Fact Checking Report “Carbon Taxes and CO_2 Emissions: Sweden as a Case Study” (Julius J. Andersson, 2019)

Federico Bertoia - 1030753

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1 Introduction

The paper “Carbon Taxes and CO_2 Emissions: Sweden as a Case Study” (Julius J. Andersson, 2019) aims at evaluating the causal effect of carbon taxes on emissions, empirically analyzing the implementation of a carbon tax and a value-added tax on transport fuel in Sweden.

1.1 Overview of the paper

The author investigates empirically the environmental efficiency of carbon taxes by analyzing the Swedish experience of introducing a carbon tax on transport fuels in the early 1990s, as Sweden was one of the first countries in the world to implement a carbon tax in 1991. In the year prior, in March 1990, Sweden also extended the coverage of its existing value-added tax (VAT) to include gasoline and diesel.
In the first half of the paper he estimates the reduction of CO_2 emissions in the transport sector using panel data and the synthetic control method, being able to construct a “synthetic Sweden” from a carefully chosen control group of OECD countries. The synthetic Sweden is a counterfactual comparable unit consisting of a weighted combination of countries that did not implement carbon taxes or similar policies during the treatment period and that prior to treatment resemble Sweden on a number of key predictors of CO_2 emissions in the transport sector and have similar levels and paths of these emissions.
In the second half of the paper he disentangles the carbon tax and VAT effect by first estimating tax and price elasticities of demand for gasoline, using time series data of consumption and price of gasoline in Sweden during 1970-2011. Then using the estimated tax and price elasticities (and the estimated emission reductions from the first half) he disentangles the effect of the carbon tax and the VAT.
The main results are the following:

1. The syntetic control method provides an estimated emission reduction from the transport sector of 10.9 percent, or 2.5 million metric tons, in an average year during 1990-2005, which is the posttreatment period of interest in this paper
2. The estimated posttreatment reduction by the carbon tax alone is 6.3 percent or 1.5 million metric tons of CO_2 emissions in an average year.

1.2 Replication of the paper

The replication package provided by the author is clear and complete, including codes, datasets and any additional material to reproduce the study. All datasets are in dta form and are already cleaned and ready to use. The main code to get the results is written in R, except for the part of tax incidence and the dinsentanglin which are Stata Do-file.
Going into deep, here is a detailed explanation of what is in the replication package:

- ReadMe (in .pdf and .docx format): it contains the references and procedures to replicate all figures and tables in the paper, i.e it indicates which code reproduces which figure and tells which dataset to use. Moreover, for each dataset there is a description about the data source.
- R script files (in .R format), that are
  - *carbontax.R*, used to replicate figures 4-10 and tables 1-2 (**Main Results**)
  - *descriptive.R*, used to replicate figures 1-3 and 11-12 (**Descriptive Figures and Possible Confounder**)
  - *disentangling.R*, used to replicate figures 13-14 (**Disentangling the Carbon Tax and VAT**)
- Stata datasets (in .dta format), that are
  - *carbontax_data.dta*, used in **Main Results**
  - *carbontax_fullsample_data.dta*, used in **Main Results**
  - *descriptive_data.dta*, used in **Descriptive Figures and Possible Confounder**
  - *disentangling_data.dta*, used in **Disentangling the Carbon Tax and VAT**
  - *disentangling_regression_data.dta*, used in **Disentangling the Carbon Tax and VAT**
  - *fullsample_figures.dta*, used in **Main Results**
  - *leave_one_out_data.dta*, used in **Main Results**
  - *tax_incidence_data.dta*, used in **Main Results**
- Stata Do files (in .do format), that are
  - *disentangling_regression.do*, used to replicate table 3 (**Disentangling the Carbon Tax and VAT**)
  - *taxincidence.do* (**Main Results**)

Throughout the replication I use also datasets not originally present in the main data folder. Those are:

- Datasets containing the results output of some stata command (in .dta format), such as:
  - *synth_results.dta*, obtained as *synth* output
  - *Permutation_results.dta*, obtained as *allsynth* output
  - *Permutation_results_panelB.dta*, obtained as *allsynth* output
- Population datasets for OECD countries (in .xlxs format), downloaded from the World Bank database here, that are:
  - *OECD Population Data.xlxs*
  - *OECD Population Data Full Sample.xlxs*

1.3 Main differences between author's results and mine

The main challenge of the replication part is being able to translate the code from R to Stata, being sure not to miss any relevant feature or detail. Overall, I would say that it has not been too difficult since the baseline datasets were really good and the author is transparent in explaining his work.
However, before going into deep the replication of the figures and tables, it is necessary to highlight a main difference between author's results and mine.
The main concern is in the estimation of the synthetic Sweden, since algorithm may slightly vary from R to Stata. Let's start by saying that a synthetic control is defined as a weighted average of the units in the donor pool. Formally, a synthetic control can be represented by a Jx1 vector of weights, $\mathbf{W}$. Given a set of weights, the synthetic control estimators of Y_{1t}^N and τ_{1t} are

$$\hat{Y}_{1t}^N = \sum_{j=2}^{J+1} w_j Y_{jt}$$

$$\hat{\tau}_{1t} = Y_{1t} - \hat{Y}_{1t}^N$$

The main question is how the weights should be chosen. Abadie (2021) summarizes the method to choose them:

1. Minimize a weighted Euclidan distance between the treatment and synthetic control in the pre-treatment period
$$||\boldsymbol{X}_1 - \boldsymbol{X}_0\boldsymbol{W}|| = \left(\sum_{h=1}^{k} v_h \left(X_{h1} - \sum_{j=2}^{J+1} w_j X_{hj}\right)^2\right)^{\frac{1}{2}}$$
under the constraint that weights should be positive and sum up to one. The positive constants $v_1 ... v_k$ reflect the relative importance of the synthetic control reproducing the values of each of the k predictors for the treated unit. Each potential choice of $\mathbf{V}$ produces a synthetic control, $\mathbf{W}(\mathbf{V})$, which can be determined by minimizing the above equation. The question now is how to choose $\mathbf{V}$. One way could be the inverse variance of the predictors, in order to have a unit variance.

2. Alternatively, Abadie proposes to choose $\mathbf{V}$ such that the synthetic control $\mathbf{W}(\mathbf{V})$ minimizes the mean squared prediction error (MSPE):
$$\sum_{t \in T_0} (Y_{1t} - w_2(\mathbf{V})Y_{2t} - ... - w_{J+1}(\mathbf{V})Y_{J+1t})^2$$

Even though the main results are close, small differences are found in computing both the donor countries weights ($\mathbf{W}$) and predictors weights ($\mathbf{V}$). However, as said in Abadie (2021), researchers should aim to demonstrate that their results are not overly sensitive to a particular choice of $\mathbf{V}$.
In my replication study I use different commands for estimating the synthetic control, such as: *synth* (Abadie, A., Diamond, A., and J. Hainmueller. 2010), *synth_runner* (Quistorff, B., and Galiani, S. 2017) and *allsynth* (Wiltshire, J.C., 2022). Each of these methods provides the same estimates for $\mathbf{W}$ and $\mathbf{V}$. As we can see from table 8 and 9, the predictor weights are quite different, however the country weights are very close. This seems to indicate that my results are consistent with those of the author. Moreover, in table 8 I also included the root mean squared prediction error (RSMPE): the one in the author's column is obtained by specifying the option *customV* in the *synth* package, which allows to arbitrarily select the diagonal matrix $\mathbf{V}$, meanwhile the other one is obtained following my code. Even though the RMSPE is close, with the unconstrained weights it is slightly lower.

2 Replication of the figures

The paper includes fourteen figures. To each of them is given an indication whether it was possible to replicate and, if necessary, a more detailed feedback.

- Figure 1: Replicated (both panels).
- Figure 2: Replicated.
- Figure 3: Replicated. For this figure you can either use *descriptive_data.dta*, where there are already the data on CO_2 emissions for both sweden and the weighted average of OECD countries, or use *carbontax_data.dta*, generate the average CO_2 emission by year and plot it.
- Figure 4: Replicated. For this figure you can either use *fullsample_figures.dta*, where there are ready to use data for both Sweden and its synthetic counterpart, or running the synthetic control code using *carbontax_data.dta* and plot the results[1]. The figure I display is obtained following the first option, however it is important to note that if we follow the second way the plot is almost identical.
- Figure 5: Replicated. See the comment for Figure 4[2].
- Figure 6: Replicated (both panels). For both panels I modified the output figures obtained by the code in the Do-file using the Stata graph editor, applying the following changes: rescaled the x-axis, recaled the y-axis and added the text indicating the placebo tax.
- Figure 7: Replicated (both panels). For these figures we can use either the command *allsynth* or *synth_runner*. Notice that for both commands nested optimization fails when estimating the placebo run for United States. However, if using *allsynth*, the synthetic control W-matrix is calculated using regresion-based V-matrix for United States. This is the reason why I would suggest to follow this method. For selecting which countries to keep in the second panel, I used the dataset *Permutation_results.dta*, which is the output of the previous command, to check which countries has a pretreatment MSPE 20 times greater than the one for Sweden. For both panels I modified the output figures obtained by the code in the Do-file using the Stata graph editor, applying the following changes: Added the text indicating the placebo tax, changing legend labels name and deleted the 5 countries placebo run for panel B.
- Figure 8: Replicated. To correctly plot this figure I added to the dataset *Permutation_results.dta* the country variable from *carbontax_data.dta*. Notice that the results are slightly different from the ones by the author[3].
- Figure 9: Replicated.
- Figure 10: Replicated (both panels). See comment for figure 4[4]
- Figure 11: Replicated. The gray shaded areas represent the two major recessions in Sweden during the sample period: the first one in 1976-1978 and the second in 1991-1993.
- Figure 12: Replicated. See comment for figure 11
- Figure 13: Replicated.
- Figure 14: Replicated. The shaded area highlights the period between 2000–2005 when the carbon tax rate was more than doubled (first tax increase in 2001)

[1] In order to plot the results first I save the output of the *synth* command as a stata dataset (*synth_results*). From this dataset we can plot both levels and gap of the treated and its synthetic counterpart

[2] See footnote 1

[3] See discussion in section 1.3

[4] However the dataset to use is *carbontax_fullsample_data*

3 Replication of the tables

The paper includes three tables, two about the synthetic control method (table 3 and table 4) and one about disentangling the effect of carbon tax and VAT (table 5). In the fact checking report I added also few tables taken from the online appendix, one about the difference-in-differences (DiD) estimate of the treatment effect (table 2) and two about the synthetic control metod with full sample countries (table 6 and table 7). Moreover, I decided to add also a table showing the results of the tax incidence (table 1) discussed in the first part of the paper, showing that the tax changes are fully passed on to consumers. Finally, as discussed previously, I added two tables showing the different predictor and country weights with RMSPE (table 8 and 9) obtained by the synthetic control estimation.
Finally, I want to specify that by running the dofile 2.Replicate_Tables you do not directly obtain the tables in .tex format for two reasons: first, I am better at designing the table by writing on Latex (tables 1, 2 and 3 are in the output folder, but are modified in Latex afterwards), second I could not use the command esttab for the matrix results about the weights and the predictors.

- Table 1: Not present in either the paper or the online appendix. At first I would have coded the regression just by using the option *vce(robust)*, however, by looking at the do-file *taxincidence.do*, the author uses the Newey-west standard errors, which is an extension of the Hubert-White estimator that produces consistent estimates when there is autocorrelation in addition to possible heteroskedasticity. In the first column are displayed the results using energy and carbon tax combined, meanwhile the second uses them separately. Below in the table are displayed the p-values of the tax elasticities equal to 1.

- Table 2: Replicated, online appendix. To get the DiD estimate, which is basically a two-way fixed effect regression, there are two different possibilities: either use the code *xtdidregress* or use the code *xtreg*.

- Table 3: Replicated[5]. As explained in the paper, the predictor means for OECD sample are calculated by a population weighted average. However, the datasets do not contain such variable. Thus, I downloaded from the World Bank database the evolution of population for OECD countires from 1960 to 2005[6] and then added that variable into the proper dataset. Results are close but slighly different.

- Table 4: Replicated[7].

- Table 5: Replicated. In addition to the original paper I added the p-value of the endogeneity test. Since I specified a robust VCE at estimation time, instead of Durbin and Wu-Hausman test it is reported the Wooldridge's score test and a regression based test of exogeneity.

- Table 6: Replicated, online appendix[8]. In this case the predictor means for OECD countries are simple averages, even though I leave in the do-file the code to calculate also the population weighted averages.

- Table 7: Replicated, online appendix[9].

- Table 8: Not present in either the paper or the online appendix.

- Table 9: Not present in either the paper or the online appendix.

[5] See discussion in section 1.3
[6] the dataset is *OECD Population Data.xlsx*
[7] See discussion in section 1.3
[8] See discussion in section 1.3
[9] See discussion in section 1.3

4 Appendix

4.1 Figures

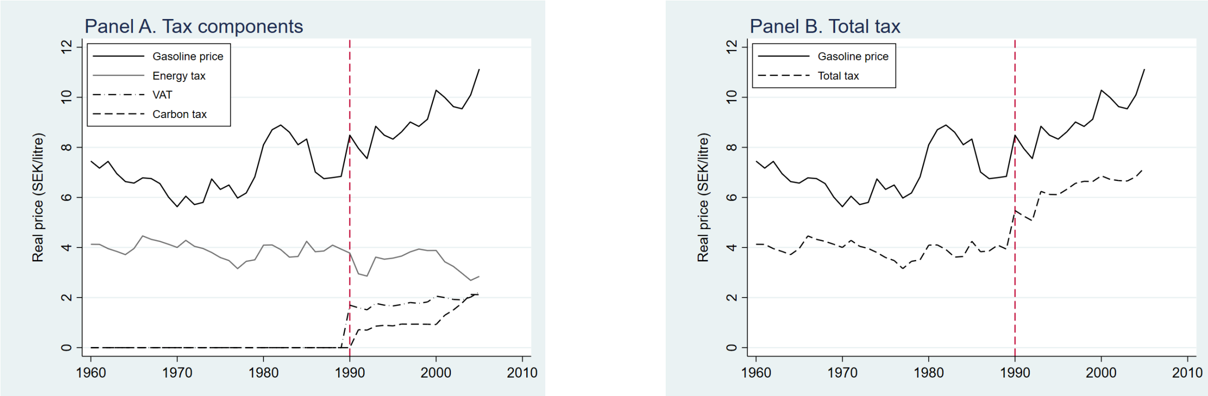

Figure 1: Gasoline Price Components in Sweden 1960–2005

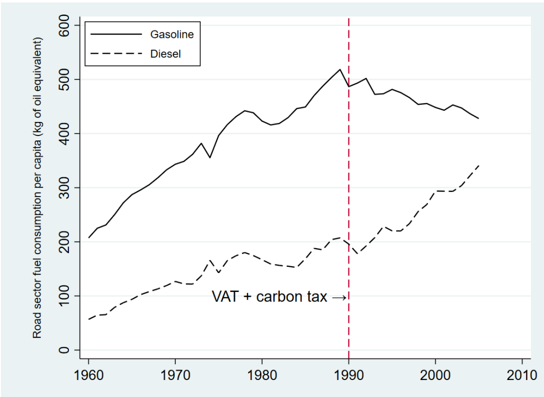

Figure 2: Road Sector Fuel Consumption Per Capita in Sweden 1960–2005

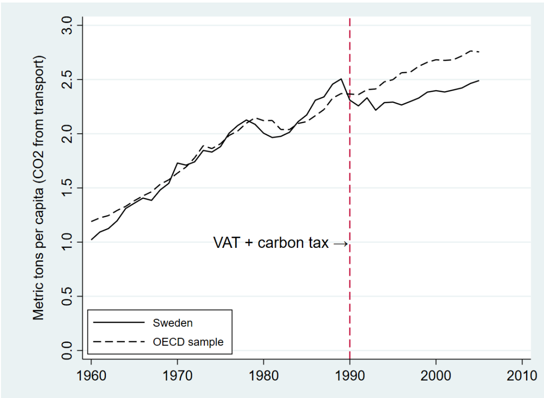

Figure 3: Path Plot of Per Capita CO_2 Emissions from Transport during 1960–2005: Sweden versus the OECD Average of My 14 Donor Countries

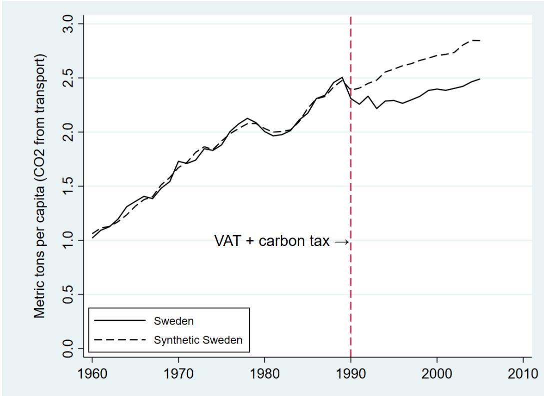

Figure 4: Path Plot of Per Capita CO_2 Emissions from Transport during 1960–2005: Sweden versus Synthetic Sweden

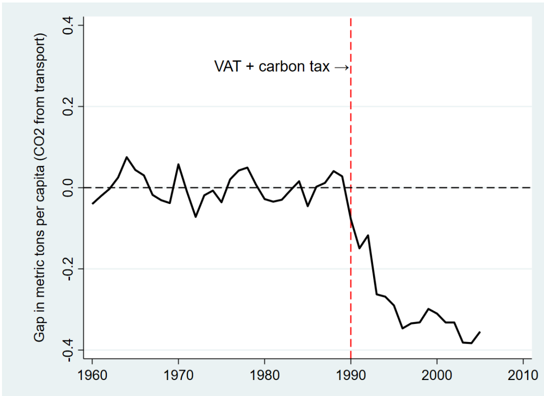

Figure 5: Gap in Per Capita CO_2 Emissions from Transport between Sweden and Synthetic Sweden: Sweden versus Synthetic Sweden

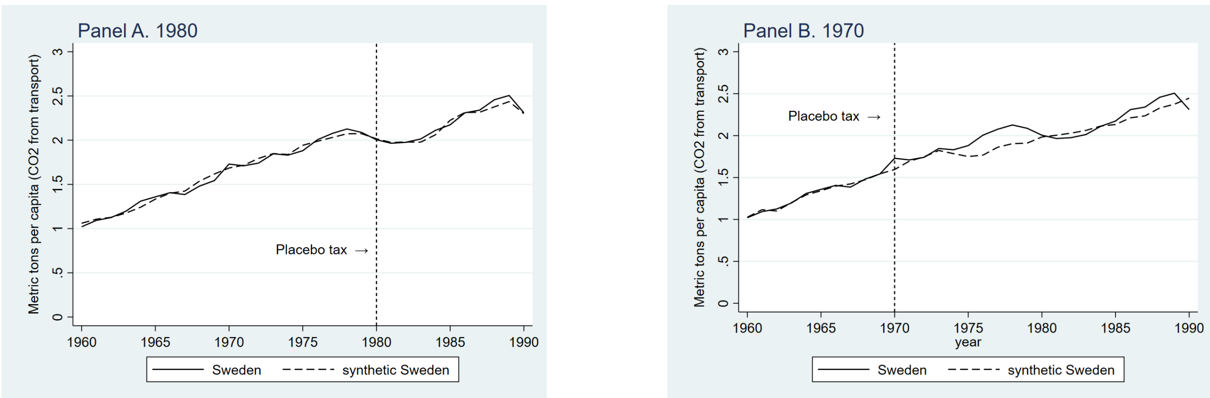

Figure 6: Placebo In-Time Tests

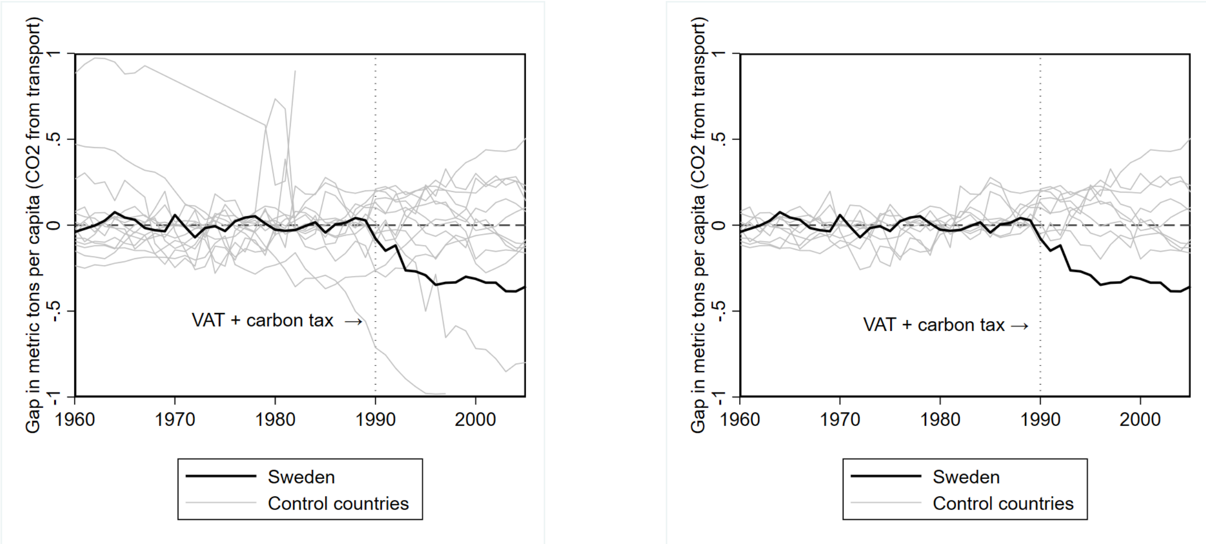

Figure 7: Permutation Test: Per Capita CO_2 Emissions Gap in Sweden and Placebo Gaps for the Control Countries

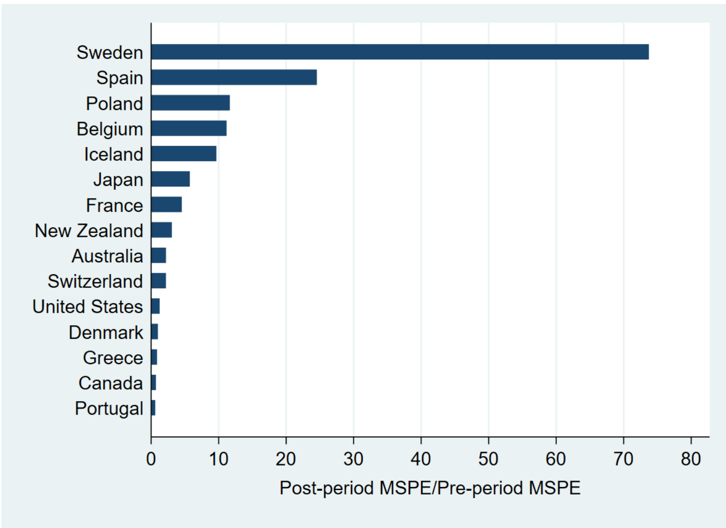

Figure 8: Ratio Test: Ratios of Posttreatment MSPE to Pretreatment MSPE: Sweden and 14 OECD Control Countries

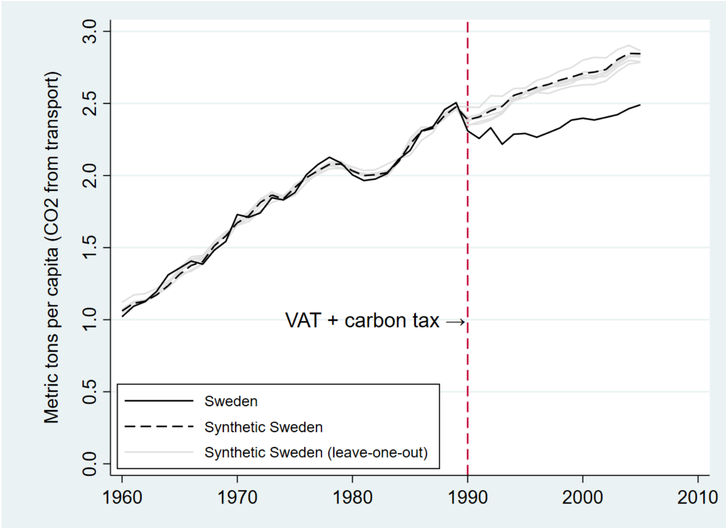

Figure 9: Leave-One-Out: Distribution of the Synthetic Control for Sweden

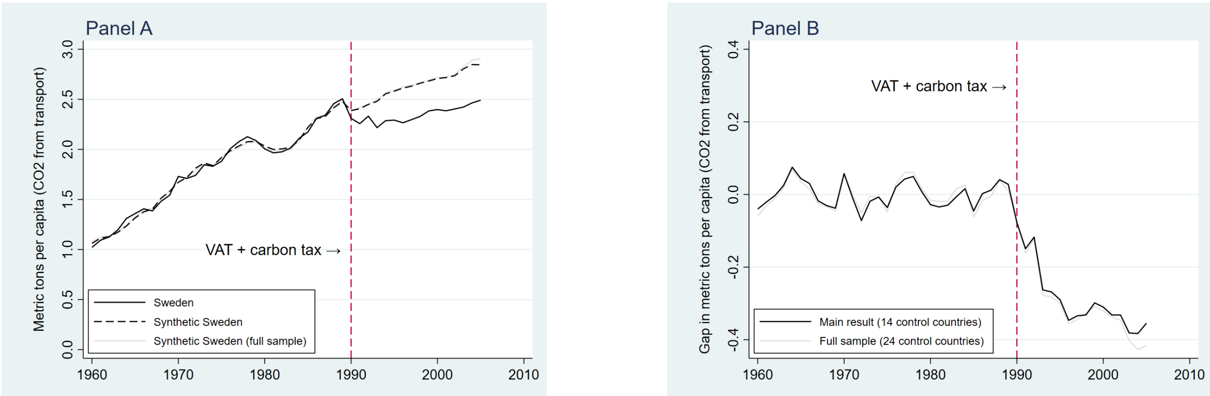

Figure 10: Path and Gap Plot of Per Capita CO_2 Emissions from Transport: Main Results versus Full Sample

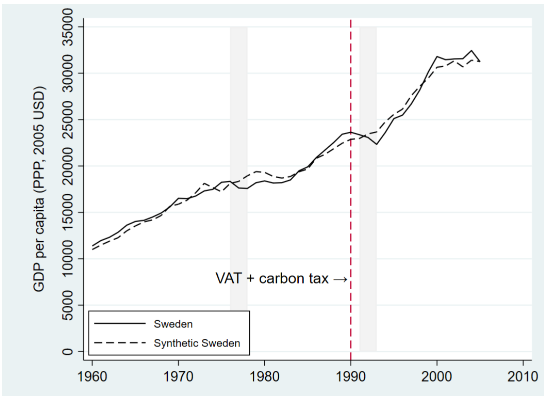

Figure 11: GDP Per Capita: Sweden versus Synthetic Sweden

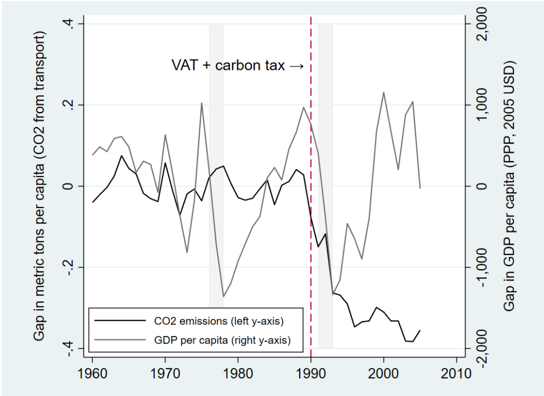

Figure 12: Gap in GDP Per Capita and CO_2 Emissions Per Capita from Transport between Sweden and Synthetic Sweden

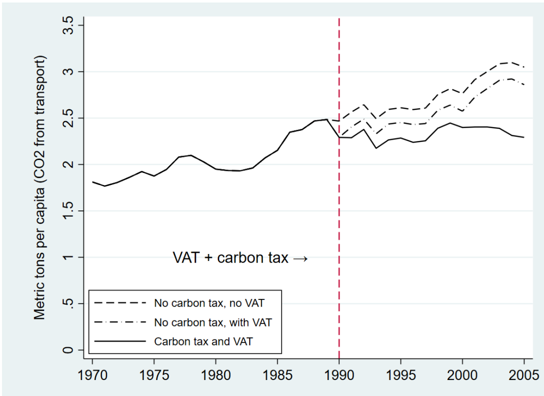

Figure 13: Disentangling the Carbon Tax and VAT

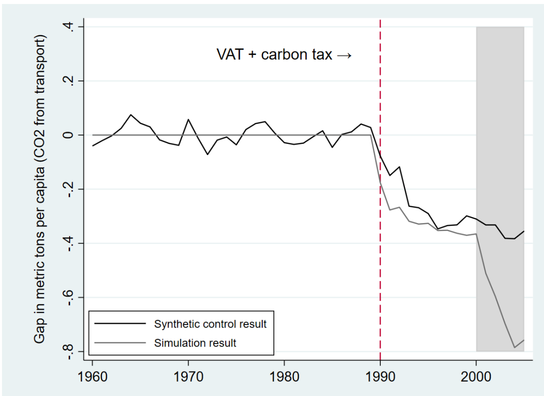

Figure 14: Gap in Per Capita CO_2 Emissions from Transport: Synthetic Control versus Simulation

4.2 Tables

Table 1: Tax incidence

Dependent variable	Retail price of gasoline	
	Compact b/se	Splitted b/se
Crude oil price	0.006***	0.006***
	(0.0004)	(0.0003)
Energy and carbon tax	1.147***	
	(0.1216)	
Energy tax		1.168***
		(0.1292)
Carbon tax		0.998***
		(0.1466)
Constant	0.099***	0.107**
	(0.0262)	(0.0310)
p-value: β_2=1	0.2327	
p-value: β_3=1		0.2006
p-value: β_4=1		0.9871
Observations	45	45

Notes: All variables are in first-difference. This table reports results from the regression of nominal tax-inclusive price of gasoline during time period t on the crude oil price and excise taxes (yearly data from 1970 to 2015). Column 1 reports the coefficient's estimate of the sum of energy and carbon tax, while column 2 reports their coefficient separately. Newey-West standard errors are in parentheses; heteroscedasticity and autocorrelation robust. Standard errors are calculated using 16 lags, chosen with the Newey-West (1994) method. P-values of tax elasticities equal to 1 are reported.

Table 2: DiD Estimate of the Treatment Effect

Dependent variable	CO_2 emissions from transport
Treatment	-0.214
	(0.0852)
Year fixed effects	Yes
Country fixed effects	Yes
Observations	690
R^2 (within)	0.806

Notes: Two-way fixed effects estimation with no covariates. Robust standard errors in parenthesis (clustered by country).

Table 3: CO_2 Emissions from Transport Predictor Means before Tax Reform

Variables	Sweden	Synth. Sweden	OECD Sample
GDP per capita	20,121.5	20.107.4	21,310.5
Motor vehicles (per 1,000 people)	405.6	407.6	518.1
Gasoline consumption per capita	456.2	406.8	679.1
Urban population	83.1	83.1	74.1
CO_2 from transport per capita 1989	2.5	2.5	3.5
CO_2 from transport per capita 1980	2.0	2.0	3.2
CO_2 from transport per capita 1970	1.7	1.7	2.8

Notes: All variables except lagged CO_2 are averaged for the period 1980–1989. GDP per capita is purchasing power parity (PPP)—adjusted and measured in 2005 US dollars. Gasoline consumption is measured in kilograms of oil equivalent. Urban population is measured as percentage of total population. CO_2 emissions are measured in metric tons. The last column reports the population-weighted averages of the 14 OECD countries in the donor pool.

Table 4: Country Weights in Synthetic Sweden

Country	Weight	Country	Weight
Australia	0	Japan	0
Belgium	0.197	New Zealand	0.183
Canada	0	Poland	0
Denmark	0.379	Portugal	0
France	0	Spain	0
Greece	0.091	Switzerland	0.063
Iceland	0	United States	0.087

Notes: With the synthetic control method, extrapolation is not allowed so all weights are between $0 \leq \mathrm{w}_j \leq 1$ and $\sum w_j = 1$.

Table 5: Estimation Results from Gasoline Consumption Regressions

	(1) OLS b/se	(2) OLS b/se	(3) OLS b/se	(4) OLS b/se	(5) IV(EnTax) b/se	(6) IV(OilPrice) b/se
Gas price with VAT	-0.057*	-0.060**	-0.061***	-0.060***	-0.062**	-0.064***
	(0.0241)	(0.0206)	(0.0162)	(0.0117)	(0.0199)	(0.0140)
Carbon tax with VAT	-0.260***	-0.232***	-0.234***	-0.186***	-0.186***	-0.186***
	(0.0422)	(0.0495)	(0.0526)	(0.0425)	(0.0378)	(0.0377)
Dummy carbon tax	0.109**	0.060	0.063	0.100	0.098	0.095
	(0.0396)	(0.0614)	(0.0610)	(0.0665)	(0.0704)	(0.0594)
Trend	0.021***	0.025***	0.024***	0.034***	0.034***	0.034***
	(0.0032)	(0.0042)	(0.0038)	(0.0031)	(0.0029)	(0.0028)
GDP per capita		-0.001	-0.001	-0.004**	-0.004***	-0.004***
		(0.0007)	(0.0007)	(0.0011)	(0.0010)	(0.0010)
Urban population			0.013	0.030	0.031	0.033
			(0.0750)	(0.0674)	(0.0643)	(0.0581)
Unemployment rate				-0.024***	-0.024***	-0.024***
				(0.0058)	(0.0053)	(0.0053)
Constant	6.228***	6.407***	5.372	4.407	4.313	4.198
	(0.1672)	(0.1419)	(6.2019)	(5.4460)	(5.1522)	(4.6934)
p-value: $\beta_1 = \beta_2$	0.001	0.004	0.003	0.004	0.004	0.001
p-value HAC score chi2					0.9881	0.8160
p-value HAC regression F					0.9399	0.4281
Instrument F-statistic					3.57	310.93
p-value					0.067	<0.001
Observations	42	42	42	42	42	42
R^2	0.72	0.73	0.73	0.76	0.76	0.76

Notes: The dependent variable is the log of gasoline consumption per capita. The real carbon tax-exclusive price of gasoline and the real carbon tax are measured in 2005 Swedish kronor. GDP per capita is measured in 2005 Swedish kronor (thousands). Urban population is measured as percentage of total population. Unemployment is measured as percentage of total labor force. Columns 5 and 6 use the real energy tax and the brent crude oil price as instrumental variables for the carbon tax-exclusive gasoline price. Newey-West standard errors are in parentheses; heteroscedasticity and autocorrelation robust. Standard errors are calculated using 16 lags, chosen with the Newey-West (1994) method. Results of endogeneity and weak instruments test are reported.

Table 6: CO_2 Emissions from Transport Predictor Means before Tax Reform Full-Sample

Variables	Sweden	Synth. Sweden	OECD Sample
GDP per capita	20,121.5	20,144.3	19,201.8
Motor vehicles (per 1,000 people)	405.6	406.1	352.4
Gasoline consumption per capita	456.2	406.3	355.9
Urban population	83.1	83.1	71.3
CO_2 from transport per capita 1989	2.5	2.5	2.3
CO_2 from transport per capita 1980	2.0	2.0	1.9
CO_2 from transport per capita 1970	1.7	1.7	1.4

Notes: All variables except lagged CO_2 are averaged for the period 1980–1989. GDP per capita is purchasing power parity (PPP)—adjusted and measured in 2005 US dollars. Gasoline consumption is measured in kilograms of oil equivalent. Urban population is measured as percentage of total population. CO_2 emissions are measured in metric tons. The values for the 24 countries in the OECD sample are simple averages.

Table 7: Country Weights in Synthetic Sweden Full-Sample

Country	Weight	Country	Weight	Country	Weight
Australia	0.001	Greece	0.001	Norway	0.001
Austria	0.001	Iceland	0.002	Poland	0
Belgium	0.082	Ireland	0.001	Portugal	0.001
Canada	0	Italy	0.001	Spain	0.001
Denmark	0.471	Japan	0.001	Switzerland	0.008
Finland	0.001	Luxembourg	0.012	Turkey	0
France	0.001	Netherlands	0.001	United Kingdom	0.180
Germany	0.001	New Zealand	0.168	United States	0.065

Notes: With the synthetic control method, extrapolation is not allowed so all weights are between $0 \leq \mathrm{w}_j \leq 1$ and $\sum w_j = 1$.

Table 8: Differences in Predictor Weights in Synthetic Sweden

Variables	Author Weights	Federico Weights
GDP per capita	0.219	0.077
Motor vehicles (per 1,000 people)	0.078	0.041
Gasoline consumption per capita	0.010	0.009
Urban population	0.213	0.339
CO_2 from transport per capita 1989	0.183	0.239
CO_2 from transport per capita 1980	0.284	0.294
CO_2 from transport per capita 1970	0.013	0.001
RMSPE	.034957	.034956

Notes: Predictor weights are calculated jointly with country weights in order to minimize the RMSPE over the entire pre-treatment period. In column 1 are reported the author's weights with the relative RMSPE, while in column 2 are reported the ones following my code.

Table 9: Differences in Country Weights in Synthetic Sweden

Country	FW/AW	Country	FW/AW
Australia	0/0.001	Japan	0/0
Belgium	0.197/0.195	New Zealand	0.183/0.177
Canada	0/0	Poland	0/0.001
Denmark	0.379/0.384	Portugal	0/0
France	0/0	Spain	0/0
Greece	0.091/0.090	Switzerland	0.063/0.061
Iceland	0/0.001	United States	0.087/0.088

Notes: FW stands for Federico Weights, AW stands for Author Weights. With the synthetic control method, extrapolation is not allowed so all weights are between $0 \leq \mathrm{w}_j \leq 1$ and $\sum w_j = 1$.