Evaluating a Carbon Tax: France as a Case Study

- CO_2 Emissions from Cars

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Degree project / Master's Thesis • 30 credits
Swedish University of Agricultural Sciences, SLU
Faculty of Natural Resources and Agricultural Sciences /Department of Economics - Environmental Economics and Management – Master's Programme
Degree project / SLU, Department of Economics, 1473 • 1401- 4084
Uppsala 2022

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Credits:	30 credits
Level:	Advanced level, A2E
Course title:	Master thesis in Economics, A2E
Course code:	EX0905
Programme/education:	Environmental Economics and Management – Master's Programme
Course coordinating dept:	Department of Economics

Place of publication: Year	Uppsala
of publication: Place of	2022
publication: Title of	Uppsala
Series:	Degree project/SLU, Department of Economics
Part number:	1473
ISSN:	1401-4084

Keywords:	Carbon Tax, Carbon Component, French Carbon tax, Synthetic Control Method

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Abstract

This quasi-experimental study is the first to evaluate the French experience of adding a carbon tax directly onto existing taxes on fossil fuel consumption by performing an econometric case study. Furthermore, the introduction of the French carbon tax resulted in the so called “yellow vests protests”, the protests acted as a catalyst, and further stressed the need to evaluate environmental taxes, not only in relation to combating global warming but also regarding the procedures of providing information to the public. Correctly estimating the effects of the French tax can then provide the crucial information needed. This thesis finds a significant effect of carbon taxes on emissions, analysing the implementation of a carbon component on transport fuel in France. After the policy intervention, carbon dioxide emissions from cars declined 6.3 per cent every year between 2016-2019, relative to a synthetic control unit constructed from a grouping of similar EU countries.

Keywords: Carbon Tax, Carbon Component, French Carbon tax, Synthetic Control Method

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Abbreviations

CO_2	Carbon dioxide
DiD	Difference in Difference
EU	European Union
GDP	Gross Domestic Product
IPCC	The Intergovernmental Panel on Climate Change
LOO	Leave-One-Out
MSPE	Mean Squared Prediction Error
SCM	Synthetic Control Method
TICPE	la Taxe intérieure de consommation sur les produits énergétiques (The Domestic Consumption Tax on Energy Products)
VAT	Value Added Tax

1. Introduction

For the past decades, several multilateral environmental agreements have been ratified, but the concern for global warming and ecosystems has been growing. General secretary of the United Nations, Antonio Guterres, expressed his concerns in the second part of the sixth assessment report, *Climate Change 2022: Impacts, Adaptation and Vulnerability* (IPCC 2022) as "…an atlas of human suffering and a damning indictment of failed climate leadership." (Guterres 2022). Guterres further explains how the IPCC report presents facts, upon facts about how people and the planet will be "clobbered by climate change".

The latest environmental agreement, The Paris Agreement, entered effect in November 2016 intending to limit global warming to well below 2 degrees Celsius (compared to pre-industrial levels). To reach the goal of limiting global warming, policies putting a price on emissions, such as carbon dioxide (CO_2), have been given attention. The policies aim at reducing the consumption of fossil fuels and greenhouse gas emissions, by either banning the consumption completely, issuing tradable permits or implementing taxes. In the EU, tradable permits on carbon emissions have been in place since 2005 and several countries have adopted an energy tax or carbon tax[1]. For example, many countries have already adopted fuel taxes that incorporate a carbon tax. The Nordic countries adopted a carbon tax as early as the 90s. France introduced a carbon tax in 2014, linking a cost to emitting carbon dioxide (CO_2).

In this thesis, the focus will be given to the French experience of adding a carbon tax directly onto existing taxes on fossil fuel consumption, by performing an econometric case study. The goal is to examine if the carbon tax reduced carbon dioxide emissions and will do so by focusing on CO_2 emissions from cars. The reason for this delimitation is that the French carbon tax has many exemptions that range across several sub-areas in the transport sector: For example, trucking companies can apply for reimbursements. This thesis will therefore focus on passenger cars and not the whole transport sector. To estimate the effects of the carbon tax, data is gathered from Eurostat and the World Bank. The data is used to estimate the treatment effect, through the use of the Synthetic Control Method (SCM), a method introduced by Abadie and Gardeazabal (2003) and further developed by Abadie, Diamond, and Hainmueller (2010)[2].

Several papers in the literature show that there is low public support for carbon taxes (Carattini et al. (2017); Hammar et al. (2005); Agostini (2015)), and Carttini et al. (2017) show that providing information about the carbon taxes to the public can increase the support. Given this low support, there is a prevalent need to evaluate the effect of carbon taxes. In the past few decades, a growing number of academic papers have examined the empirical evidence of a gasoline tax, and whether it mitigates the negative externalities. Examples include Johansson et al. (1997), Portney et al. (2003), Li et al. (2014), and Andersson (2019). At the same time there are studies that find little to no effect of gasoline taxes, see Lin et al. (2011) and Bohlin (1998). Andersson (2019) uses the Synthetic Control Method to evaluate the Swedish

[1] The purposes of a carbon tax are to equate the private and social costs of releasing carbon to reduce emissions, i.e., placing a price on carbon.

[2] See Abadie et al. (2011) for a detailed explanation of this model.

experience of adding a carbon tax and found a causal effect of carbon taxes on emissions. Li et al. (2014) used price elasticities of demand for gasoline in ex-ante simulations, where they estimate reductions in consumption of fuel in the US. On the contrary, Lin et al. (2011) uses the difference in difference (DiD) framework and find no causal effect for the Swedish scenario. Lin et al. (2011) also examines the effects of carbon taxation in Norway, Finland, Denmark, and the Netherlands. They only find one significant effect, which was for Finland with a 1.7 per cent reduction in CO2 per capita emissions. Following the arguments made by Andersson (2019), Lin et al. (2011) fails to find correct estimates. Partly due to limitations of the DiD, since they violate underlying assumptions on causal inference, and use outcome variables as covariates. Furthermore, they combine treated and untreated sectors in the design by using total CO_2 emissions.

The previous literature does also show that consumers respond more strongly to environmental taxes compared to equivalent price changes. Andersson (2019) shows that the tax elasticity is three times higher than the price elasticity. Li et al. (2014) show that the effect of the environmental tax is larger than the expected price effect. Simulations, as used in Li et al. (2014), that use price elasticities will thus undervalue the real effect of carbon taxes on CO_2 emissions. Whereas with the SCM, we use ex-post empirical data on CO_2 emissions as the outcome variable, meaning that there is no need to use a simulation method to estimate changes to the emissions.

The main findings in this thesis suggest that the carbon tax had the desired effect of reducing carbon dioxide emissions, at least from cars. With an average annual effect of - 6.3% (between 2016 to 2019). The results are significant from 2016 and show robustness when conducting placebo tests. Furthermore, due to the lack of European countries that have not changed their fuel tax in the last decade, the control group is relatively small and consists of countries that have altered their fuel tax. Thus, raising concern for potential bias being present in the estimation.

This thesis hence contributes to the literature on environmental taxation using the synthetic control method. In the absence of literature that has evaluated the French carbon tax, this thesis could offer insights into how CO_2 emissions are affected in a new setting, but also when existing taxes are comparatively high, and the carbon tax is planned to be revaluated every year. The French carbon tax is considered unique because it resulted in the so called "yellow vests protests", which caused the carbon tax increases to come to a halt. The protests acted as a catalyst and further stressed the need to evaluate environmental taxes, not only in relation to combating global warming but also regarding the procedures of providing information to the public. Correctly estimating the effects of the French tax can then provide the crucial information needed.

The rest of the paper is organized as follows: Section 2 introduces a background to the French carbon tax. Section 3 presents the method and data. Section 4 presents the results as well as robustness checks. Section 5 compares the paper's findings in a discussion. Finally, Section 6 concludes.

2. The French Carbon Tax

The carbon tax introduced in France in 2014, often referred to as the carbon component, was added to the domestic consumption tax on energy products TICPE (la Taxe intérieure de consommation sur les produits énergétiques). The TICPE originates from a domestic oil tax in 1928 and has evolved to its current form after the European Union adopted the directive *restructuring the Community framework for the taxation of energy products and electricity* (2003/96/EC). From 2007 until 2012 the TICPE for gasoline and diesel were constant[3], when a temporary tax reduction was introduced, which progressively increased between December 2012 and ended in 2013. In 2013 it was decided that the carbon component should be added to the TICPE in 2014 as part of the "national low-carbon strategy" (LOI n° 2015-992) to combat global warming. The TICPE, including the carbon component, is also subjected to a 20 per cent VAT.

To ease the implementation of the carbon component, the pre-existing TICPE without the carbon component was lowered, with the equivalent amount that was added by the price of carbon, the initial amount of € 7 /t of CO_2. Thus, in theory, the actual price change for consumers at the pump was seen first when the price of carbon increased again in 2015 meaning that the TICPE was constant from 2013 to 2015. The carbon component scheme is reassessed on a yearly basis, with a target value of €100 in 2030. In recent years, the cost of carbon has increased four times after its introduction at €7 in 2014. Subsequent increases are as follows – €14.50 in 2015, €22 in 2016, €30.50 in 2017, and €44.6 in 2018. Despite frequent increases in the past, the carbon component has been unchanged since 2018 because of the yellow vests protests. The yellow vests' protests started in the fall of 2018 and were triggered by the rise in fuel prices. Because of the protest's extent, both in the volume of people and violence, it was covered by the media globally. In the end, the price increase for the carbon component was halted because of these protests.

There are also several exceptions from the TICPE, and therefore also the carbon component, for example in aviation, fishing and river transport, public transport, and agriculture. The road transport sector is affected by a partial exemption, where the agents in the road transport sector can apply for a reimbursement. Hence, it is feasible to examine the effect of the carbon component on passenger cars which are not subject to an exemption.

[3] There exists some regional difference (see LOI n° 2007-1824)

3. Methodology and Data

In the method section, the Synthetic Control Method is explained in greater detail, as well as how it is applied in the thesis. The equations used are numbered and enclosed by parentheses, and all the parameters are defined on their first appearance. Finally, the data that is used is described in detail.

3.1 Methodology – Using the Synthetic Control Method

The purpose of the Synthetic Control Method is to estimate the differences between a treatment group (France) and a control group (Synthetic France). Synthetic France is created using a data driven method developed by Abadie et al. (2003) and Abadie et al. (2010) where the data driven approach minimizes the differences between France and its synthetic counterpart. The synthetic control is constructed through a weighted average of countries that are similar to France, which represents the levels of CO_2 in France if no tax had been introduced given that the method is successful, and the assumptions of the method hold. The difference between France and the synthetic France after the tax is implemented will be the estimated effect of interest. Given that the synthetic France follows the trajectory of CO_2 emissions during the pre-treatment period, we assume that the synthetic control can successfully replicate the development in France without the tax.

Since Abadie et al. (2003) and Abadie et al. (2010) introduced the synthetic control method many details on how and when to use the method have been provided. Abadie et al. (2015) extend the discussion on potential comparison units and predictor variables, and a review of the framework was done by Abadie (2021). Several papers evaluate a wide range of different policy interventions using the synthetic control method. For example, Kleven, Landais, and Saez (2013) study the effects of taxation on football players and Andersson (2019) study the effects of an environmental tax policy in Sweden.[4]

In the Synthetic Control Method approach, the synthetic control group consist of weighted averages of the units in the donor pool. allow the units to be indexed by J, where $J = 1$ is the ‘treated unit’ and let $J + 1$ be the EU countries included in the so-called donor group. Thus $J = 1$ is France, since France is the unit affected by the environmental tax intervention, and $J = 2, \dots, J + 1$ is the untreated units unaffected by the policy intervention. The synthetic control unit is represented by a vector of weights, W, which is subject to a convexity constraint and sums to one as shown in equation (1).

[4] See Donohue, Aneja, and Weber (2019), Kreif et al. (2016), Bohn, Lofstrom, and Raphael (2014), for other examples of using the model.

(1) $$W = (w_2, \dots, w_{J+1})' \text{ with } 0 \leq w_j \leq 1 \text{ and } w_2 + \cdots + w_{J+1} = 1.$$

The countries are observed during time periods $t = 1, 2 \dots, T$. To construct the synthetic unit, one requires data over several periods before the treatment occurs, $t = 1,2 \dots, T_0$. Furthermore, one also requires data after the treatment, $t = T_0 + 1, \dots, T$ to evaluate the effects of the treatment. The synthetic control unit needs to replicate the trajectory of CO_2 emissions, but also be similar to France's pre-treatment predictor variables. Assume that we find:

(2) $$W = W^* = (w_2^*, \dots, w_{J+1}^*)$$

Then, as proved in Abadie (2021), we can use the unbiased estimator, $\hat{\tau}_{1t}$, for measuring the post-treatment effect (at time $t = T_0 + 1, \dots, T$) on emissions, Y, for France:

(3) $$\hat{\tau}_{1t} = Y_{1t} - \sum_{j=2}^{J+1} w_j^* Y_{jt}$$

Finding W^* is achieved by minimizing the measurable difference between the affected unit and its control units. The predictors and the outcome variable denoted k, are combined in a pre-treatment $(k * 1)$ vector, denoted as X_1, for France. Let a $(k * J)$ matrix, denoted X_0, contain similar variables for the control units.

Given the restriction that W is nonnegative and sum to one, we want to find W^* to minimize the distance, $\|X_1 - X_0W\|$, for the pre-treatment period. Thus, the optimization process attempts to find the linear combination of X_0 that fits X_1 the best by using the following distance metric to calculate the difference:

(4) $$\|X_1 - X_0W\|v = \sqrt{(X_1 - X_0W)'V(X_1 - X_0W)}$$

Each choice of W is a different combination of weights and characterises a possible synthetic control. The predictor weights are given by the diagonal matrix $(k * k)$ denoted V. V is a symmetric and positive semidefinite matrix, which purpose is to minimize the Mean Squared Prediction Error (MSPE) of the outcome variable between the treated unit and the synthetic control.

Hence, for given a set of predictor weights $[V = (v_1, \dots, v_k)]$, searching for a positive W summing to one, the inner optimization is then as shown in equation (5):

(5) $$\sqrt{(X_1 - X_0W)'V(X_1 - X_0W)} \overset{W}{\rightarrow} min$$

The outer optimization is when we choose V, where I use the data-driven approach[5] proposed by Abadie and Gardeazabal (2003) and Abadie, Diamond and Hainmueller (2010). In the data-driven approach (where V and W are jointly chosen), the outer optimization process

[5] In my code I use *synth2* and *synth_runner (*Galiani et al. 2017), where *synth2* is a wrapper program for the package *synth* but is more user-friendly compared to its predecessor.

to find V is done to minimize the MSPE. The data-driven method uses a quadratic programming routine which finds the best fitting W weights restricted by a regression-based V matrix. I use an option, *nested,* that also searches among all diagonal semidefinite V matrices and W weights combination of the predictors. This is done to produce the best fit and convex combination that achieve even lower MSPE compared to the "default method"[6].

When investigating the potential environmental effects of carbon taxation, using one treated unit, and aggregate data, the advantages of using the SCM over the DiD framework are for example highlighted by Lin et al. (2011). By allowing the effects of unobserved confounders to vary over time, the parallel trends assumption is relaxed, which in the DiD framework is underlined in the DiD estimator (Abadie et al. 2010, Andersson 2019). In the SCM the control group is weighted to create a comparison unit so that optimal countries are chosen. Furthermore, Andersson (2019) explains that we can use the predictive power of the covariates to construct a weighted comparison unit, without a confounding effect when including them posttreatment. i.e., the predictor variables in the SCM can be affected by the implementation of the policy intervention, which in the DiD framework is considered as "bad controls."

Comparatively to the DiD or simulation methods, the SCM do not easily estimate 'normal' confidence intervals or p-values, which is considered a disadvantage of the SCM. However, p-values can be estimated and are by Abadie et al. (2015) described as a comparison of the distribution of placebo effects and the estimated effect of the synthetic control. In this context, this permutation test does allow for inference and the calculation of p-values after adjusting for the pre-fit in the placebo estimations. The calculated p-values are so-called standardized p-values and show the probability that the estimated effect is random. I.e., if the placebo effects yield effects as large, or larger as the synthetic control, then it is likely that the estimated effect was random.

The main criteria for excluding from the donor pool of countries that are used to create the synthetic control is whether a country has altered/implemented its own fuel/carbon tax during the sample period. The exclusion is to ensure that the estimated treatment effect is not influenced by similar policy interventions in other countries as one of the identifying assumptions is that the control countries have not been subjected to a similar 'shock' or intervention as in the treated country. Meaning that countries that have experienced a distinctive shock to CO_2 emissions per capita from cars should be excluded. This raises concern since every country in the donor pool has passed new carbon taxes or enacted large changes to existing fuel taxes. Therefore, it is impossible to claim that the results are unbiased according to the method specifications. The three countries that receive weight in the donor pool, see Table 3, all had previous fuel taxes. Germany increased their tax almost every year during the beginning of the pre-sample period, from 1991 – 2003, and between 2002 and 2003 the tax increased from € 624 to € 655 for gasoline and € 440 to € 470 for diesel. Spain also increased their tax during the pre-treatment period, between 1992 – 2002 the tax for both gasoline and diesel increased seven times. In 2002 the tax amounted to € 396 for gasoline and € 294 for diesel, the tax was later increased in 2009, € 425 and € 331 for gasoline respectively diesel. In

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[6] I also specify *allopt,* in the data-driven approach. *Allopt* runs the nested optimization procedure three times from different starting points, this is due to avoid finding a local minimum. (See fmwww.bc.edu/RePEc/bocode/s/synth.html for the help package for *Synth)*

2019 the tax was once again increased, to € 473 for gasoline and € 379 for diesel. Slovakia introduced a fuel tax in 2003, which was increased in 2009, € 514 for gasoline and € 481 for diesel. In 2011 the tax for gasoline was increased to € 551 for gasoline and reduced to € 386 for diesel, and in 2018 the tax was reduced for both gasoline and diesel, to € 514 respectively € 368.

Another potential bias is that the stable unit treatment value assumption (Rubin 1980) is not fulfilled, i.e. there is interference across units, thus breaking the stable unit treatment value assumption. Abadie (2021) explains that this is an important assumption, and the treatment in question should not affect the outcome in the control countries. The French carbon component could however have led to leakage effects on countries close to France. A leakage effect refers to when an unrelated event in one nation affects the economies of other nations. An example could be if French cars cross the border to e.g., Germany or Spain would result in an overestimation of our results. There is no immediate solution to test for carbon leakage in this context.

Abadie (2021) further explains that there should not be any anticipation of the policy intervention, when the new carbon tax was approved in 2013, France introduced a reduction in the TICPE that was realised to accommodate the implementation of the new carbon tax. Therefore, I will backdate the treatment date to 2013. Even though the "real" treatment, in monetary terms, starts when the carbon tax was increased in 2015.

3.2 Data

The data applied is annual panel data on CO_2 emissions from combustion in cars during 1990-2019 for 32 European countries, including France.[7] The CO_2 emissions are then adjusted to the per capita level by dividing by the total population. The CO_2 data is obtained from Eurostat and measured in metric tons, and the population data is obtained from the World Bank. By "cars" I assume the standard definition of a motor vehicle designed for passengers on at least four wheels not exceeding 3.5 tons. The data period provides 23 years of pre-treatment data and 6 years of post-treatment data, which is enough to create a counterfactual and see the effect of the added carbon tax. The predictor variables used in the synthetic control follow closely from the arguments by Andersson (2019) and are as follows: cars per one thousand people, GDP per capita, urban population density, gasoline and diesel consumption per capita, and lagged CO_2 per capita. Where GDP per capita is closely linked with CO_2 emissions, countries with fewer people in cities have a higher usage of cars and therefore also emissions from cars. I have additionally chosen to include the unemployment rate as a predictor variable since the

[7] Included are the thirty-one countries that were EU and EFTA members in 2019 except Liechtenstein. Additionally, Turkey is also included in the data set.

unemployment rate is thought to be linked to both GDP and the number of cars. The variables are obtained from Eurostat[8], the European Commission's Oil Bulletin[9], and the World Bank[10].

Abadie et al. (2015) and Abadie (2021) stress the importance of selecting appropriate control units in the donor pool of countries. They recommend that the potential control units that were either affected by the treatment or that may have experienced distinctive shocks to the dependent variable (CO_2 per capita), should be omitted from the sample, given that the shocks would not happen without the treatment. Moreover, it is recommended to compose the donor pool of units similar to the treated unit. Using similar units will avoid overfitting- and interpolation bias. To comply with the recommendations, the countries included originating exclusively from the European Union, with the idea that all countries are affected by the same overall legislation and hence the donor pool is restricted to units that have the same structural process.

The initial sample of 32 countries was reviewed to assess the suitability of being included in this study. Countries which have passed new carbon taxes or enacted large changes to existing fuel taxes have been excluded. Countries omitted due to already having fuel taxation are: Denmark, Greece, Croatia, Cyprus, Netherlands, Romania, Slovenia, Finland, and Sweden. Moreover, Luxembourg is excluded due to having the highest CO_2 per capita. The elevated CO_2 emissions per capita could be due to "fuel tourism" (see Wlazlowski et al. (2009) and Sterner (2006) for discussion on cross-border purchases.). However, Anderson (2019) argues to also exclude Austria, due to its higher $C0_2$ per capita emissions. The higher per capita emissions are caused by "fuel tourism" from lower taxes in Austria. Moreover, Anderson (2019) excludes Ireland due to the economic uplift that increases their GDP per capita and CO_2 emissions, causing dissimilarities in the post-treatment period between the treated unit and the rest of the donor pool. Given that the donor group already is very small, I leave these countries in the donor pool. However, they attain a zero weight in synthetic France and should therefore not result in any potential bias, as discussed by Anderson (2019). In addition, dropping Austria and/or Ireland is considered in a robustness check, and the results are robust.

Belgium is also excluded due to a distinct difference in characteristics. Belgium has a much higher population density compared to France, and since population density is a key predictor of CO_2 emissions from cars, I have chosen to exclude Belgium from the final sample. Lastly, the countries not in the European Union that have been excluded are: Iceland, Norway, Switzerland, Turkey, and United Kingdom. The final sample thereby consists of 13 countries: Austria, Bulgaria, Czechia, Estonia, France, Germany, Hungary, Italy, Ireland, Lithuania, Poland, Slovakia, and Spain.

[8] Cars per 1000 people, and CO_2 are obtained from: https://ec.europa.eu/eurostat/data/database.

[9] Gasoline and diesel consumption are obtained from: https://energy.ec.europa.eu/data-and-analysis/weekly-oil-bulletin_en#bulletin.

[10] GDP per capita, urban population density, and unemployment rate: are obtained from: https://data.worldbank.org/indicator/.

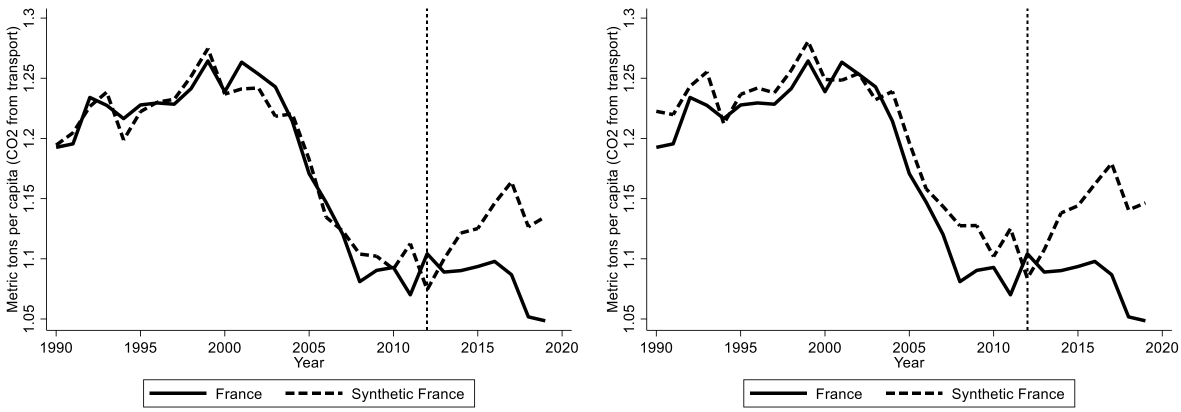
4. Results

The main results of this thesis are presented in this section, along with placebo tests and robustness checks. The results are discussed, together with the results of the placebo tests and robustness checks, in section 5.

4.1 France vs Synthetic France

Panel A illustrates the path plot of per capita CO2 emissions from cars both in France and Synthetic France doing a fully nested optimization. This result suggests that CO2 emissions from cars in France and Synthetic France follow each other in the pre-treatment period, making it possible to estimate the treatment effect. Panel A also shows that the emissions from France and its counterpart do in fact separate in the post-treatment period, which suggest that the carbon tax had the intended effect of reducing CO2 emissions from cars. Panel B also illustrates the path plot of per capita CO2 emissions from cars in France and Synthetic France, but by using the default optimization method. Panel B shows similar results compared to Panel A, but during the pre-treatment period Panel A shows a better fit compared to Panel B. Because of the better pre-treatment fit in Panel A, the nested method is our main method of choice.

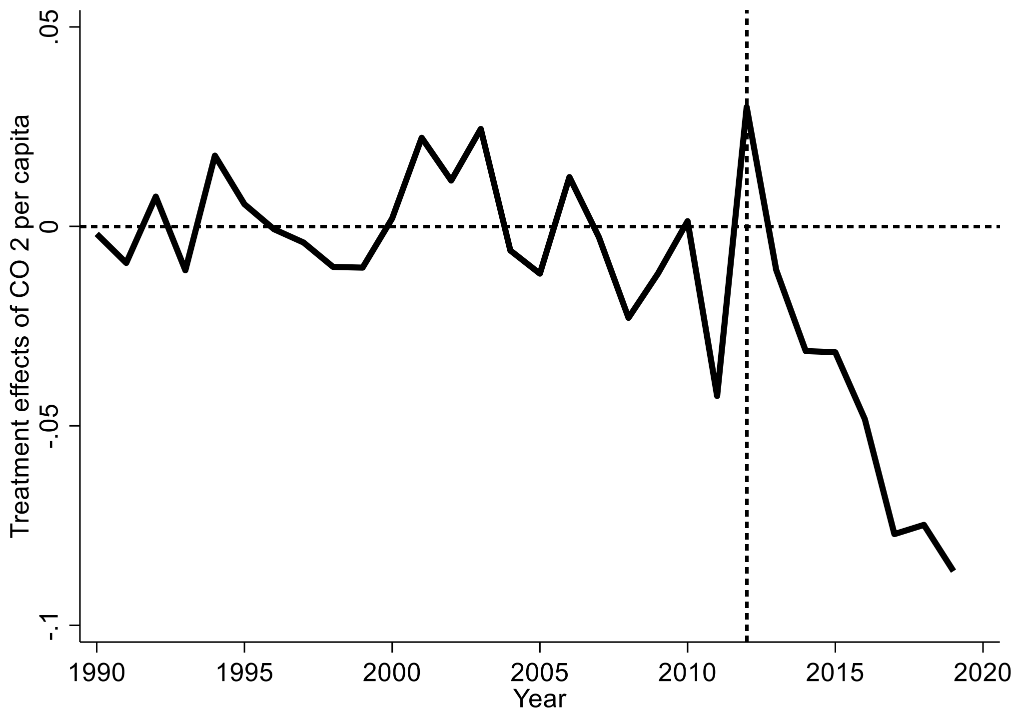
Figure 1 - CO2 Per Capita Emissions from Cars during 1990–2019:
France vs Synthetic France



Panel A: Fully nested optimization *Panel B: The default method*

Figure 2 emphasizes the treatment effects by showing the distance between France and synthetic France in Figure 1. The trustworthiness of the Synthetic Control Method is based on the ability of the synthetic France to track the CO_2 emissions from cars during the pre-treatment period. France and synthetic France follows each other closely until 2010. In 2010 (which is emphasized by Figure 2) there is volatility in how close they track each other, yet the graph suggests that something occurs at our cut-off. Figure A1, found in the appendix, shows a worse fit in the default method in the pre-treatment period compared to the nested method. Using the default method does also produce both a higher last year effect and a higher average effect, as can be seen in Table A1 in the appendix.

Figure 2 - Gap effects



Note: CO_2 per capita is measured in metric tons

When examining the last year of the sample period, 2019, Table 1 shows that the treatment effect is -0,0864 metric tons, i.e., 86,4 kilo grams per capita or 7.6%, and the average treatment effect for the whole post-period is -0,0515 metric tons. Table 1 also shows standardized p-values, which are calculated using the in-space placebo test (see the next section) to show the difference between the estimated effects in France and the placebo effects. Given that the first increase was seen in 2015, and is relatively small, it’s not surprising that we do not see significant results until 2016. When averaging the treatment effect during the significant years, between 2016 to 2019, the CO_2 emissions are reduced by approximately 6.3 per cent each year. When aggregating over the total population, the last year (2019) reduction is equivalent to 5.8 million metric tons of CO_2 and an average reduction for the 2016–2019 period of 4.8 million metric tons of CO_2. The total aggregate reduction in CO_2 emissions for the 2016 – 2019 post-treatment period is 19.2 million metric tons of CO2.

Table 1 - Prediction results in the post-treatment periods

Time	Actual Outcome	Predicted Outcome	Treatment Effect	P-Values standardized
2013	1.089	1.0999	-0.0109	58.3%
2014	1.0902	1.1214	-0.0313	16.7%
2015	1.0936	1.1252	-0.0316	16.7%
2016	1.0978	1.1462	-0.0483	0.0%
2017	1.0868	1.1639	-0.0771	0.0%
2018	1.0518	1.1266	-0.0748	0.0%
2019	1.0485	1.1349	-0.0864	0.0%

Note: The 0,0% p-values show that France, compared to the placebo test, has the most extreme effect for the significant years compared to the countries in the donor group when the pre-fit is accounted for, and not that there is a zero probability for the effect to be random.

Table 2 reports the predictor weights of the V matrix, as well as the mean values of all predictors, for both France and synthetic France during the pre-treatment time.[11] all predictors are averaged between the period 1990 and 2012, except for the lagged CO_2 variables and gasoline and diesel consumption. CO_2 per capita for the three years 2000, 2007 and 2012 as predictors represents CO_2 from cars per capita in Those respective years. Gasoline and diesel consumption are averaged between 2002 and 2012 due to data limitations.

[11] Table 2 also shows the simple average of control units in the donor pool with equal weights, as a comparison if not optimizing the weights.

Table 2 - Predictor balance in the pre-treatment periods

Predictor	V.weight	Treated	Synthetic Control		Average Control	
			Value	Bias	Value	Bias
Cars (per 1,000 people)	0.4%	453.0	468.2	3.35%	365.0	-19.43%
GDP per capita	36.6%	27088.1	27063.3	-0.09%	20464.0	-24.45%
Unemployment rate	0.0%	9.8	10.1	2.76%	10.3	4.73%
Urban population	0.1%	76.3	73.4	-3.70%	66.8	-12.35%
Gasoline consumption per capita	1.7%	0.6	0.6	-4.00%	0.5	-10.56%
CO_2 per capita (2012)	0.1%	1.1	1.1	-2.71%	0.9	-16.51%
CO_2 per capita (2007)	46.3%	1.1	1.1	0.24%	1.0	-10.05%
CO_2 per capita (2000)	14.8%	1.2	1.2	-0.16%	0.8	-35.13%

The V.weight column shows the predictor variable weights. stated in percentages. The predictors with a weight above 1 per cent are: GDP per capita (36.6%), Gasoline consumption per capita (1.7%), CO2 per capita (2007) (46.31%), and CO2 per capita (2000) (14.8%). Unsurprisingly, GDP per capita contributes a lot to synthetic France with a weight of 36.6%. The lagged CO_2 variables from 2000 and 2007 contribute by a lot as well, third respectively first place. Surprisingly, Gasoline consumption per capita is only given a 1.7% weight, which can possibly be explained by its large bias. Table A2 in the appendix presents the weight distribution when using the default regression-based matrix, which produces very similar results, but less weight is given to the lagged CO_2 (2007) variable. The Treated column represents France, i.e. the observed post-treatment values from our data set. The Synthetic Control column represents the synthetic France, where the *Value* shows the reproduced mean values of all predictors and *Bias* shows how far off the fit is between France and its synthetic control. For Average control see footnote 11. The mean values are almost identical when comparing France and its synthetic counterpart, where the predictor for the unemployment rate, cars per 1000 people and urban population density have a small discrepancy. Comparing France with the average control, we can see that the synthetic control has a much better fit. No other combination of lagged CO_2 (or using lagged GDP) yields different results as compared to the main analysis.

Table 3 - Optimal Country Weights

Country	Weight
Germany	74,3%
Spain	15,5%
Slovakia	10,2%

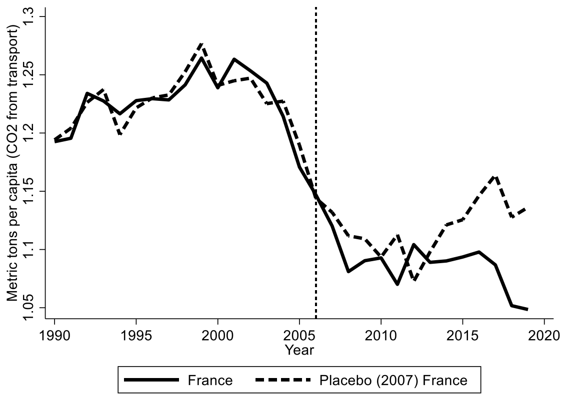
Table 3 states the countries included and their weights in the synthetic control, and the estimated synthetic control group to reproduce CO_2 emissions from cars consists of: Germany (74,3%), Spain (15,5%), and Slovakia (10,2%)[12]. Austria, Bulgaria, Czechia, Estonia, Hungary, Ireland, Italy, Lithuania, and Poland get a weight of zero. Furthermore, it is reasonable that Germany and Spain receive the highest weights since they are most similar, both geographically and demographically.

4.2 Placebo Tests

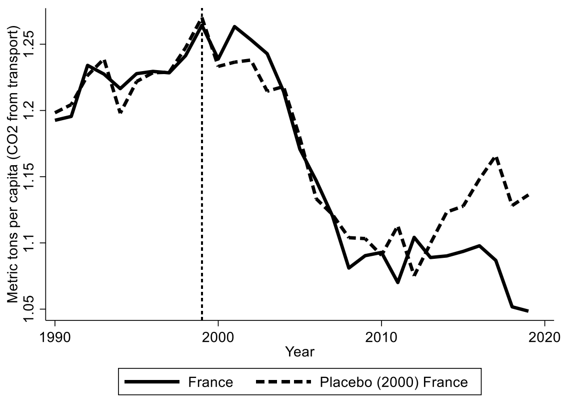
To evaluate result validity and integrity, several placebo studies are conducted using the pre-built tests in *Synth2*: “in-time” and “in-space”. The in-time tests reassign the treatment to a period before the actual treatment time when no treatment occurred. The objective is to demonstrate that this placebo treatment does not result in a large discrepancy in emission trajectory. If the placebo treatment results in a divergence in emissions, it would cast doubt on the conclusion from Figures 1 and 2, which shows the effect of the carbon component. The periods that are used for the in-time place check are 2000 and 2007, the same as the lagged CO_2 variables, 13 respectively six years before the backdated treatment.

[12] Interesting to mention is that Slovakia is not include when using the default method, see Table A3 in the appendix.

Figure 3 - Placebo Test Using Fake Treatment Time



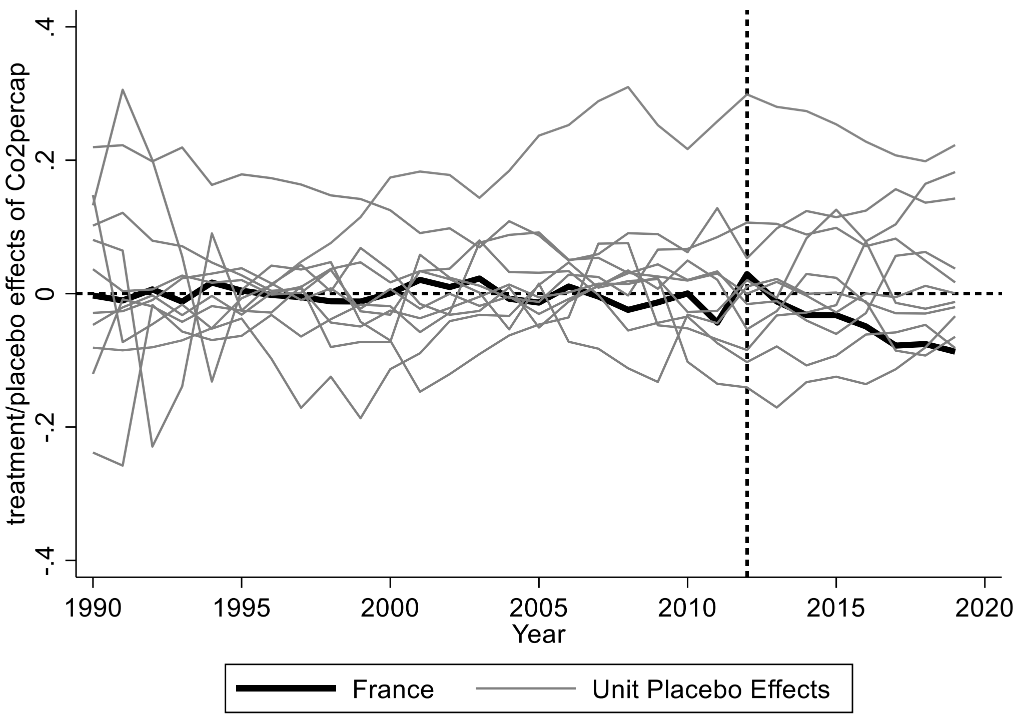
Panel A: Using 2007 as a Fake Treatment Time.



Panel B: Using 2000 as a Fake Treatment Time

As can be seen in Figure 3, there is no substantial discrepancy in emission trajectory. Both placebos closely reproduce the path from Figure 1. Even though the tax-treatment is artificially backdated, the estimated impact of the treatment occurs in line with the treatment, providing confidence to the synthetic control estimator, $\hat{\tau}_{1t}$, used to estimate the main results, with the dotted lines being the placebo treatment cut-off. Figures A2 and A3 in the appendix show that using the default method also produces robust results when the in-time placebo tests are considered.

Figure 4 - Placebo Test Using Fake Treatment Countries



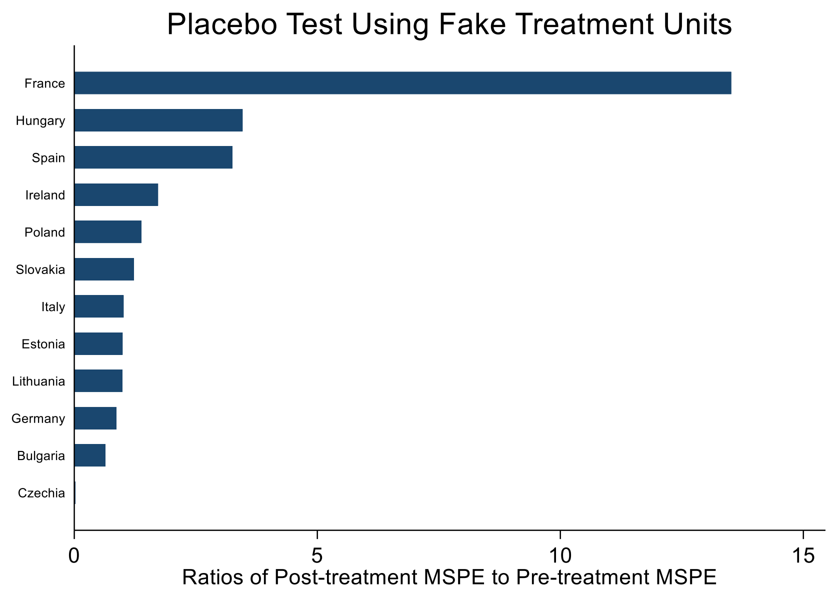
Note: Austria is not included due to a matrix error in Synth2.

The in-space placebo reassigns the treatment to a comparison unit, in our case another country. This allows us to calculate estimates for the countries which did not experience treatment, and vis-à-vis be able to compare the placebo 'effects' that are generated from the test, with the treatment effect from France. We are interested to compare if the effect for France is unusually large relative to the placebo 'effects'. In Figure 4 we can see that the in-space placebo does not manage to produce convincing fits for six of the placebo estimates of the CO_2 emissions in the pre-treatment period. However, France is amongst the most extreme in the raw comparison, and when the pre-fit is adjusted for it is the most extreme for the last years, as can be seen in Table 1.

An alternative to the in-space placebo and standardized p-values is the ratios of post/pre-treatment MSPE, as suggested by Abadie et al. (2010) and Abadie et al. (2021). A potential advantage, according to Andersson (2019), is that the comparison of ratios is possible when you have a small number of control units.

Figure 5 shows the ratios of post/pre-treatment MSPE for the donor pool and France. France certainly has the largest ratio: The post-treatment gap is about 13.5 times larger than the pre-treatment gap whereas Hungary only has 3.5 times higher ratio. Thus, the probability of obtaining a post/pre-treatment MSPE ratio as large as France's is: $\frac{1}{13} = 0{,}0769$. In other words, if one were to assign the treatment to the sample at random, the probability of finding a ratio such as this one would be 7.69%. The ratio considers the whole post-treatment period and is the smallest possible p-value given my sample size, whereas the standardized p-values in Table 1 compare the estimated effects. The ratio results once again show that France stands out compared to the other countries and that this is a good sign of a true effect being present.

Figure 5 - Ratio Test of Fake Treatment Units



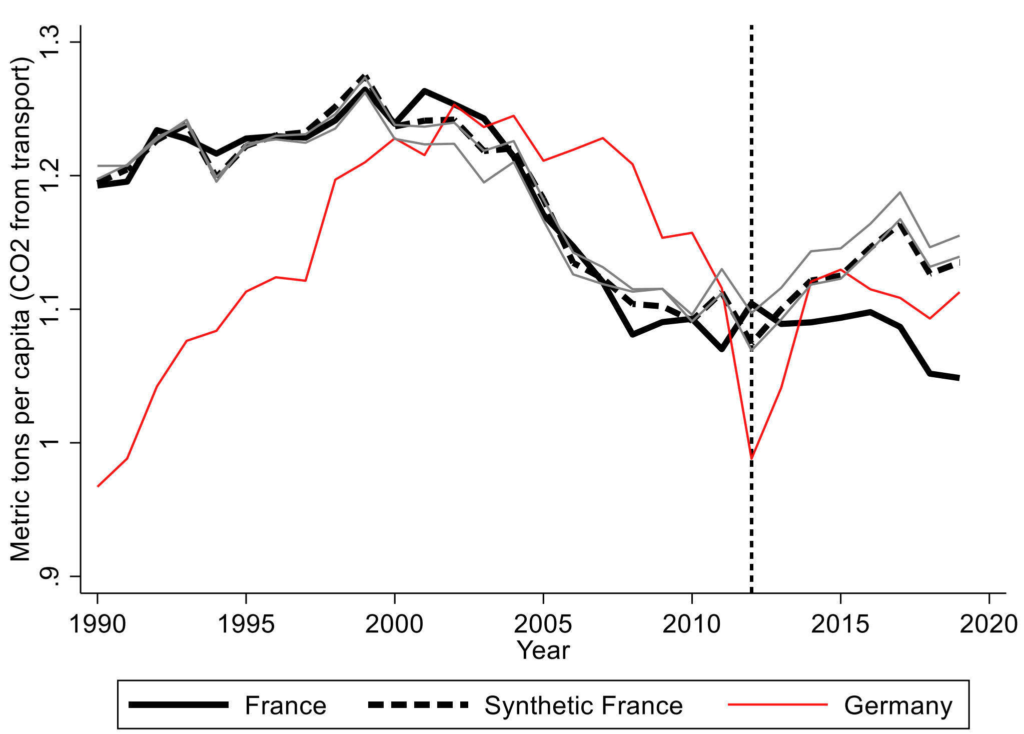
Note: France's ratio is 13,52 and Hungary's is 3,47

4.3 Robustness test

To continue to assess the sensitivity of the results, I run three robustness checks: “Leave-One-Out” (LOO), “full sample” and “Drop-One-Out”. For the leave-one-out test I use the baseline model, but iteratively omit each positive weighted country from smallest weight to highest, to evaluate if the main results are driven by a specific country. If the results are driven by a specific country, it could raise concern that it was a shock on CO_2 emissions in that country that was imposing the estimated effect and not the carbon tax implementation in France. The results are shown in Figure 6, where we can see that the main results are not robust to omitting Germany.

When omitting Germany, illustrated by the red line, we can see that the synthetic control method fails to predict the path of CO_2 per cap emissions from cars. Therefore, our results are highly reliant on Germany, whilst excluding the other countries one by one yields the same or a nudge larger effect. This is however not surprising as Germany is both very similar to France and has a very large weight (75 per cent) in the baseline estimation. Table A5 in the appendix reports the minimum and maximum treatment effects when conducting the LOO, which translates the graph in Figure 6 into numbers. When excluding Germany (the red line), during the first year there is an increase in CO_2 per capita consumption of 0,0478, but then in the second and continuing years the red line is above the line plotting France, and we have a similar but reduced effect.

Figure 6 - Leave-One-Out Test



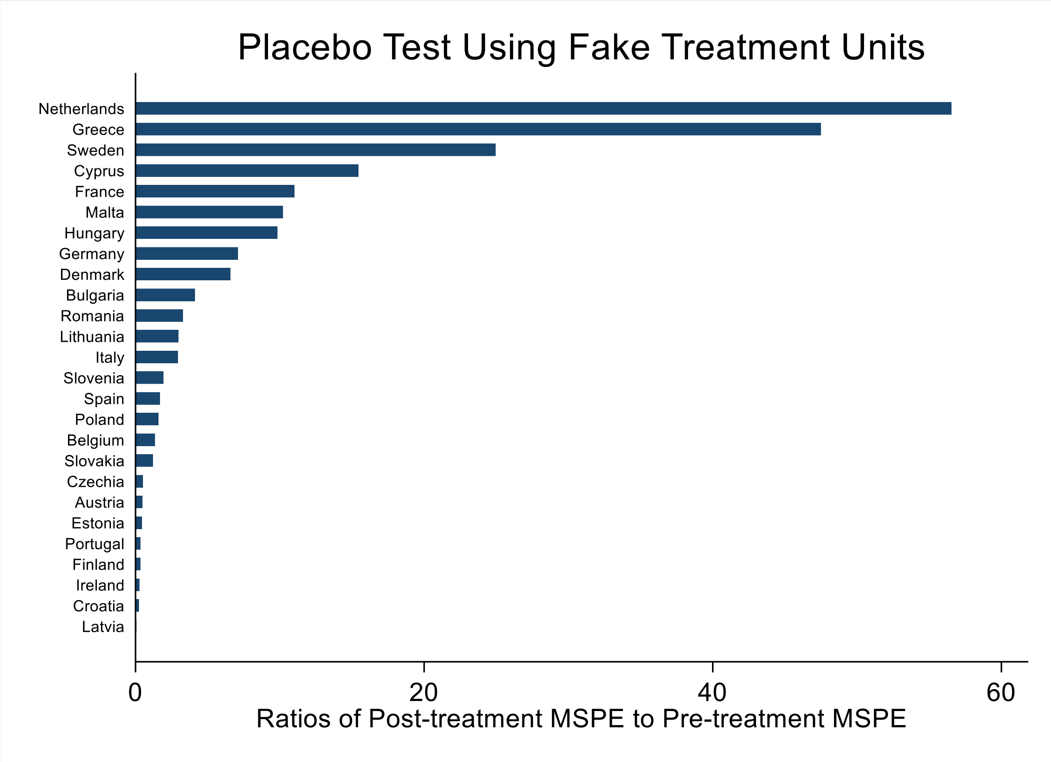
Note: The grey lines represent when omitting the other weighted countries.

One way to influence the results in the design of synthetic control framework is through the choice of the units in the donor pool. The objective of the full sample robustness test is therefore mainly to show any dissimilarities in the main results.

The full sample test uses all the 27 European Union countries[13] in the control group and yields similar estimates as our main results, with an average effect of -0.042, i.e., 42 kilograms (compared to the main result average effect, -0.0515). The full sample results are available in Figure A8 in the appendix. Comparing the results of the full sample to the main results shows little change in trajectories of CO2 emissions for France and its synthetic counterpart. The predictor means of the full sample (shown in Table A4 in the appendix) are given a lot of weight to GDP and the lagged CO_2 variables, similarly to the main results. Although, one difference is that the unemployment rate also receives a weight when including the full sample of countries. The full sample synthetic control still gives weight to Germany, Spain, and Slovakia, in decreasing order. The only previously left out countries now included, with a weight above 1%, is Sweden (5%) and Malta (1,6%). Figure 7 depicts the full sample post/pre-treatment MSPE-ratios[14], and unsurprisingly the post/pre-treatment MSPE-ratio for France is not unusually large, as was the case in the main result (see Figure 5). When including all countries, we have now included several countries that had altered their taxes around the same time as France. Therefore, we would expect to see several countries that also have a large ratio, making France's ratio not 'unusually' large. If one were to assign the treatment to the sample at random, the probability of finding a ratio as large as the one for France would be approximately 20% or 1/5. Which would suggest that the French carbon component is not the cause for the reduction in carbon emissions, given the (farfetched) assumption that no other country altered their fuel tax. The full sample robustness test stresses the importance of an appropriate donor pool and is further discussed in section 5.

[13] Note that the original data set includes thirty-two countries, but due to missing data in other predictor variables and excluding non-EU-countries, Turkey, Switzerland, UK, Norway, and Iceland are not included.
[14] Luxembourg is dropped due to not achieving convergence.

Figure 7 - Ratio Test: Full Sample



Note: France's ratio is 10.99, Hungary's 9.82 and Netherland's 56.54.

The last robustness check, Drop-one-Out, iteratively omits one predictor variable, and the purpose is to find how important these variables are in the construction of the synthetic control. The main results are stable to omit every predictor except the lagged CO_2 in 2007. Figure A4 in the appendix shows the results when omitting the lagged CO_2 (2007) variable, which displays a relatively poor pre-treatment fit. The lagged CO_2 years are chosen to not be affected by the fact that almost all countries made large changes in their fuel taxes during the sample period, due to the directive in 2003. Therefore, it is not surprising that the model fails to fit the trajectory of the CO_2 emissions when omitting the predictor using CO_2 from cars per capita in 2007. This result could therefore confirm the reasoning behind my lagged variables. Figure A5 and A6 in the appendix depict the path plot when omitting gasoline and diesel consumption, and cars per one thousand people, which shows almost identical graphs compared to the main results. Hence, the results are stable and robust to also exclude gasoline and diesel consumption, which are further discussed in section 5.

5. Discussion

Compared to the synthetic counterpart the results suggest a last year decrease in CO_2 per capita by -0.0864 metric tons, i.e., 86.4-kilo grams, or 7.6 per cent, meaning that the added carbon component had the intended effect. Furthermore, the placebo and robustness tests suggest that the overall treatment effect is robust and valid, especially given the placebo tests.

Potential confounders in the SCM are the predictor variables that could be causally linked with the outcome variable. Anderson (2019) argued that the link between GDP growth and growth in CO_2 is worth examining. Since if there is an economic shock that reduces the GDP growth and the reduction in GDP could be the cause for a reduction of CO_2 emissions, and therefore worth examining further. France and the Synthetic France should be affected by the same economic shock according to the method design which is examined in Figure A7 in the appendix. Figure A7 shows that GDP per capita in France shows no sign of treatment effect, and the synthetic counterpart follows the path of France well through the whole time window. The results shown in Figure A7 along with the main results indicate that it is not GDP that has driven the reduction. Furthermore, it suggests that there is no negative effect on GDP from the environmental tax reform. Another possible confounder is the element of using the consumption of gasoline and diesel, and registered cars as predictor variables. A shock in these predictors, which are substantial enough to reduce CO_2 emissions in only one country, has not happened during the time period. A potential shock could for example be a policy intervention that subsidies the purchase of an electric car, but to the best of my knowledge, no such large difference has been implemented. Andersson (2019) also explains that the predictive power of the variables is needed to construct a weighted comparison unit, without a confounding effect when including them posttreatment. Furthermore, the last robustness test shows that the main results are practically unaffected by including or excluding the variables in question.

Another concern of bias could be due to backdating the treatment effect to 2013. However, Abadie (2021) claims that backdating the treatment should not be a concern of bias since the method does not restrict the time variation in the effect estimator, and therefore there should be no mechanical bias. Hence, the only effect of backdating would be that the years hardly affected by the treatment could show small or zero effects. Table 1 shows that the first three years are insignificant but that should not be important since we can still see a significant effect when increasing the carbon component. Important to remember is that the total tax pressure was not increased until 2015, since the first tax increase only made the tax pressure go back to the 'normal'. Additionally, the treatment effect does grow over time, along with the cost of carbon. Therefore, our results would suggest that a higher price of carbon would give a larger reduction in CO_2.

The main results suggest that including a carbon component in fuel taxes is producing its intended effect and therefore should be considered an important intervention for climate policy, which is in line with the findings of Sterner (2007), and Agostini et al. (2015). Moreover, the main results are in line with the previous literature that finds a mitigation effect on CO_2 emissions, see especially Andersson (2019) but also Li et al. (2014). Andersson (2019) finds almost an eleven per cent average reduction of CO_2 from the transport sector in Sweden, whereas I find a 6.3 per cent average reduction of CO_2 from only passenger cars in France.[15] An annual CO_2 reduction of 6.3 per cent, or 72 kilograms per capita, is comparable to the greenhouse gas emissions from 286.5 kilometres driven by an average gasoline-powered passenger car. Over the entire population, it is equivalent to 19.27 billion kilometres driven by gasoline-powered passenger cars or 1.04 million gasoline-powered passenger cars driven for one year.[16]

The findings are, nonetheless, in contrast to Lin et al. (2011). Lin et al. (2011) examines the effects of carbon taxation in Sweden, Norway, Finland, Denmark, and the Netherlands using a DiD framework. They only find one significant effect for one of the examined countries, which was Finland with a 1.7 per cent reduction in CO2 per capita emissions. However, I argue that Lin et al. (2011) possibly provides biased estimates, since they violate underlying assumptions on causal inference. Lin et al. (2011) use outcome variables as covariates and combine treated and untreated sectors in the design by using total CO_2 emissions, which should bias the results.

The robustness test when doing the "leave-one-out" test produces a large effect on the results when excluding Germany from the donor pool, however, according to Abadie (2021) this should not be of concern since there is a distinct change in the pre-treatment fit when Germany is dropped. If there were no change in the pre-treatment fit, it would raise concern that there was a shock on CO_2 emissions in Germany that was driving the estimated effect and not the carbon tax implementation in France. Additionally, Abadie (2021) writes that is critical to collect information on the treated unit and the donor pool since the choice of

[15] It is noteworthy to mention that the Swedish tax was increased from the initial $30 rate and then increased during the 1990s to US$44 in 2000. Finally, from 2001–2004, the rate was increased to US$109. Compared to the French tax which increased from €7 to €44.6 between 2014–2018. The difference in price levels and time period evaluated should be considered when comparing the reductions.

[16] Estimates from United States Environmental Protection Agency's Greenhouse Gas Equivalencies Calculator: https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

including or excluding countries affects the conclusion of the results, and the full sample robustness test exemplifies the importance of due diligence when examining the potential control units. Figure 7 shows that the post/pre-treatment ratio of the treatment effect is larger in Netherlands, Greece, Sweden, and Cyprus. This is not surprising since all these countries altered their taxes on fuel in either 2012, 2013 or 2014, and exemplifies the importance of your due diligence when collecting information.

Another potential bias is that there is a concern of carbon leakage, failing the stable unit treatment value assumption (Rubin 1980). Thus, the treatment effect in France could “leak” to neighbouring countries and positively bias the results. There is no immediate solution to test for carbon leakage in this context, however, it is important to remember that Germany and Spain are the highest weighted donor pool countries. The leave-one-out test should also raise awareness of leakage in Germany since the pre-fit show almost a mirror image effect when leaving Germany out, which could be due to carbon leakage.

The last robustness test also shows that the results are affected by excluding the lagged CO_2 variable in 2007. The year 2007 was chosen since the existing TICPE were unchanged from 2007 as well as trying to weight the synthetic France to not be influenced by changes made by countries in their fuel/carbon taxes. Additionally, it is not surprising that the fit of the synthetic control is weakened when removing the highest weighted predictor, and all things considered, the test shows stable estimates.

Lastly, the main concern for bias is that the countries in the synthetic control have either altered- or implemented a fuel/carbon tax within the sample period. Meaning that they are not a completely untreated group. It is therefore impossible to claim that the results are unbiased. This bias is however a negative bias, as similar policies in other countries will result in a smaller counterfactual level of CO_2 than if these countries were completely untreated. All the weighted countries were introduced to the same ‘shock’ in 2002/2003 due to the EU directive introduced in 2003, as did France which also had a large change in their tax in 2002. Hence, there should be similar changes in CO_2 emissions for France and synthetic France from these changes. Therefore, the changes that are of higher concern are the increases made by Spain in 2009 and 2019, the changes made by Slovakia in 2011 and the reduction in 2018. Meanwhile, Germany (weighted to almost 75%) has not changed their tax since 2003 which will limit the negative bias.

To conclude, the results could be negatively biased due to similar changes in the pre-treatment period. The results could be positively biased due to the reduction made by Slovakia in 2018 and due to potential carbon leakage. I still argue that the introduction of the carbon component did in fact mitigate the emission of CO_2, due to the noteworthy estimated effect and the discussion above about the validity of the result.

6. Conclusion

In this thesis, the French experience of adding a carbon component to existing taxes emissions of CO_2 is estimated using the synthetic control method. Using the synthetic control method, we constructed a synthetic France to track the emissions of CO2 before treatment. Making it possible to compare, and evaluate the effects of the intervention, assuming that the synthetic control will simulate the counterfactual development in France without the carbon component. The main results show that the last year effect, in 2019, was a 7.6 per cent reduction, and when averaging the treatment effect during the significant years, the CO_2 emissions are reduced by approximately 6.3 per cent each year. This result is smaller but still in accordance with Andersson (2019), but in contrast to Lin and Li (2011) who find a much smaller or no decline in CO_2.

The results show validity to the placebo tests and other robustness tests and are significant when the cost of carbon is increased above € 15. France had a much larger post/pre-treatment MSPE ratio compared to the other countries. The mitigation effect could be negatively biased due to similar changes in Spain and Slovakia. Whereas an overestimation (positive bias) of the effects could also exist since there is no easy solution, in this context, to test for carbon leakage to neighbouring countries. One example would be to check gas station level fuel consumption on both sides of the border. The findings do however suggest a reduction in carbon dioxide emissions, partly due to the validity of the placebo tests but also since there are an unusually large post/pre-treatment MSPE ratio and the standardized p-values suggest that the treatment effect is significant.

Further research could examine and correct potential biases in the optimization routine used in Stata[17], but most importantly evaluate the possibility of expanding the control group. Adding additional qualified control units to the donor pool could reduce the potential bias gained from including countries that previously implemented or changed their fuel tax during the pre-treatment sample period. However, since no other paper has evaluated the French carbon tax, the findings of this thesis are the first of its kind, meaning that it exists an academic gap concerning this specific case.

Given that the existing literature suggests low public support (Carattini et al. (2017), Hammar et al. (2005) and Agostini (2015)) for carbon taxes, and that the

[17] See Becker et al. (2018)

yellow west movement halted the price increase of the carbon component, I argue that further research and studies could provide adequate and correct information to the public. Especially since Carattini et al. (2017) show that providing the public with information on the mitigation effects can increase support for carbon taxes. The findings of this thesis thus stress the importance of further conveying the true cost of carbon, since there are mitigation effects from implementing a carbon component, at least for fuel consumption. Further studies could focus on defining the true effects since not having accessible information makes it harder to muster the public support needed to combat climate change.

References

Abadie, alberto. (2021) Using Synthetic Controls: Feasibility, Data Requirements, and Methodological Aspects. Journal of Economic Literature, Volume 59, Issue 2, Pages 391-425, https://doi.org/10.1257/jel.20191450

Abadie, alberto. alexis, Diamon. Jens. Hainmueller. (2010) Synthetic Control Methods for Comparative Case Studies: Estimating the Effect of California's Tobacco Control Program. Journal of the American Statistical Association, Volume 105, Issue 490, Pages 493-505, https://doi.org/10.1198/jasa.2009.ap08746

Abadie, alberto. alexis, Diamon. Jens. Hainmueller. (2011) Synth: An R Package for Synthetic Control Methods in Comparative Case Studies. Journal of Statistical Software, Volume 42, Issue 13), Pages 1–17, https://doi.org/10.18637/jss.v042.i13

Abadie, alberto. alexis, Diamon. Jens. Hainmueller. (2015) Comparative Politics and the Synthetic Control Method. American Journal of Political Science, Volume 59, Issue 2, Pages 495–510, https://doi.org/10.1111/ajps.12116

Abadie, alberto. Gardeazabal, Javier. (2003) The Economic Costs of Conflict: A Case Study of the Basque Country American. Economic Review, Volume 93, Issue 1, Pages 113-132, https://doi.org/10.1257/000282803321455188.

Agostini, Claudio, A. Jiménez, Johanna. (2015) The distributional incidence of the gasoline tax in Chile. Energy Policy, Volume 85, 2015, Pages 243-252, https://doi.org/10.1016/j.enpol.2015.06.010.

Andersson, Julius J. (2019) Carbon Taxes and CO2 Emissions: Sweden as a Case Study. American Economic Journal: Economic Policy, Volume 11, Issue 4, Pages 1-30, https://doi.org/10.1257/pol.20170144.

Antonio, Guterres. (2022) Secretary-General's video message to the Press Conference Launch of IPCC Report. United Nations. https://www.un.org/sg/en/content/sg/statement/2022-02-28/secretary-generals-video-message-the-press-conference-launch-of-ipcc-report-scroll-down-for-languages

Becker, Martin. Klößner, Stefan. (2018) Fast and reliable computation of generalized synthetic controls. Econometrics and Statistics, Volume 5, 2018, Pages 1-19. https://doi.org/10.1016/j.ecosta.2017.08.002.

Bohlin, Folke. (1998) The Swedish Carbon Dioxide Tax: Effects on Biofuel Use and Carbon Dioxide Emissions. Biomass and Bioenergy, Volume 15, Issue 4–5, Pages 283–91, https://doi.org/10.1016/S0961-9534(98)00036-1

Bohn, Sarah. Lofstrom, Magnus. Raphael, Steven. (2014) Did the 2007 Legal Arizona Workers Act Reduce the State's Unauthorized Immigrant Population?. The Review of Economics and Statistics, Volume 96, Issue 2, Pages 258–269. https://doi.org/10.1162/REST_a_00429.

Buysse, Claire. Miller, Josh. (2021) Transport could burn up the eu's entire carbon budget. International Council on Clean Transportation. https://theicct.org/transport-could-burn-up-the-eus-entire-carbon-budget/

Carattini, Stefano. Baranzini, Andrea. Talman, Philippe. Varone, Frédéric. Vöhringer, Frank. (2017) Green Taxes in a Post-Paris World: Are Millions of Nays Inevitable? Environmental Resource Economics, Volume 68, Pages 97–128, https://doi.org/10.1007/s10640-017-0133-8

Directive 2003/96/EC. Restructuring the Community framework for the taxation of energy products and electricity. European Parliament, Council of the European Union. http://data.europa.eu/eli/dir/2003/96/oj.

Donohue, John, J. Aneja, Abhay. Weber, Kyle, D. (2019) Right-to-Carry Laws and Violent Crime: A Comprehensive Assessment Using Panel Data and a State-Level Synthetic Control Analysis. Journal of Empirical Legal Studies, Volume 16, Issue 2, Pages 198-247, https://doi.org/10.1111/jels.12219.

European Commission's Oil Bulletin. (2022) Weekly Oil Bulletin. European Commission. https://energy.ec.europa.eu/data-and-analysis/weekly-oil-bulletin_en#bulletin.

Eurostat. (2021) Database. European Commission. https://ec.europa.eu/eurostat/data/database.

Galiani, Sebastian. Quistorff, Brian. (2017) The Synth_Runner Package: Utilities to Automate Synthetic Control Estimation Using Synth. The Stata Journal 17, 834–849. https://doi.org/10.1177/1536867X1801700404.

IPCC. (2022) Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. al.egría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press. In Press.

Johansson, Olof. Lee, Schipper. (1997) Measuring the Long-Run Fuel Demand of Cars: Separate Estimations of Vehicle Stock, Mean Fuel Intensity, and Mean Annual Driving Distance. Journal of Transport Economics and Policy, Volume 31, Issue 3, Pages 277–292, http://www.jstor.org/stable/20053740.

Kleven, Jacobsen, Henrik. Landais, Camille. Saez, Emmanuel. (2013) Taxation and International Migration of Superstars: Evidence from the European Football Market. American Economic Review, Volume 103, Issue 5, Pages 1892-1924, https://doi.org/10.1257/aer.103.5.1892.

Kreif, Noémi. Grieve, Richard. Hangartner, Dominik. Turner, al.ex James. Nikolova, Silviya. Sutton, Matt. Examination of the Synthetic Control Method for Evaluating Health Policies with Multiple Treated Units. Health Economics. Volume 25, Issue 12, Pages 1514-1528, https://doi.org/10.1002/hec.3258.

Li, Shanjun. Linn, Joshua. Muehlegger, Erich. (2014) Gasoline Taxes and Consumer Behavior. American Economic Journal: Economic Policy, Volume 6, Issue 4, Pages 302-42, http://doi.org/10.1257/pol.6.4.302

Lin, Boqiang. Li, Xuehui. (2011) The effect of carbon tax on per capita CO2 emissions. Energy Policy, Volume 39, Issue 9, 2011, Pages 5137-5146. https://doi.org/10.1016/j.enpol.2011.05.050.

LOI n° 2007-1824. du 25 décembre 2007 de finances rectificative pour 2007. https://www.legifrance.gouv.fr/jorf/id/JORFTEXT000017839505 (In French)

LOI n° 2015-992. LOI n° 2015-992 du 17 août 2015 relative à la transition énergétique pour la croissance verte. https://www.legifrance.gouv.fr/loda/article_lc/LEGIARTI000031048231/. (In French)

Portney, Paul, R. Parry, Ian W.H. Gruenspecht, Howard, K. Winston, Harrington. (2003) Policy Watch: The Economics of Fuel Economy Standards. Journal of Economic Perspectives, Volume 17, Issue 4, Pages 203-217, http://dx.doi.org/10.1257/089533003772034961.

Rubin, D. B. (1980). Randomization Analysis of Experimental Data: The Fisher Randomization Test Comment. Journal of the American Statistical Association, 75(371), 591–593. https://doi.org/10.2307/2287653

Sterner, Thomas. (2006) Survey of Transport Fuel Demand Elasticities. Stockholm: Naturvårdsverket.

Sterner, Thomas. (2007) Fuel taxes: An important instrument for climate policy.
Energy Policy, Volume 35, Issue 6, 2007, Pages 3194-3202, https://doi.org/10.1016/j.enpol.2006.10.025.

Szymon Wlazlowski, Monica Giulietti, Jane Binner, Costas Milas, Price dynamics in European petroleum markets, Energy Economics, Volume 31, Issue 1, Pages 99-108, https://doi.org/10.1016/j.eneco.2008.08.009.

World Bank. (2022) World Bank Data: Indicators. World Bank. https://data.worldbank.org/indicator/.

Acknowledgements

Special thanks to my assistant supervisor Jonathan Stråle, without you this would not have been as enjoyable.

Appendix

Figure A1 - – Treatment effects: "Default method"

Table A1 - Prediction results in the post-treatment periods: "Default method"

Time	Actual Outcome	Predicted Outcome	Treatment Effect	P-Values standardized *
2013	1,089	1,1075	-0,0185	42%
2014	1,0902	1,1381	-0,0479	0%
2015	1,0936	1,1441	-0,0505	0%
2016	1,0978	1,162	-0,0642	0%
2017	1,0868	1,1792	-0,0924	0%
2018	1,0518	1,1406	-0,0888	0%
2019	1,0485	1,1464	-0,098	0%

Table A2 - Predictor balance in the pre-treatment periods: "Default method"

Predictor	V.weight	Treated	Synthetic Control		Average Control	
			Value	Bias	Value	Bias
carscap1000	2,1%	453,0	474,4	4,7%	365,0	-19,4%
gdpcap	37,5%	27088,1	26889,4	-0,7%	20464,0	-24,5%
unemprate	0,2%	9,8	9,8	-0,3%	10,3	4,7%
popdens	3,1%	76,3	74,9	-1,8%	66,8	-12,4%
gas_cons_cap(2002(1)2012)	6,2%	0,6	0,6	-4,1%	0,5	-10,6%
Co2percap(2012)	5,2%	1,1	1,1	-1,8%	0,9	-16,5%
Co2percap(2007)	22,1%	1,1	1,1	2,1%	1,0	-10,1%
Co2percap(2000)	23,7%	1,2	1,2	0,8%	0,8	-35,1%

Table A3 - Optimal Country Weights: "Default method"

Country	Weight
Germany	76,0%
Spain	15,6%
Bulgaria	7,1%
Hungary	1,3%

Figure A2 - In-Time Placebo: Default Method (2000)

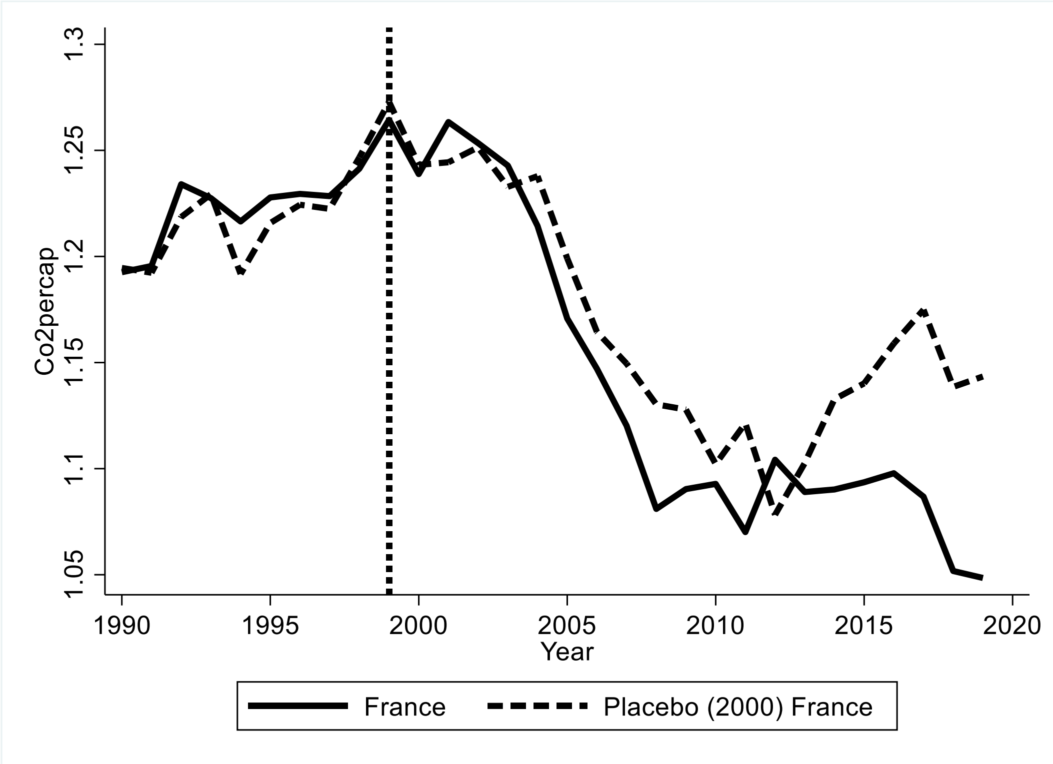


Figure A3 - In-Time Placebo: Default Method (2007)

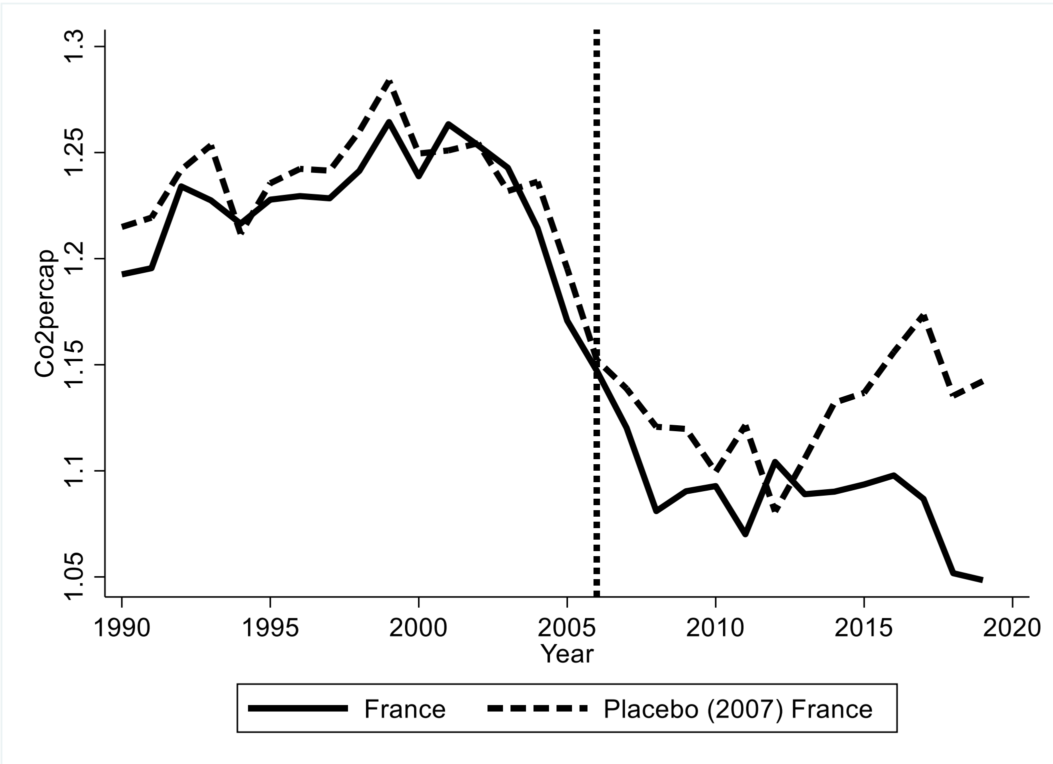


Table A4 – Full sample Predictor balance in the pre-treatment periods

Covariate	V,weight	Treated	Synthetic	Control	Average	Control
			Value	Bias	Value	Bias
carscap	0.0%	453.0455	465.1808	2.7%	375.3989	-17.1%
gdpcap	73.0%	27088.147	27078.3658	0.0%	23313.749	-13.9%
unemprate	20.4%	9.8323	9.8308	0.0%	8.9228	-9.3%
popdens	0.0%	76.2674	73.9985	-3.0%	70.3882	-7.7%
gas_cons_cap(2002(1)2012)	0.2%	0.6063	0.5883	-3.0%	0.7258	19.7%
Co2percap(2012)	0.0%	1.1042	1.0754	-2.6%	1.1781	6.7%
Co2percap(2007)	3.9%	1.1203	1.1234	0.3%	1.2827	14.5%
Co2percap(2000)	2.5%	1.2388	1.2331	-0.5%	1.1167	-9.9%

Table A5 – Leave-one-out (LOO) Effects

Time	Treatment Effect	Treatment Effect (LOO)	
		Min	Max
2013	-0.0109	-0.027	0.0478
2014	-0.0313	-0.0532	-0.0282
2015	-0.0316	-0.052	-0.0292
2016	-0.0483	-0.0662	-0.0171
2017	-0.0771	-0.1007	-0.0217
2018	-0.0748	-0.0946	-0.0413
2019	-0.0864	-0.1066	-0.0643

Figure A4 - Robustness "drop-one-out": Dropping Lagged Co2 2007

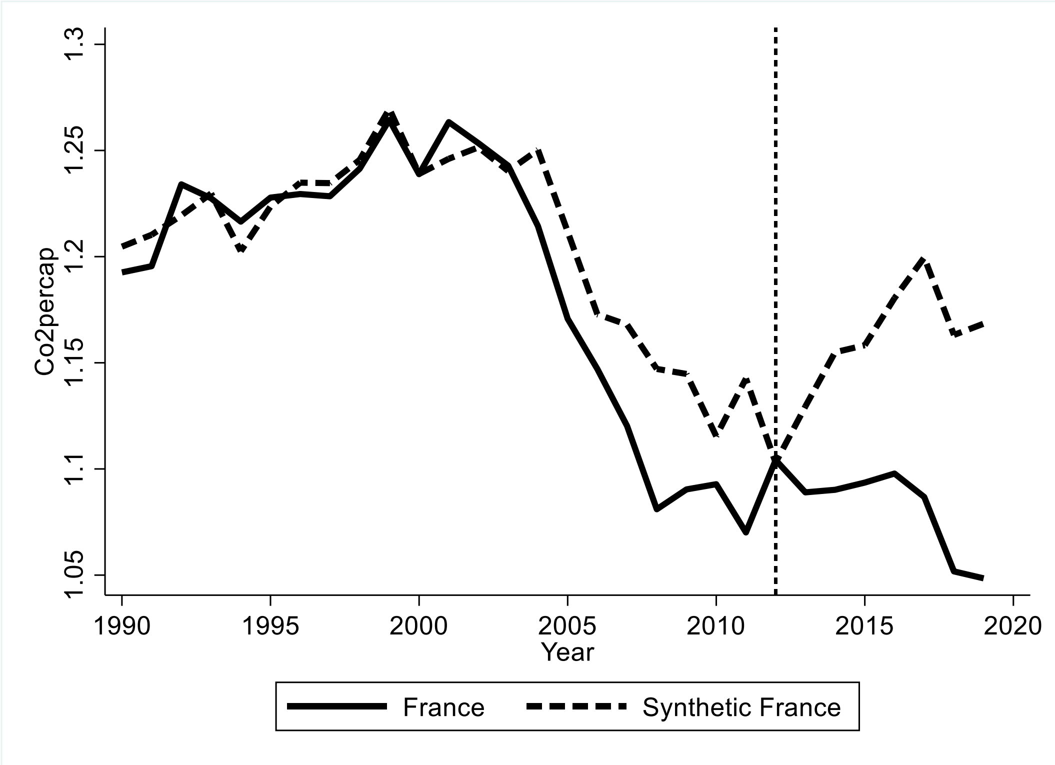


Figure A5 - Robustness "drop-one-out": Dropping Gasoline and Diesel Consumption

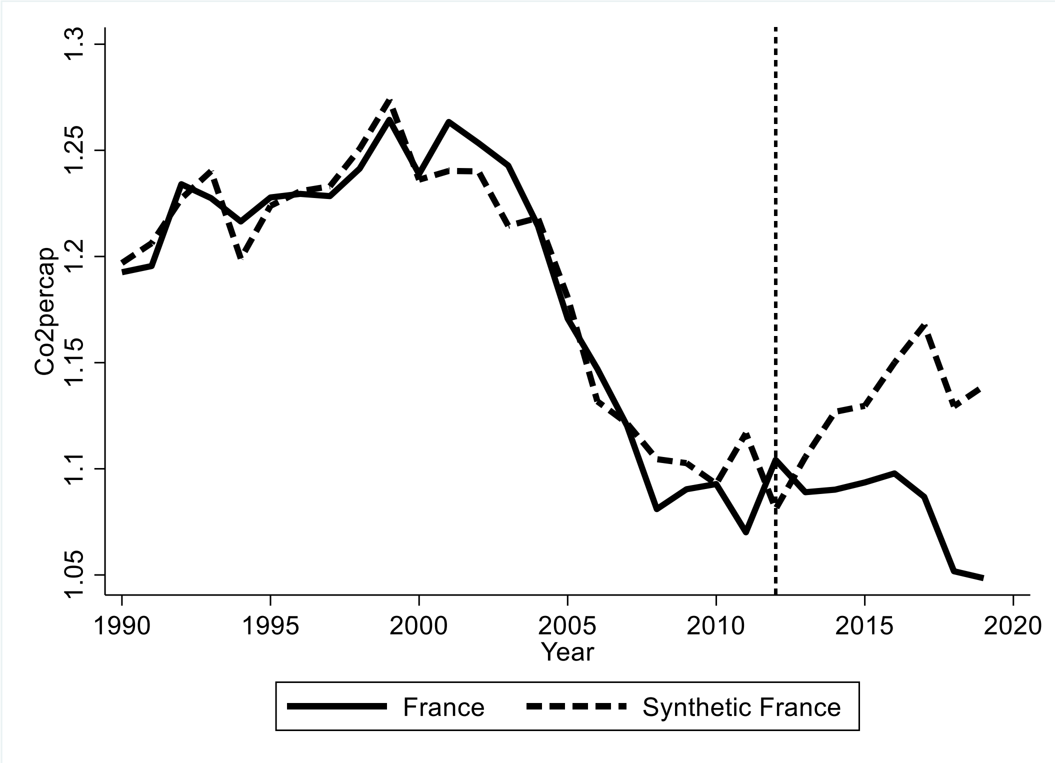


Figure A6 - Robustness "drop-one-out": Dropping Cars per 1000 people

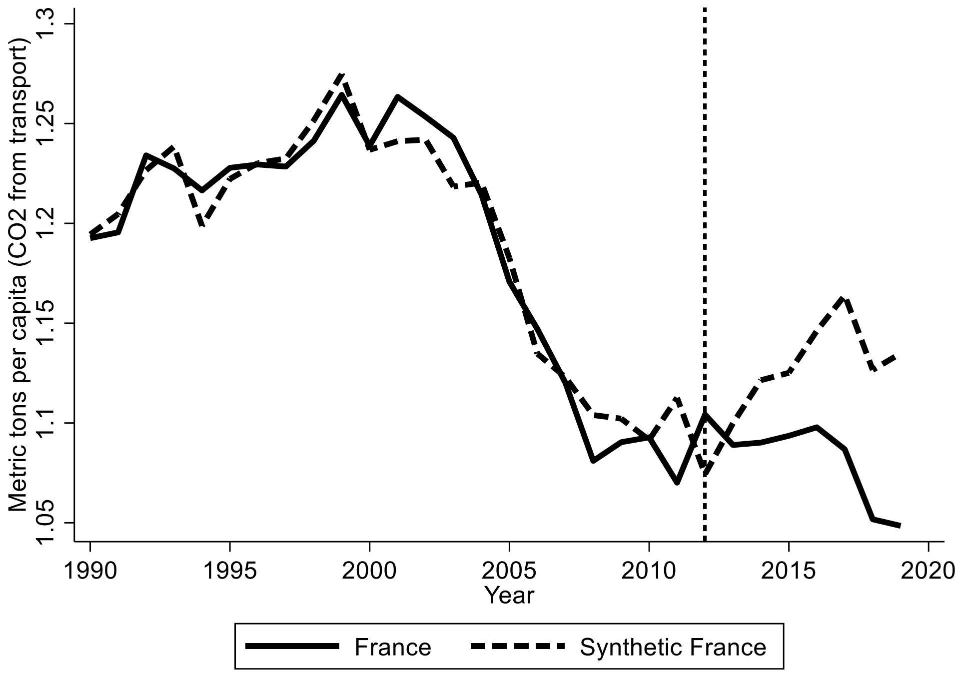
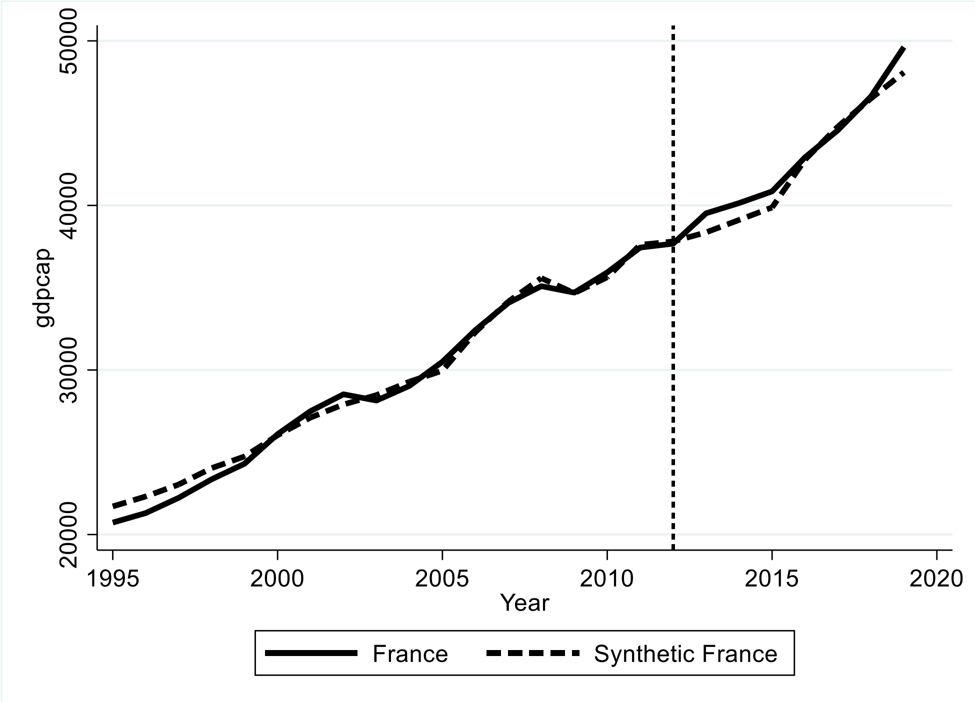
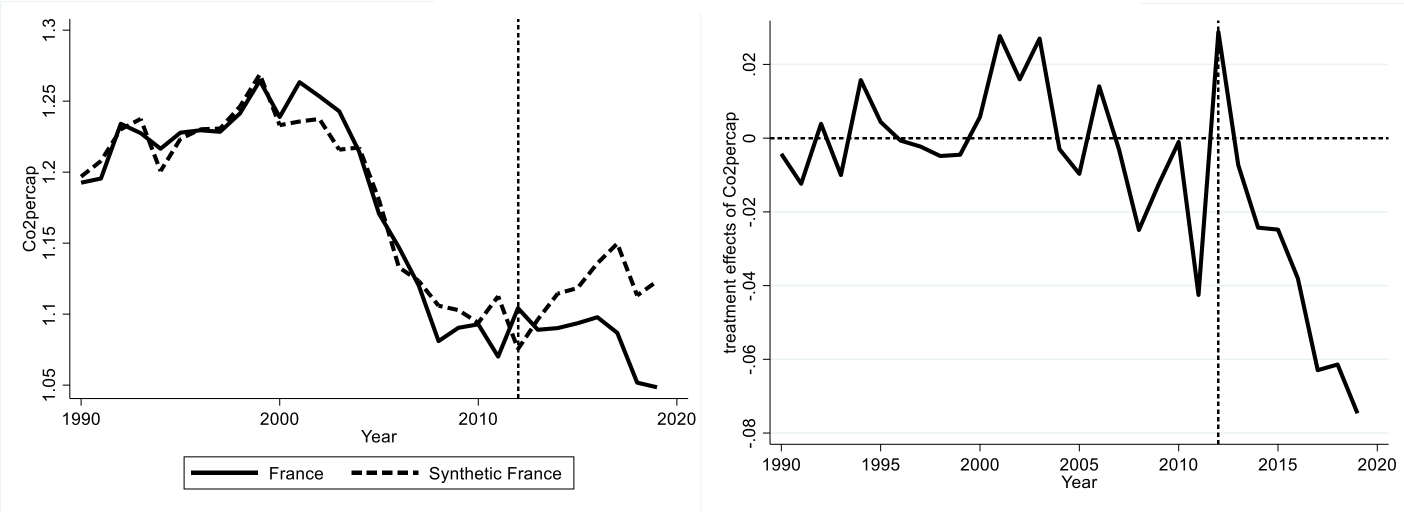


Figure A7 – Synthetic GDP



Note: Due to missing datapoints in GDP per capita in four donor pool countries, the estimation starts in 1995.

Figure A8- Full Sample plots



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