax on Swiss households' heating demand through a DiD method, concluding no significant effect. This paper only looked at the 2016 carbon tax increase, having only two years worth of data. In addition, this paper has not been peer-reviewed (Lilliestam, Patt and Bersalli, 2021). This paper will be the first to perform an ex-post analysis on the Swiss energy sector, which will be done through the application of methodologies used by both Lin and Li (2011) as well as Andersson (2019), thereby filling a gap in the literature.

III. Methodology

I. Data

We refer to country-level panel data from 12 OECD countries: Australia, Austria, Belgium, Germany, Greece, Italy, Japan, Netherlands, New Zealand, Poland, Switzerland, and the United States. The panel data is limited to the years 1990 through 2019, as energy sector emissions (comprising buildings, manufacturing and construction, and industry; transport is excluded) data is scarce for all countries prior to 1990. The carbon taxation was implemented in Switzerland in 2008, giving us 18 years of pre-treatment as well as 11 years of post-treatment data.

Runst and Thonipara (2019) include countries with a carbon tax of less than US$20 per tonne in their sample deeming them as low intensity treatments when comparing Sweden's pricing (in the realm of US$100 per tonne). The cut-off is used for countries with carbon taxes in the US$10-US$15 range. On this basis, I apply this point by including Japan in my sample which has a carbon tax of US$2 per tonne — one of the lowest carbon tax rates in the world, and lower than any of the other countries in the sample used by Runst and Thonipara (2019).

Also, they exclude the Netherlands, Germany, Italy, and Greece on the basis of them having high energy tax enactments in the 2000s; the authors' data end in 2005. My data runs until 2019, and thus I include them as they are very similar in nature to Switzerland (in terms of geography, culture, and economic backgrounds). By this time, most countries have employed measures to target emission reduction; however, I cannot simply discard all countries based on this. The Netherlands enacted its carbon tax in 2021 (after the post-treatment period), and many other countries are planning to do the same.

This suggests that the measures for combating emissions previously employed have not necessarily been effective in emissions reduction as they are turning to carbon taxation as a method. Therefore, to level carbon tax with that of other employed measures, and exclude them on this basis is not an ideal approach. In addition to this, the difference in pricing is very important, with Switzerland's carbon tax rate being as high as Sweden's in more recent years, despite it only being around for approximately a third of the time (World Bank, 2017).

My dependent variable is energy carbon emissions per capita (by country and year). As my focus is to only look at the taxed sectors of the Swiss economy, transport is excluded from the energy sector variable. Hence, energy carbon emissions are composed of emissions from buildings, manufacturing and construction, and industry. The data for emissions in all countries in the donor sample is taken from "Our World in Data Per capita CO_2 emissions by sector" (Ritchie, Roser and Rosado, 2020). The aforementioned sectors are then added together to create the total energy CO_2 emissions for each country.

II. Difference-in-Difference

The first part of the methodology involves running difference-in-difference (DiD) regressions. This model is utilized in comparative studies to assess the effect of an intervention through analysis of pre-treatment and post-treatment. For the model to be effective, a control is appropriated of countries with relevant factors (primarily if they are a part of the OECD, as this is an indicator of high economic standing) and similar carbon emissions to Switzerland prior to the intervention year. Other plausible factors are geography and social backgrounds. Similar studies primarily comprise their control groups of European countries, however to date, there is only a small number of European countries similar to Switzerland that have not implemented a carbon tax. Thus, to increase the control group size, I look to the OECD pool and include the United States, Japan, Australia, and New Zealand – the most similar to Switzerland in terms of economy and emissions outside of Europe. This will allow a comparison of each country's carbon emissions before and after a carbon tax – enabling a degree of isolation of the treatment effect of carbon tax.

My primary DiD regression will use the panel data of all countries specified in the data section. In the regression, energy CO_2 emissions (measured in tonnes) act as the dependent variable. The first dummy variable (treated) equals to 1 if the country is Switzerland and 0 for the control group. The second dummy variable (after) equals to 1 when the year is 2008 or later, and equals to 0 when the year is prior to 2008. The variable (treated * after) is the interaction term and it equals to 1 if the observation is from 2008 onwards and is Switzerland, while all other observations will equal to 0. I expect a negative effect of the interaction term, however, the statistical significance of the said result is difficult to estimate.

$\beta 1$ provides a measure for the difference in CO_2

emissions between the treated and control groups before the treatment. $\beta 2$ provides a measure for the difference in CO_2 emissions for all countries in my model between the post-treatment and pre-treatment periods. $\beta 3$ is the difference in the effect of the treatment on CO_2 emissions between the treated and the control group – it captures the treatment effect.

Next, I run a DiD regression in which I create an unweighted synthetic Switzerland, whereby the energy carbon emissions of all countries in the control group are averaged equally (each representing an eleventh). This can be effective to some degree, as it may prove to harbor more significant results due to a lower sample size – and will be useful as a base for the second part in the methodology.

As the carbon tax in Switzerland is only focused on certain sectors, it can be useful to assess spillover effects into other sectors. This can indicate whether there has been an actual reduction in emissions, and not just a transfer to another industry. To do this, two DiD regressions are run, one where transport emissions per capita is the dependent variable and the other for electricity and heat emissions per capita. This way I can test if the 2008 carbon tax had any significant effect upon the other two significant sectors in Switzerland. The electricity sector is comprised of hydroelectricity (61.5%), nuclear power (28.9%), fossil fuels (1.9%) and other renewable sources (7.7%) (Bradley, 2022). It would be interesting to see the effect on emissions considering the carbon tax on the other sectors. Hydropower is a relatively lower-carbon source and nuclear power does not produce any carbon (as it uses nuclear fission) – this can give an idea if it is being used as an alternative. On the other hand, for the transport sector, there may be possible indirect effects as a result of the carbon tax. This can provide insight into the overall emissions across all sectors, and see if any reductions in the energy sector are meaningful.

DiD regressions can be beneficial to gauge policies. However, it does not account for the carbon tax increases. Only a few countries closely resemble Switzerland's pre-treatment emission path, with the rest being quite high or quite low; this may impact the results' significance. I hope an unweighted average may improve the significance as to be able to show negative causality. However, unweighted averaging poses problems, as overall, countries that are not as good of a fit for Switzerland within the donor pool will contribute more to the pre-treatment path, potentially distorting my counterfactual.

The results can only be seen as causal if the treated and control would have developed equally in absence of treatment – the parallel trends assumption. This assumption is very difficult to identify in the DiD method especially post-treatment. This deficiency of the DiD method can be compensated with the synthetic control method as it relaxes this assumption (Andersson, 2019). The synthetic control method is favorable as it allows for variance over time of potential unobserved confounders upon the dependent variable. This is done through the weighting of the control group in an effort to resemble the pre-treatment phase of the treated unit (Switzerland) based on CO_2 emissions and any other relevant predictors. Due to the limitations of DiD for the case of Switzerland, I mainly rely upon the synthetic control method (SCM). I will turn to SCM as a means of getting a better picture.

III. Synthetic Control Method

To depict the effects of the carbon tax implementation and its continual increases upon energy sector emissions, it is imperative to know how Switzerland's energy carbon emission would have developed in the absence of this carbon tax. Hence the application of the SCM, which constructs a synthetic control group from weighted-averages of the donor sample countries. Whereas the method employed in the DiD took an equal average, this method can account for more factors and assign weights to more relevant data.

What is needed is the synthetic Swiss energy sector as a control group that is as close as possible in mimicking the carbon emissions prior to the intervention.

Let $J + 1$ be the total number of OECD countries in the sample, (indexed by j), and let $j = 1$ represent the treated country – Switzerland. Thus, there are J untreated countries forming the donor sample. Let $T0$ represent the number of years pre-treatment and $T1$ for the number of years post-treatment, $T = T0 + T1$. We assume that $j1$ is subject to a treatment effect in the years $T0 + 1$, T, and nothing prior (Abadie, Diamond and Hainmueller, 2010).

Synthetic Switzerland is formed as a weighted average of the control countries ($j = 2, \ldots, j + 1$) that are subsequently represented by a ($J * 1$) vector of weights $W = (w2, \ldots, wj + 1)$, holding that $0 \leq wj \leq 1$ and $\sum wj = 1$. Every value of W characterizes a weighted average of the countries in the control unit – a synthetic control.

The synthetic control method selects a W that minimizes the difference between Switzerland and the control units in the pre-treatment period and certain predictors. More important predictors receive a larger weight, as they are more decisive in replicating a counterfactual. To select matrix predictor weights V various methods rely on cross-validation methods or choosing weights based on empirical findings in relevant literature as to which factors contribute to CO_2 (Abadie, Diamond and Hainmueller, 2015). However, I follow the method used by Andersson (2019) and Elbaum (2021), which involves selecting V and W matrices concurrently such that the mean squared predictor (MSPE) of emissions is lessened over the course of the pre-treatment period.

The current empirical literature mainly focuses on the transport and residential sector in Sweden. The Swiss carbon tax is only levied at 40% for industry, and 100% for buildings (Burkhardt, 2021). With many exemptions and technicalities, it can be difficult to gauge accurate predictors apart from energy emissions in the pre-treatment phase. Hence, I refer to the methodology used by Runst and Thonipara (2019), where three specifications are run just using emissions data and lags, and two including control variables. The tests using only emissions and lags as well as the tests using control variables exhibited a very low RMSPE (root mean squared prediction error), indicating a good pre-treatment fit. Had this not been the case, they would not have used the specifications consisting of only emissions and lags for further analysis. Therefore, I can assume that emissions and lags can be sufficient as key predictors. Hence my main predictors are the emissions trend during the pre-treatment period, as well as lagged years of CO_2 emissions in the years 1993, 2001, and 2006 (as these provide the lowest MSPE).

It would be ideal for further research to test multiple specifications that look at several combinations of controls and lags to determine higher levels of validity. Finally, the SCM method allows for the use of placebo testing in order to determine the validity of the results – it will test whether there is causality or if it was due to chance. It is a form of robustness checking that can improve causal inference, should there be any. For this method, there are several placebo tests: “in- space”, “in-time”, “leave-one-out" and “full sample”. For this study, I will employ the first listed placebo test in-space.

IV. Results

I. Ordinary Least Squares Regression

The carbon emissions per capita of the energy sector were plotted against carbon tax rate as shown in Figure 1, Linear Regression, showing the inverse relationship that exists between the two variables. As evident in the downward sloping line, as the carbon tax rate increases, the energy emissions per capita in Switzerland decreases. This is purely to highlight the general effect of the carbon tax on emissions; this does not take into account a control group.

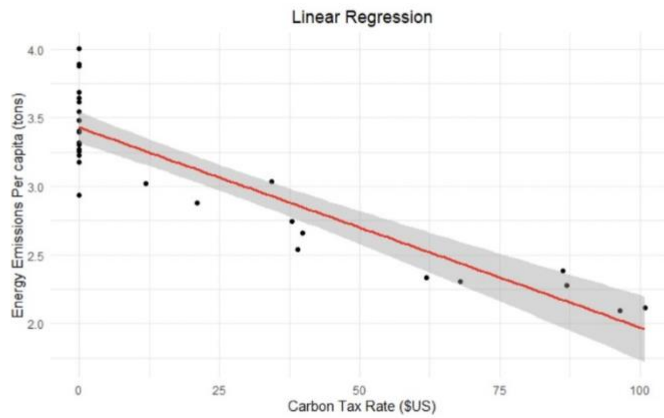

Figure 1: Linear regression of carbon tax rate on energy emissions per capita

	Energy
(Intercept)	3.25 ***
	(0.06)
treated	0.22
	(0.21)
after	-0.69 ***
	(0.09)
treated:after	-0.25
	(0.33)
N	360
R2	0.15

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1

Table 1: DiD Model, where Energy is the dependent variable

II. DiD

The regression results of my first DID model are used to provide information that will allow inference of the relationship between carbon taxation and its effect on CO_2 emissions and the trend of CO_2 emissions over time for the countries in my model. Table 1 displays that 3.25 tonnes is the predicted energy emissions when both the dummy variables equal to zero. This means that the countries that are not treated in a period before 2008, they are associated with a predicted value of 3.25 tonnes of carbon emissions in the energy sector. Looking into the coefficients of each dummy variable, we see that before 2008, Switzerland is associated with an additional 0.22 tonnes of carbon emissions compared to the rest of the countries in my model. For countries that were not treated, there is an associated decrease of 0.69 tonnes of carbon emissions in the energy sector between 2008 and 2019 (post policy) compared to the period from 1990 to 2007 (pre policy). The interaction term is the central indicator for the effects of the carbon tax on CO_2 emissions in Switzerland. Finally, tying back into the paper's main study, carbon emissions for Switzerland after 2008 are reduced by 0.25 tonnes (250kg) compared to years before 2008. Looking at other relevant literature in terms of DiD regressions, we once again refer to (Runst and Thonipara, 2020), where the range of 200-525kg per capita per year was deemed substantial. My value falls within this range, therefore validating the treatment effect. However, the effect of the carbon tax on CO_2 emissions not being statistically significant means that this evidence is not strong enough to draw causal links.

Energy (average of donor sample)	
(Intercept)	3.25 ***
	(0.06)
treated	0.22
	(0.08)
after	-0.69 ***
	(0.09)
treated:after	-0.25 .
	(0.13)
N	60
R2	0.76

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1

Table 2: DiD Model, where Energy (avg) is the dependent variable

I extend upon the previous DiD model by creating a synthetic version of Switzerland that is based on unweighted averages of all countries in the control group; this is not a formal SCM method as key predictors are not accounted for, which is vital in determining the assignment of weights for each country. For this model, as shown in the table, the coefficients are of statistical significance. The interaction term is statistically significant at the 10% level. The model is able to explain 76% of the variation in the carbon emissions in the energy sector, which is 51% more than my first model. In this regression, identical to the first, carbon emissions for Switzerland post-2008 are reduced by 0.25 tonnes compared to pre-2008.

PANEL A	Transport
(Intercept)	2.52 ***
	(0.09)
treated	-0.34
	(0.30)
after	-0.01
	(0.14)
treated:after	-0.13
	(0.47)
N	360
R2	0.19

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1

PANEL B	Electricity and Heat
(Intercept)	4.65 ***
	(0.17)
treated	-4.18 ***
	(0.59)
after	-0.42
	(0.27)
treated:after	0.37
	(0.93)
N	360
R2	0.19

Table 3: DiD Model where other sectors are the dependent variable

The last two DiD regressions use the transport sector and the electricity and heat sector as the dependent variables, respectively. This was done to test for any potential spillover effects resulting from the carbon tax. We are able to note that the effects on carbon taxation are inconsistent in these two regressions implying a negative effect on CO_2 emissions in the transport sector and a positive effect in the electricity and heat sector. For the transport sector, the interaction term displays a decrease of 0.17 tonnes in CO_2 emissions in the post-treatment period compared to the pre-treatment period for Switzerland — showing no spillover.

On the other hand, for the electricity and heat sector, the interaction term reveals a difference of an increased 0.37 tonnes in CO_2 emissions in the post-treatment period compared to the pre-treatment period for Switzerland. The increase in emissions would hold to a spillover effect. However, both of these coefficients are not statistically significant. Therefore, they are unable to indicate a relationship between emissions and carbon tax. This gives weak evidence for a spillover effect in the electricity and heat sector as we cannot statistically distinguish it from noise.

III. SCM

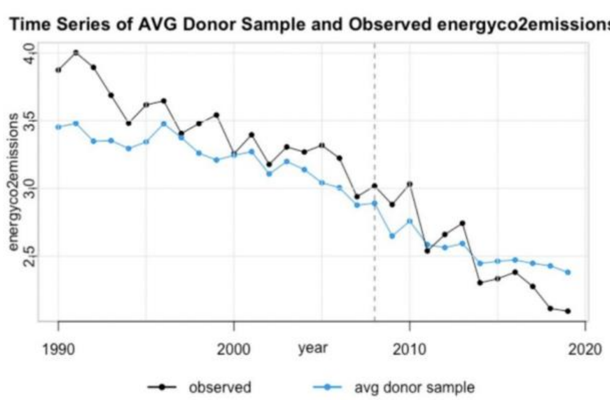

Figure 2: DiD Model where other sectors are the dependent variable

Figure 2 displays the path of per capita energy CO_2 emissions in Switzerland VS. unweighted average of control group. The fit is very poor and does not account for a suitable synthetic version of Switzerland. The plots consistently remain below Switzerland's outcome in the pre-treatment phase, deviating much more than it aligns. It is not viable to evaluate any sort of causal effect. The trajectory of the average donor sample seems to be converging with Switzerland at a certain point; hence the parallel trends assumption is violated. The pre-treatment fit is the most important factor here and the plotted values are much lower, suggesting that the averaging of emissions across the control countries led to a significantly higher contribution from the countries that less resemble Switzerland. This visually represents the downside of DiD's method of an unweighted averaged donor sample.

III.1 Synthetic Switzerland

Variables	Switzerland	Synth. Switzerland	Donor Sample
CO_2 from energy per capita 1990-2008	3.45	3.45	3.23
CO_2 from energy per capita 1993	3.69	3.69	3.35
CO_2 from energy per capita 2001	3.40	3.40	3.27
CO_2 from energy per capita 2006	3.22	3.22	3.01

Note: CO_2 emissions are measured in metric tons

Table 4: Predictor means before treatment

Country	Weight	Country	Weight
Australia	0.0298	Japan	0.0437
Austria	0.101	Netherlands	0.424
Belgium	0.0369	New Zealand	0.0265
Germany	0.207	Poland	0.0312
Greece	0.0320	United States	0.0365
Italy	0.0309		

Note: The w_j weights are between $0 \leq w_j \leq 1$ and $\sum w_j = 1$

Table 5: weights of countries in synthetic Switzerland

Synthetic Switzerland must be able to resemble the pre-treatment CO_2 emissions in the energy sector for Switzerland in order for it to be a credible counterfactual. The table derived from the SCM method, displays the similarity between the treated and synthetic control unit (Abadie, Diamond and Hainmueller, 2010).

Table 4 reports on the values of the key predictors for Switzerland prior to 2008 alongside those of the synthetic Switzerland as well as the average of the donor sample. The table depicts the closeness in values between Switzerland and its counterfactual (synthetic Switzerland). The table displays identical values and proves a better fit of Switzerland and its synthetic counterpart compared to the donor pool average, showing that the synthetic control method is able to track the emissions data the pre-treatment period and assign weights to resemble it to a significantly close degree, something the DiD model fails to do.

The V matrix led to weights being assigned to the predictors. The weights are: CO_2 emissions per capita 1990-2008 (0.576), CO_2 emissions per capita 2001 (0.305), CO_2 emissions per capita 2006 (0.101), CO_2 emissions per capita 1993 (0.0184).

As well as predictors, each country is also given a weight (W weight). Table 5 displays that Switzerland's energy sector CO_2 emissions are best crafted from a combination of the following countries, in decreasing order: Netherlands, Germany, Austria, Japan, Belgium, United States, Greece, Poland, Italy, Australia, and New Zealand. The Netherlands has the highest weight of 0.424, which is suitable as much social and economic context is similar to Switzerland. The same reasoning can be applied to Germany and Austria, two countries that are very similar to Switzerland in many cultural, economic, and social aspects. Those three countries contribute to three-fourths of the synthetic Switzerland. Japan, the United States and Belgium have relatively lower percentages of overall contribution (together making up only around a tenth of synthetic Switzerland).

III.2 Carbon Tax Effect

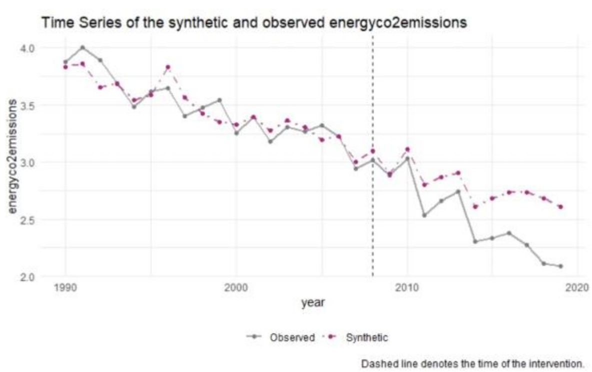

Figure 3: path of per capita CO_2 emissions from energy in Switzerland and Synthetic

Figure 3 displays the path of CO_2 emissions from the energy sector for both Switzerland and synthetic Switzerland – the synthetic version consisting of the different weights obtained in Table 4 (previous section). Overall, synthetic Switzerland demonstrates a good resemblance of Switzerland's pre-treatment phase. Aside from minor deviations in the early 90s and partially again in 1996, the fit is excellent. The graph in general shows a steady decline in emissions with consistent minor fluctuations. Compared to the DiD estimated Graph 2, the fit is much better and it is evident that the ideal weights (regarding the outcome variable and predictors) have been assigned to the required countries to best resemble Switzerland in the pre-treatment period.

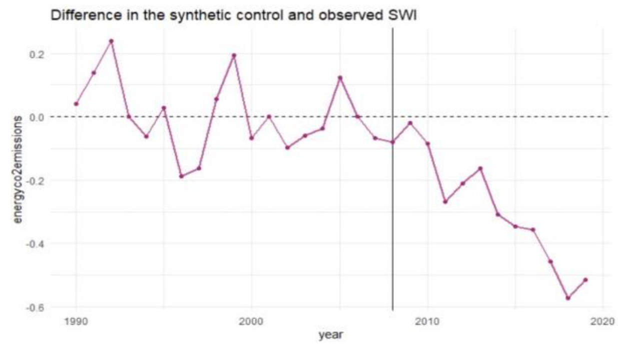

Figure 4: difference in path of per capita CO_2 emissions from energy in Switzerland and Synthetic

Figure 4 displays the difference between synthetic Switzerland and Switzerland. The treatment from carbon tax resulted in increasing gaps with some fluctuations during the post-treatment period. In 2009, one year after the treatment, there was a very minor increase of 0.02 metric tonnes per capita (0.7% increase). Then in the following year, there is the same amount of decrease bringing it to the 2008 level followed by a relatively larger decrease of 10%. The fluctuations are very apparent in the post-treatment phase until 2013, where carbon emissions start to steeply decrease until the last period of the post-treatment phase in 2019 of 0.52 metric tonnes (20% decrease).

Andersson (2019) found the reduction in 2005 for the 1991 Swedish carbon tax to be 12.5% in 2005, whereas Elbaum (2021) found the reduction in the same year for the 1990 Finnish carbon tax to be as large as 48% (for both papers, post-treatment periods end in 2005). The estimate of a 20% decrease – which is larger than that of Sweden – can be potentially attributed to the pricing nature of the Swiss carbon tax. 2014 saw a major price change of carbon tax increase of 79% (US$37.95 to US$67.94) which is where in the graph any noticeable fluctuations cease to exist. The price change, percentage-wise, is larger than Sweden ever saw. Switzerland continues to have faster rising carbon tax rates which may contribute to the larger decrease in emissions.

III.3 Placebo Testing

Synthetic control methods often employ placebo testing to evaluate whether obtained results actually exhibit causal effects or are purely due to chance (Abadie, Diamond and Hainmueller, 2010). Hence, to test for the validity of the results, I performed an in-space test.

The in-space placebo test repeatedly reassigns the treatment effect to every country in the donor pool via the synthetic control method to create its synthetic counterparts. This provides me with an array of estimated effects, from which I can compare the result with Switzerland with placebo results from all countries in the donor sample and their respective effects. This method essentially allows me to test whether the treated country (Switzerland) has a rather large effect (Abadie, Diamond and Hainmueller, 2015).

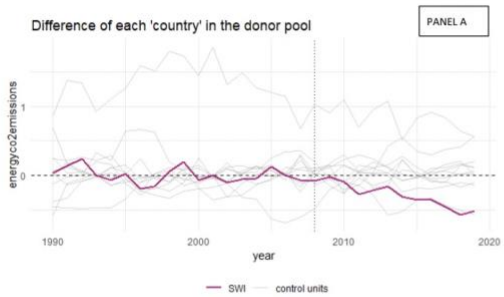

Figure 6: per capita CO_2 emissions gaps in Switzerland and placebo gaps in control units

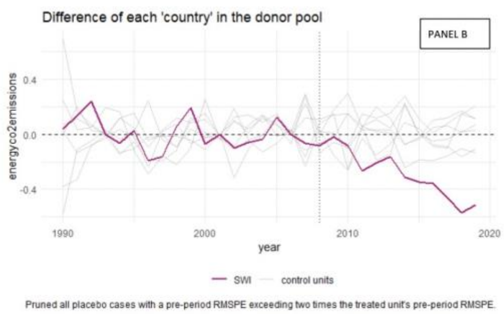

Figure 6 shows the results for the in-space placebo test. Panel A shows that the synthetic control method is unable to reproduce a convex combination of CO_2 emissions in other countries for the 1990-2008 period. This concerns Greece, Poland, Belgium, and New Zealand – Belgium has the highest CO_2 emissions during the pre-treatment period, whereas Poland, Greece and New Zealand have the lowest.

Hence, in panel B, countries with a pre-treatment MSPE that is at least twice as large as Switzerland's pre-treatment MSPE are excluded. This is the case of the aforementioned countries (Belgium, Greece, Poland and New Zealand), and thus leaves seven countries remaining in the donor sample. Considering panel B, from the countries remaining, Switzerland exhibits the largest gap in emissions in the post-treatment period.

Many papers have utilized the in-space placebo test, mainly excluding MSPE values 20 times higher than that of the treated. However, in Abadie, Diamond and Hainmueller's 2010 paper, many in-space placebo tests are conducted, lowering MSPE cut-off each time; finalizing on an MSPE two times higher than that of the control being the optimal (which is the cut-off my placebo tests use).

Despite the magnitude displayed in Switzerland's post-treatment phase in Figure 6; Panel B, this alone is not enough to assess the extent of the effect. A more inferential approach is to study the ratio of post-treatment MSPE to pre-treatment MSPE. The held assumption is that a large ratio for the country in question and small ratios for those in the donor sample would provide more evidence of a true causal effect from treatment (Abadie, Diamond and Hainmueller, 2010). This form of testing removes the need for having a cut-off for any ill- fitting placebo tests – this is beneficial when there are already a small number of control units.

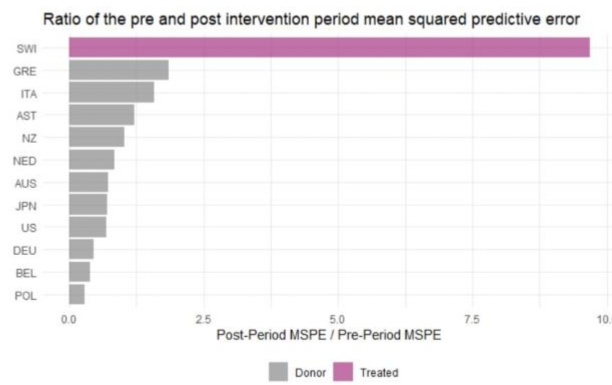

Figure 7: Ratio of post-treatment to pre-treatment MSPE for Switzerland and the control countries

Figure 7 shows that Switzerland's ratio surpasses all the rest in the sample by a great margin. The result stands out amongst the rest; post-treatment MSPE is almost ten times as much as the pre-treatment MSPE. Switzerland's ratio is more than five times the size of Greece (the country in second place).

If carbon tax was randomly assigned, the probability of attaining a ratio of this magnitude would be 1/12 = 0.083 (which is the smallest attainable p value with the sample size). This result is aligned with (Anderson, 2019) who had Sweden's (treated country) ratio far larger than the rest; with a probability of 1/15 = 0.067. The ratio for Sweden to the country in second place was also around five times the size.

Elbaum (2021) also found a rather high ratio for Finland (a treated country); however, Ireland had a considerable ratio that made the author question the validity of his results. Despite having had an in-space placebo test display a large gap in the post-treatment phase, the ratio testing allowed him to get a more invasive look into the sizes of these effects and realize the major presence of Ireland; the ratio for Finland was only 1.5 times the size of Ireland's. This then prompted him to conduct further robustness checks. It is evident that ratio testing provides a better picture and makes up for the challenges the in-space placebo test as a standalone method may pose. It can also provide information on whether further robustness checks would be required.

III.4 Limitations

There is a possibility that the overall tax effect has been undermined. The countries with the highest weights – the Netherlands and Germany, respectively – account for three-quarters of the synthetic model, and were both subject to high energy taxes in the 2000s. Despite my rationale explained in the data section as to their selection, it still would come under a similar treatment to carbon tax. However, this is unavoidable, as most countries now have energy pricing mechanisms. Thus, constructing a suitable counterfactual may prove to be difficult, and hence, showing mainly lower-bound estimates than the actual estimate.

I only performed two robustness checks: an in-space placebo test and a ratio test. While they did conclude validity in my results, it would be further improved by using further placebo tests such as in-time and leave-one-out.

My variable of energy emissions per capita consisted of three sub-sectors (buildings, manufacturing and construction, and electricity), hence there was difficulty in estimating key predictors for all sectors. The other literature looked at a singular sector (mainly transport), and thus the predictors set out by Andersson (2019) were also applicable to Elbaum (2021). However, in my case it was a specific culmination of sectors with no other piece of literature looking at the combination that my paper does. Hence, further research is required into viable predictor weights that would be optimal for Switzerland.

Due to the nature of the tax exemptions present in the industrial sector, it can be difficult to gauge the true effect of energy emissions. Hence, it may prove beneficial to run individual synthetic control models for each sector comprising energy emissions — buildings, manufacturing and construction, and industry. It is plausible that within the energy sector, one specific sector (i.e., buildings) may account for the majority of emission reduction. This deduction would provide a more accurate picture of where the levy is most effective in emission reduction. This would provide a more detailed overview compared to my method.

The nature of the Swiss industrial sector must also be considered. As it is only partially taxed and subject to many exemptions (unlike the rest of the taxed sectors). The question arises as to how it would be possible to accurately account for this discrepancy. Would this involve a method similar to the SCM of assigning weights based on key predictors and emissions to each of the sub-sectors?

While my method experimented with various lags to find the optimal choice, my SCM still only used in specifications concerning varying lagged years of certain CO_2 emissions. It would be wise to follow the methodology of Runst and Thonipara (2020) to test for many specifications with varying lagged years and varying control variables. This would allow for more options to choose a model with a better pre-treatment fit, and suitable weights for any explicit covariates. Allowing the effect of the covariates to be explored in the synthetic control method – however as mentioned in the previous limitations, we would need to decipher the best predictors for carbon emissions for all the sub-sectors.

V. Conclusion

The need for combating climate change, as put out by the Paris Agreement, requires a carbon levy to be the main method of reducing CO_2 emissions. This paper as such uses econometric analysis and meets the goal of this study – empirically evaluating the effects of the 2008 Swiss carbon tax on carbon emissions in the energy sector.

Published literature specifically focused on carbon tax effects on emissions through ex-post analysis is very minimal, and this paper is among the few. This paper is the first to assess the impact of the Swiss carbon tax on carbon emissions in the energy sector.

Data on energy carbon emissions comprising buildings, manufacturing and construction, and industry from select OECD countries were compiled to create a control group. I ran a DiD regression, where the Swiss tax of 2008 was the intervention. The results suggested a negative relationship between carbon taxation and energy carbon emissions, and statistical significance was absent. However, through creating an unweighted average of countries to create an informal synthetic control, statistical significance improved to the 10% level.

I then employed an actual synthetic control method, where the synthetic Switzerland was formed from a weighted combination of countries in the donor sample to best resemble the counterfactual. The ten years post-intervention saw minor fluctuations in percentage changes, nevertheless, it depicted the difference of emissions reduction rising from less than 1% in 2009 to 20% in 2019, compared to synthetic control - supporting evidence of a negative causal effect. The in-space placebo test and the ratio test support the notion of the estimates being robust.

The findings from this study bring suggestive evidence that carbon tax can be a functional instrument in the pursuit of CO_2 reduction, in hopes to combat climate change. The case for Switzerland is made to some extent, however, future research and additional testing are required to increase the evidence of

Causality of carbon tax on carbon emissions in the energy sector for Switzerland. This research aims to aid in extracting lessons from existing policies for countries that are yet to adopt climate mitigation measures.

The results from this paper hope to provide a baseline for future ex-post analysis that can better evaluate the effect of the Swiss carbon tax upon emissions. An extensive study into the subject is required to build upon the existing literature – especially ex-post analyses.

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