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Effects of Carbon Taxes on CO_2 Emissions in the Nordic Countries: A Synthetic Control Analysis

Ismael Moreno Martinez (41428)

Abstract: This quasi–experimental study estimates the effects of transport fuel taxation reforms on CO_2 emissions in Sweden and Finland through a synthetic strategy. Panel data from OECD countries is used to construct control units that closely resemble the treated countries. This is the first application of this methodology to the Finnish case, finding a non–significant effect of the introduction of a carbon tax and sustained increases of excise taxes on transport fuels. At the same time, through the implementation of a carbon tax and the VAT, Sweden reduced its yearly CO_2 emissions from transport by 10.6 percent. Besides, the carbon tax elasticity of demand for gasoline in Finland is 6.7 times the price elasticity. This evidence suggests the contrasting impacts of these two carbon tax reforms stem from the relatively low carbon tax rate imposed in Finland. Additionally, an unsuccessful attempt at measuring the causal effect of transport fuel taxation in Norway points out that a valid empirical estimate of carbon tax effects for this study case is still pending.

Keywords: Carbon Tax; Synthetic Control; Environmental Policy; Climate Change
JEL: H230, L91, Q54, Q58

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Discussant:	Terence Carr
Examiner:	Kelly Ragan

189 countries, responsible of more than 97 percent of global greenhouse gas emissions, have ratified or acceded to the Paris Agreement (UNFCCC, 2015, 2020). Under the agreements' framework, each country commits to determine, plan and report its particular contribution to the mitigation of global warming. Hence, national policies will be at the center of the shared mitigation effort.

From an economic point of view, human–induced climate change is an externality. Thus, at the core of policy efforts should be pricing the social cost of greenhouse gas emissions such as carbon dioxide (CO_2), either through markets of emission permits or a carbon tax (Arrow et al., 1997; Howard and Sylvan, 2015). While most economists support the carbon tax (Climate Leadership Council, 2019; Nordhaus 2013; Weitzman 2015), public support for such an instrument is rather low. However, when accompanied by evidence of their usefulness reducing emissions, carbon taxes gather greater support (Murray and Rivers, 2015; Carattini et al., 2017). In any case, not many countries have adopted carbon taxes so far. Even more, there is a surprising lack of empirical ex post study of their causal effects on CO_2 emissions (Baranzini and Carattini, 2014; Sterner, 2015). This is worrying given the pressing time frame the world faces. Holding the increase in global average temperature to well below 2°C above pre–industrial levels will take an efficient curbing of emissions. Therefore, it is important to test whether existing national policies have been effective, as evidence can encourage governments to follow successful interventions and gather public support for their adoption.

The aim of this thesis is to estimate the effectiveness on CO_2 emission reductions of carbon taxes imposed on transport fuels, focusing on the cases of Sweden, Norway and Finland. Between 1990 and 1991, these three countries carried out tax reforms that (1) imposed a carbon tax that covered transport fossil fuels and (2) marked the beginning of a period with significantly higher taxes on their retail price, both in absolute terms and as a proportion of the total. Hence, being among the first countries in the world to introduce a carbon tax makes the Nordics interesting study cases to estimate the long-term effects of this environmental economic instrument.

Throughout this paper, I follow the methodology implemented by Andersson (2019) in the first quasi–experimental study to find a significant causal effect of carbon taxes on emissions. This study focused on the Swedish case, which I replicate and take as a reference for comparative purposes. Therefore, I implement the synthetic control method (Abadie and Gardeazabal, 2003; Abadie, Diamond, and Hainmueller, 2011, 2015) to construct counterfactuals of the treated countries: "Synthetic Sweden", "Synthetic Norway" and "Synthetic Finland". With that aim, I use panel data from a meticulously filtered sample of OECD countries that did not implement carbon taxes. A subsample of those is weighted through a data driven process in such a way that closely resembles the treated unit during the pre–treatment period both in, (1) a set of key predictors of CO_2 emissions of the transport sector and (2) the path of these emissions. Conclusively, I find the Finnish carbon tax did not have a significant impact on emissions for the post–treatment period of interest (1990 to 2005). For the Swedish case, my replication results are almost identical to those of Andersson (2019), with emission reductions of 10.6 percent on the average year, equivalent to 2.5 metric tons of CO_2. Unfortunately, this methodology proves to be unfit for the Norwegian study case. This stems from Norway experiencing 90 percent growth in its GDP per capita in the post–treatment period, while no country in its economic environment with a similar starting point gets even closer to that pace of growth. This idiosyncratic confounder can not be controlled for through the synthetic strategy. Nevertheless, my attempt with Norway still generates insight about the limitations of the existing literature. Particularly, the violation of the parallel trends assumption incurred by previous Difference–in–Difference approaches (Lin and Li, 2011).

Previous empirical literature has found evidence of a larger demand sensitivity to gasoline taxes, particularly carbon taxes, than to changes in prices driven by other factors, like oil value (Davis and Kilian, 2011; Li et al., 2014; Rivers and Schaufele, 2015; Antweiler and Gulati, 2016). Equally, Andersson (2019) found the carbon tax elasticity was three times higher than the price elasticity for gasoline in Sweden, and proposed this as an explanation to the sizable effect in CO_2 emissions found through the synthetic control strategy. Equally, as a complementary analysis, I assess if the insignificant effect of the Finnish tax reforms could be consistent with a large carbon tax elasticity. Consequently, I find a carbon tax elasticity 6.7 times larger than the carbon–tax–exclusive price elasticity. Nevertheless, a simulation of the effects of the gasoline tax changes throughout the treatment period reveals that its effects on emissions could in fact go unnoticed by the synthetic control strategy. In conclusion, the much lower rate of the Finnish carbon tax could explain the contrast between its small effects and the substantial impact of the Swedish fuel taxation adjustments.

Several are the benefits of using the synthetic control method. To start, it estimates the effects of carbon taxes using empirical ex post CO_2 emissions data. In contrast, a majority of the previous

literature has relied on simulation approaches (see e.g. Andersen et al., 2001; Bruvoll and Larsen, 2004; Ministry of the Environment and Energy, 2009), most of them using gasoline consumption as a proxy for CO_2 emissions of the transport sector or the total economy. However, there are some caveats associated with simulation–based estimations. As mentioned, there is growing evidence suggesting gasoline consumption reacts more strongly to changes in taxes, and carbon taxes, than to equivalent price movements (Davis and Kilian, 2011; Li et al., 2014; Rivers and Schaufele, 2015; Antweiler and Gulati, 2016). Therefore, simulations relying on regular price elasticities will underestimate the effect of taxes on carbon emissions. At the same time, data on gasoline consumption cannot capture relevant effects on consumer behaviors like substitution between fuels or modes of transport. Substitution between gasoline and diesel is particularly relevant in Europe, where the diesel share of the road fuel market is much higher than in North America (Eurostat, 2020; Chambers and Schmitt, 2015). In fact, the large European fleet of diesel–powered vehicles (more fuel efficient than gasoline cars) could be explained by a relatively high fuel taxation (Sterner, 2006). In 1990, passenger cars with diesel engines accounted for between 2.9 and 8 percent of the total car fleets of Sweden, Norway and Finland. In 2005, the shares of diesel cars were between 5.2 and 15.5 percent. In 2018, this share was 26, 35.1 and 47.2 percent for Finland, Sweden and Norway, respectively (Eurostat, 2020). Therefore, capturing this substitution effect will be important to obtain unbiased estimates and evaluate the environmental effects of fuel taxation. Another advantage of focusing on transport CO_2 emissions as a whole is capturing all adjustments in the extensive margin of fuel demand. For example, substitution of car driving by the use of public bus.

Additionally, the synthetic strategy employed in this papers offers some advantages over the differences–in–differences (DiD) method, frequently used in comparative empirical studies. DiD settings are, apart from simulations, the most usual method used to identify the effects of carbon taxes (see, e.g., Elgie and McClay, 2013; Lin and Li, 2011). However, the synthetic control method allows unobserved confounders affecting the outcome variable to change over time, being less restrictive than the parallel trends assumption needed for a DiD (Abadie et al., 2010). On top of that, the synthetic strategy takes advantage of a set of key predictors of the outcome variable, so the counterfactual unit resembles relevant characteristics of the treated unit: gasoline consumption or vehicles per capita, for example. In comparison, these variables would only make for "bad controls" in a DiD regression, given they are themselves affected by the carbon tax. The synthetic strategy employs the predictive power of these variables to construct a credible counterfactual, while avoiding their confounding effect after the treatment. Furthermore, the synthetic unit, being the controls weighted by a data drive process, is arguably less arbitrary in its construction than a DiD counterfactual. Finally, the characteristics of the synthetic unit are transparent: the weights assigned to the control group, or the predictor variables, are open to assessment and the similarities on observable variables of the treated country with its synthetic control are verifiable.

The methodological advantages mentioned were already present in Andersson (2019); the first quasi–experimental study to use a synthetic control unit to estimate the effects of a carbon tax on CO_2 emissions. I contribute to the empirical literature by applying this identification strategy to Finland, a study case with some relevant features. Finland, like Sweden and Norway, was an early adopter of the carbon tax, which allows me to test the effects of its taxation changes for a post–treatment period of 16 years. This is advantageous, as it is time enough to account for changes in both the intensive (reductions in driving mileage) and the extensive (e.g., shift to diesel cars or public transport) margins. Nevertheless, the carbon tax rate charged to transport fuels in Finland was relatively low, with an initial nominal tax rate of 2, against the 41 and 42 USD per ton of CO_2 of Sweden and Norway, respectively. Given this, my findings underscore the importance for policy makers of setting appropriate, high enough, carbon tax rates to send a sufficiently strong price signal. Hence, this piece of evidence accompanies the common view among economists that carbon tax rates should increase until emissions reductions goals are met (Climate Leadership Council, 2019).

The remainder of this this thesis proceeds as follows. Section I presents the main features of the carbon tax reforms in Finland, Sweden and Norway. Section II presents the data an methods used to estimate the effect of transport fuel taxation on CO_2 emissions. Section III presents the empirical results of the synthetic control strategy, together with some robustness checks. Section IV estimates the carbon tax elasticity of demand for Finland. Section V compares this paper's findings with previous literature and discusses the lessons derived from the analysis. At last, Section VI concludes.

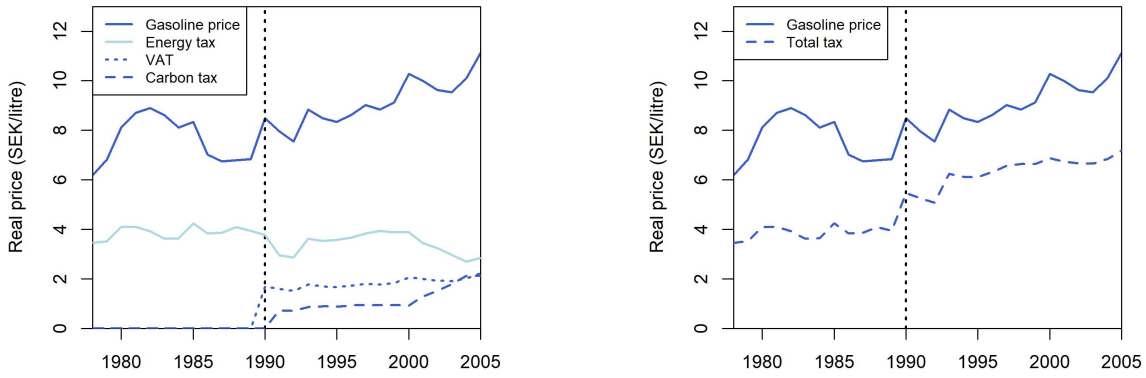
I. The Nordic Fuel Taxation

At the beginning of the 1990s, the governments of most of the Nordic countries imposed new taxes on fossil fuels. In 1990, Finland was the first nation to establish a carbon tax, with a relatively low rate of less than 2 USD per ton of CO_2. Sweden and Norway followed along in 1991 with nominal carbon tax rates of 41 and 42 USD per ton of CO_2, respectively. Denmark also implemented a carbon tax starting in 1992 with a nominal tax rate of 16 USD per ton of CO_2 (Haugland, 1993). Nevertheless, the Dannish carbon tax did not cover the transport sector.[1] Apart from the Finnish case, there were many economic sectors exempted from these new taxes, or subject to lower rates. This was the case for several energy–intensive industries that could suffer a competitive disadvantage if charged the whole rate. As a result, effective carbon taxes for some of these economies were below 50 percent of the nominal rate initially (Vehmas, 2005, Bruvoll and Dalen, 2009, Haugland, 1993). However, the transport sector was covered with full rates in Sweden, Norway and Finland. Equally, transport made up 40.4, 39 and 22.5 percent, respectively, of emissions from fossil fuel combustion in these countries as of 1989 (World Bank, 2020). Therefore, the transport sectors of Sweden, Norway and Finland are a proper study case of the effect of carbon taxes on CO_2 emissions.

Retail prices of fossil fuels consists of the tax–exclusive price p_t, the carbon tax τ_{t,CO_2}, other excise taxes $\tau_{t,excise}$ and the value added tax.[2]

$$p_t^* = (p_t + \tau_{t,excise} + \tau_{t,CO_2})VAT_t \tag{1}$$

Figures 1 to 3 show the real (inflation–adjusted) price components structure of gasoline for Sweden, Norway and Finland from 1978 to 2005. In Panel A of each figure, the tax component is disaggregated in the different taxes mentioned above, while Panel B shows the aggregated tax component together with the total price. The beginning of the treatment, as define by the quasi–experimental setting of this paper, is marked by vertical dashed lines. As can be observed, what this study considers the treatment is a series of fuel taxation reforms that (1) introduce a carbon tax and (2) significantly increase other taxes on transport fuels, both in absolute terms and as a proportion of the total price.



Panel A. Tax components

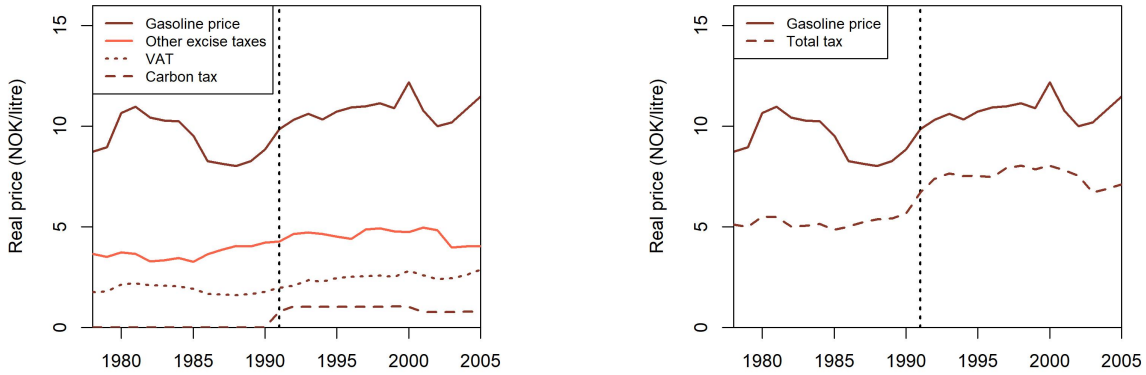
Panel B. Total tax

Figure 1: Gasoline price components in Sweden 1978–2005

Source: Andersson (2019)

[1] This is the reason for not including Denmark in this study and why it is still suitable to be considered an untreated country.

[2] Sweden has an energy tax levied on gasoline and diesel since 1924 and 1937, respectively (Speck, 2008). Norway introduced duties on gasoline and diesel since 1933 and 1993 (IEA, 2019b). Finland introduced its environmental tax in 1990, which was added to the excise taxes on road sector fossil fuels and to a small precautionary stock fee. For leaded gasoline, the carbon tax was a component of the environmental damage tax. In my analysis, I consider this tax equivalent to a carbon tax itself, given it is an economic instrument aimed at pricing environmental externalities of fossil fuels. For other road sector fossil fuels, the carbon tax component was part of an energy tax until 1996, when 100 percent of this excise became linked to the carbon content of fuels (IEA, 1999).



Panel A. Tax components

Panel B. Total tax

Figure 2: Gasoline price components in Norway 1978–2005

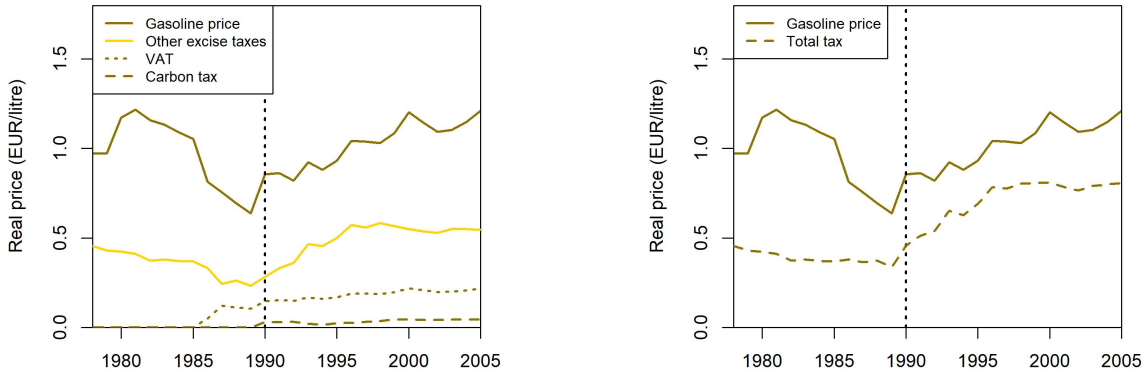
Source: IEA (2019c)

Figure 1 shows the evolution of the price components of gasoline in Sweden. The fuel taxation reform of 1990 in Sweden imposed the value added tax on transport fuels, increasing retail prices by an official rate of 25 percent. This was followed by the introduction of the carbon tax in 1991, adding 0.7 SEK in its first year. Hence, as Andersson (2019), I will consider 1990 the start of the treatment in Sweden. It is worth paying attention to the energy tax component, the other excise duty on transport fuels apart from the carbon tax. The energy tax for gasoline was relatively constant up until the temporary decrease of 1991, that came as a compensation for the introduction of the carbon tax. Equally, the energy tax rate decreased from 2001 to 2005, but simultaneous increases of the carbon tax made the total tax component increase continually, as shown in Panel B. Overall, these changes resulted in an average total tax component of 6.3 SEK during the post–treatment years, an increase of 2.5 SEK with respect to the period 1978–1989. The carbon tax accounted for 1.1 SEK, or 44 percent, of that average increase.

Norway imposed its carbon tax in 1991 (see Figure 2), with an initial value of 0.8 NOK per liter, or 8 percent of the total price for that year. Other excise taxes were stable throughout most of the period, with a slightly upward trend starting in 1985 and a drop of 17 percent in 2003. At the same time, the value added tax of Norway was at a 20 percent rate until 1993. Then, gradual increases took the VAT to a rate of 25 percent in 2005. On average, taxes accounted for 69.6 percent of the retail price of gasoline since the imposition of the carbon tax, in comparison with just 56.6 percent from 1978 to 1990. 8 out of those 13 percentage points increase belong to the carbon tax. Hence, the Norwegian carbon tax carried most of the tax level increase, even though prices after the treatment were just 15 percent higher than for the previous 13 years, on average. At the same time, gasoline taxes in Norway did not follow an upward trend for the whole period, but reached a maximum of 8 NOK per liter in 2000.

Total taxes per liter of gasoline in Finland kept a slightly downward path in the pre–treatment years (see Figure 3), following decreases of the net price. This was despite the VAT coverage of gasoline starting in 1986, as it was compensated by reductions in the excise tax. In 1990, environmental taxes were imposed in transport fuels, at a modest rate of 0.03 euros per liter of gasoline. That same year, excise taxes were raised 21 percent to 0.28 euros per liter, and continued being raised till the mid nineties, fluctuating in the 0.5 to 0.59 window in the remaining time. Overall, the total tax rate charged per liter of gasoline was of 0.71 euros in the average post–treatment year, raising from 0.39 euros in the pre–treatment period. In relative terms, taxes accounted for 41 percent of the total gasoline price in the 1978–1989 period, in comparison to almost 70 percent since 1990. Nevertheless, only 3.2 percent of the price belonged to the carbon tax from 1990 to 2005. In comparison, carbon taxes in Sweden and Norway represented on average 12.5 percent and 8.6 percent, respectively, of the total price of gasoline from 1991 to 2005.

Figure 4 shows consumption patterns in the period 1960–2005, consistent with an apparent sub-

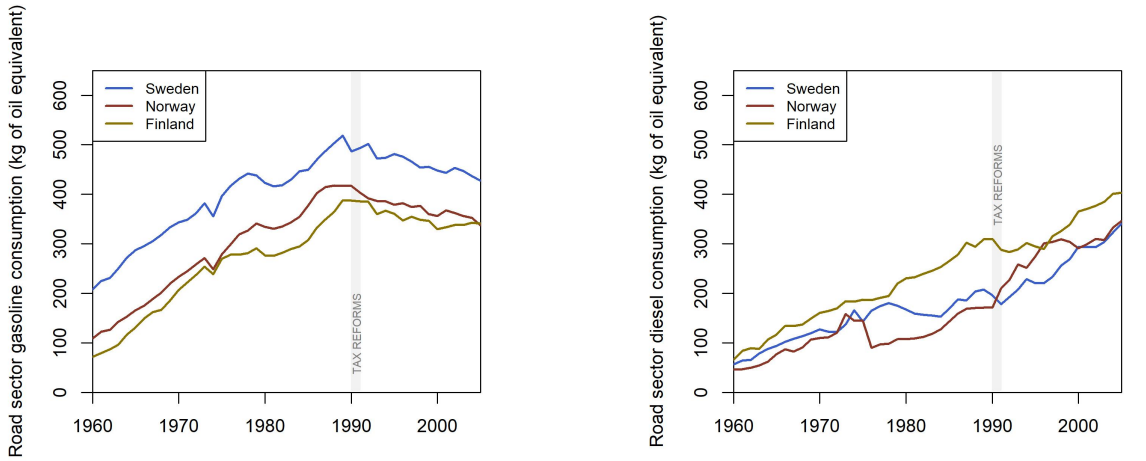


Panel A. Tax components

Panel B. Total tax

Figure 3: Gasoline price components in Finland 1978–2005

Source: IEA (2019c)



Panel A. Gasoline

Panel B. Diesel

Figure 4: Road sector fuel consumption per capita 1960–2005

Source: World Bank (2020)

stitution of gasoline consumption by diesel, a fuel more energy–efficient and with a lower carbon content.

The analysis in the following sections will depend on the premise that carbon tax increases are passed through to consumers at the fuel pump. This will result in demand adjustments and potential fuel combustion decreases. Additionally, if the carbon tax is fully assumed by consumers, we can consider estimated tax elasticities as the demand elasticity to tax rates fluctuations. Previous literature has found US gasoline excise taxes are fully borne by consumers (e.g. Marion and Muehlegger (2011), Marion and Muehlegger (2011), Li et al. (2014)). Equally, Andersson (2019) found excise taxes in Sweden have an incidence statistically indistinguishable from 1, both when the energy and carbon taxes are aggregated or when included separately in the equation. Using first differences, I regress the nominal price of gasoline p_t^* during year t on its excise taxes (including the carbon tax) τ_t and crude oil prices θ_t.

$$\Delta p_t^* = \alpha_0 + \alpha_1 \Delta\theta_t + \alpha_2 \Delta\tau_t + \varepsilon_t \tag{2}$$

In line with previous studies, I find consumers in Finland fully bear the costs of gasoline excise taxes. The point estimate of the tax incidence coefficient, α_2 is 1.15 and is statistically indifferent from 1 (with 95 percent confidence interval [0.78,1.51]). This result is robust to the separation of the carbon tax from the other excise taxes. Estimates of tax incidence are in this case 1.57 for the carbon tax, and 1.14 for the other excise taxes, both statistically indistinguishable from 1. In the case of Norway, I find aggregated excise taxes to have an incidence of 0.6. This point estimate is still statistically indifferent from 1 (with a 95 percent confidence interval [0.11,1.12]). However, the specification with separate tax components reveals the excise taxes on gasoline (apart from the carbon tax) may not be borne by Norwegian consumers, with a point estimate of 0.23 statistically insignificant. Carbon tax estimated incidence in Norway is still indistinguishable from 1 (with an estimate of 1.73 and confidence interval [0.83,2.63]). In conclusion, these results difficult the estimation of demand sensitivity to fuel tax changes in Norway through elasticity estimations.

II. Empirical Methodology

A. Data

My empirical analysis is based on panel data from 25 OECD countries from 1960 to 2005.[3] I define CO_2 per capita emissions of transport as the outcome variable, measured in metric tons. Source of the data is the IEA (2019a) and emissions are computed as the equivalent combustion of transport fuels sold in the country. This data covers therefore transport by road, rail, domestic navigation and domestic aviation, leaving out international aviation and international marine bunkers. Fluctuations of CO_2 emissions from fuel combustion capture aggregated substitution effects between modes of transport, as well as substitution between fuels with different carbon content (mainly gasoline and diesel).

As Andersson (2019), I define 2005 as the end of my sample period because that year marked the beginning of the Emissions Trading Scheme (ETS) of the European Union. Equally, many countries implemented new carbon taxes of fuel taxation reforms from 2005. Hence, this sample leaves us with 30 years of pre–treatment data and 16 years of treated observations (with the exception of Norway, where treatment starts one year after).

Following Andersson (2019), I filter the original sample of 25 countries of countries that implemented significant changes in fuel taxation along the period of interest. This means none of my treated countries appears in the pool of donors of the others. Equally, this rules out the Netherlands, Germany, Italy, and the United Kingdom. Austria and Luxembourg are also excluded, given their emissions data being inflated by "fuel tourism" (Sterner, 2006). Finally, it is also recommended to leave out those countries very dissimilar to the treated unit in the outcome variable, this will reduce the possibility of over–fitting and interpolation bias (Abadie et al., 2015). For this reason, I drop Turkey, which has average per capita emissions way lower than any of the other countries, out of the sample. At the same time, Ireland is kept out of the pool of donors for Synthetic Finland and Sweden, given its extraordinary growth in the post–treatment period. Ireland's GDP per capita grew 142 percent in these years (Feenstra et al., 2015), more than any other country in the sample. Nevertheless, Ireland is kept in the donor pool of Norway, which grew by 90 percent in per capita terms during the same period. Therefore, the final pool of donors includes Australia, Belgium, Canada, Denmark, France, Greece, Iceland, Japan, New Zealand, Poland Portugal, Spain, Switzerland, and the United States, with the addition of Ireland for Synthetic Norway.

B. The Synthetic Control Method

The Difference–in–Difference (DiD) estimator is a common method used in comparative studies. An unweighted average from a control group is used as a counterfactual in this identification strategy. Hence, emissions reduction from a treatment (e.g. a carbon tax) are estimated by the differences of the change in the outcome variable in the post–treatment period, for the treated and the control group. This empirical strategy has the advantage of eliminating the unmeasurable effects of unobserved covariates on the outcome variable, under the assumption of these effects being constant over time. Additionally, a DiD approach needs to assume that any economic shock or time trends are common to the treated and the control group. These two assumption form the typically known as "parallel trends assumption". In the case at hand, this assumption implies Sweden, Norway, Finland, and the

[3]The sample contains the 24 members of the OECD in 1990 and Poland, that joined the organization in 1996.

average of their control groups would have followed parallel paths in emissions if their respective fuel tax reforms had not been implemented. Unfortunately, the parallel trends assumption is hard to verify pre–treatment and impossible post–treatment, for obvious reasons. This comes as a caveat of the DiD method, as its estimations will be biased if treated and control units do not follow a common trend. Therefore, comparative studies should explore methods that may overcome this limitation of the DiD strategy. The synthetic control method allows the effects of unobserved covariates on the outcome to vary over time. This is done by weighting the control group in such a manner that, prior to treatment, follows a similar path of emissions and resembles the treated unit (namely, Sweden, Finland or Norway) on a set of predictors of CO_2 emissions of the transport sector. Hence, the synthetic unit strategy overcomes some of the limitations of the DiD estimator by relaxing the parallel trends assumption.

For a single synthetic control strategy we have a sample comprised of countries $j = 1, ..., J + 1$ and years $t = 1, ..., T$, where the first unit ($j = 1$) is the only one exposed to the treatment (namely, the carbon tax reform) and the remaining J countries form the sample that can contribute to the synthetic control, what we call the donor pool. The treatment happens at time $T_0 + 1$, so that the sample is divided in the pre–treatment $1, 2, ..., T_0$ and post–treatment $T_0 + 1, ..., T$ periods, both of which need to be large enough to evaluate the pre–treatment goodness of fit and the posterior intervention effect. Given that, Synthetic Sweden, Norway and Finland consist of a weighted average of countries $j = 2, ..., J + 1$ with weights in the vector $W = (w_2, ..., w_{J+1})$ where $w_j \geq 0$ and $w_2 + ... + w_{J+1} = 1$. Each W available represents, therefore, a synthetic control candidate. W is chosen so that the difference between the control and the treated unit for a vector of emissions predictors U_i is minimized. These predictors can be either some measures of emission drivers (e.g. GDP per capita or fuel sales) or some linear combination of pre–treatment observations of the outcome variable (Abadie et al., 2011). I choose as predictors a set of variables that are widely accepted (Andersson, 2019; Neumayer, 2004) as determinants of CO_2 emissions: GDP per capita, number of motor vehicles, gasoline consumption per capita, and percentage of urban population.[4] The average of each of these predictors for the ten last pre–treatment periods is used to measure the distance the treated country an its synthetic counterfactual. I also add lagged observations of the outcome variable for the last pre–treatment period, for 1980 and 1970. These are considered "special predictors" introduced to account for unobserved drivers of the outcome variable (Abadie et al., 2011). Weights are assigned to predictors, so that those with more predictive power have higher weights. Several methods can be used to construct the diagonal matrix of predictor weights, V. For example, setting it based on previous empirical findings on the relationship between the the emission predictors and the outcome variable. Nevertheless, I let V (and in response to it, W) be determined so that mean squared prediction error (MSPE) of the outcome variable over the pre–treatment period is minimized. An accurate tracking of the outcome variable in the pre–treatment period makes more plausible the treated countries and their synthetic counterparts are subject to common time–varying unobserved covariates and trends. The intuition is then that the observed differences in the outcome variable during the post–treatment period must be the result of the treatment.

III. Results

A. Nordics Versus Synthetic Nordics

Tables 1 to 3, contain a comparison of pre–treatment data of each country with both its synthetic unit and the unweighted average of the 'pool of donors'. See the appendix for the complete information regarding the weights assigned to each country and to each key predictor of CO_2 emissions (that is, the elements of matrices W and V, as described in the previous section), I will be mentioning the most important features of these throughout this section.

My version of Synthetic Sweden (see Table 1) coincides with that of Andersson (2019) in its good resemblance of Sweden for most key predictors of CO_2 emissions, with a better fit in almost all the variables than the simple average of the pool of donors. It is specially remarkable how well it resembles its GDP per capita, with just 3 USD of distance. Only in gasoline consumption, the synthetic unit fails to get as close as the simple average. Nevertheless, this is a variable with a low predictive power as its weight of 0.01 in matrix V indicates. Variables with the larger weights are, aside from emission observations themselves, urban population (0.166) and GDP (0.188). Furthermore, it seems this goodness of fit is achieved through a combination of (in order of decreasing weights)

[4]Sources: Feenstra et al. (2015); Dargay et al. (2007); World Bank (2020)

Table 1: CO_2 Emissions from Transport Predictor Means before Tax Reform

	Sweden	Synth. Sweden	OECD Sample
GDP per capita	23470.7	23473.8	21167.1
Urban population	83.1	83.1	76.0
Gasoline consumption per capita	456.2	412.3	425.5
Motor Vehicles (per 1000 people)	405.6	406.7	402.4
CO2 from transport per capita 1989	2.5	2.5	2.4
CO2 from transport per capita 1980	2.0	2.0	2.1
CO2 from transport per capita 1970	1.7	1.7	1.6

Notes: All variables except lagged CO_2 are averaged for the period 1980-1989. GDP per capita is purchasing power parity adjusted and measured in 2005 USD. 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 simple averages of the 14 OECD countries in the donor pool.

Table 2: CO_2 Emissions from Transport Predictor Means before Tax Reform

	Norway	Synth. Norway	OECD Sample
GDP per capita	25445.8	25239.7	21101.5
Urban population	71.4	80.8	74.8
Gasoline consumption per capita	380.8	393.0	416.0
Motor Vehicles (per 1000 people)	420.9	410.7	402.2
CO2 from transport per capita 1989	2.4	2.3	2.3
CO2 from transport per capita 1980	2.1	2.0	2.1
CO2 from transport per capita 1970	1.7	1.7	1.6

Notes: All variables except lagged CO_2 are averaged for the period 1981-1990. GDP per capita is purchasing power parity adjusted and measured in 2005 USD. 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 simple averages of the 15 OECD countries in the donor pool.

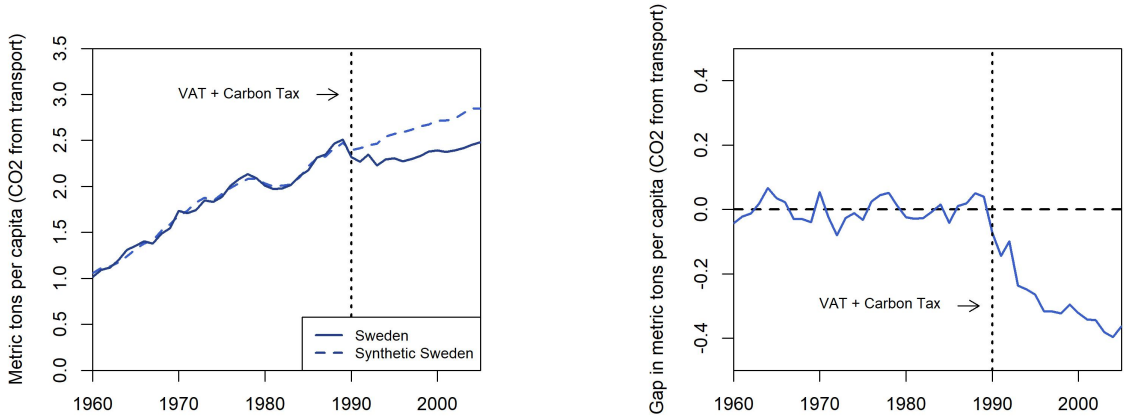
Table 3: CO_2 Emissions from Transport Predictor Means before Tax Reform

	Finland	Synth. Finland	OECD Sample
GDP per capita	21195.0	21339.3	21167.1
Urban population	75.3	86.5	76.0
Gasoline consumption per capita	316.0	318.5	425.5
Motor Vehicles (per 1000 people)	352.5	352.6	402.4
CO2 from transport per capita 1989	2.3	2.2	2.4
CO2 from transport per capita 1980	1.7	1.8	2.1
CO2 from transport per capita 1970	1.3	1.3	1.6

Notes: All variables except lagged CO_2 are averaged for the period 1980-1989. GDP per capita is purchasing power parity adjusted and measured in 2005 USD. 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 simple averages of the 14 OECD countries in the donor pool.

Switzerland, Belgium, Iceland, Portugal, Spain and United States. Switzerland, with 0.368, is the control country with the highest weight, a point where my synthetic unit differs from that of Andersson (2019). Nevertheless, both Sweden and Switzerland had relatively constant and high rates of urban population, and a fleet of motor vehicles per capita remarkably similar throughout the pre–treatment period. Hence, parallels in these two relevant predictors make the presence of Switzerland reasonable. Equally, Belgium and Iceland, with weights of 0.189 and 0.147, share with Sweden similar paths in GDP per capita. In combination, Switzerland, Belgium and Iceland, make more than 70 percent of Synthetic Sweden.

Table 2 summarizes how Norway is far from the unweighted average of the pool of donors in most dimensions. Nevertheless, the goodness of fit of Synthetic Norway improves considerably in almost all the summary statistics. It is particularly remarkable that the synthetic control gets to a differences of only 206 USD in the GDP with respect to Norway, from a sample of countries with an average more than 4 thousand USD below. In the case of Norway, gasoline consumption and GDP per capita are the two observable variables with the most predictive power of CO_2 emissions per capita, with weights



Panel A. Path plot

Panel B. Gap in emissions

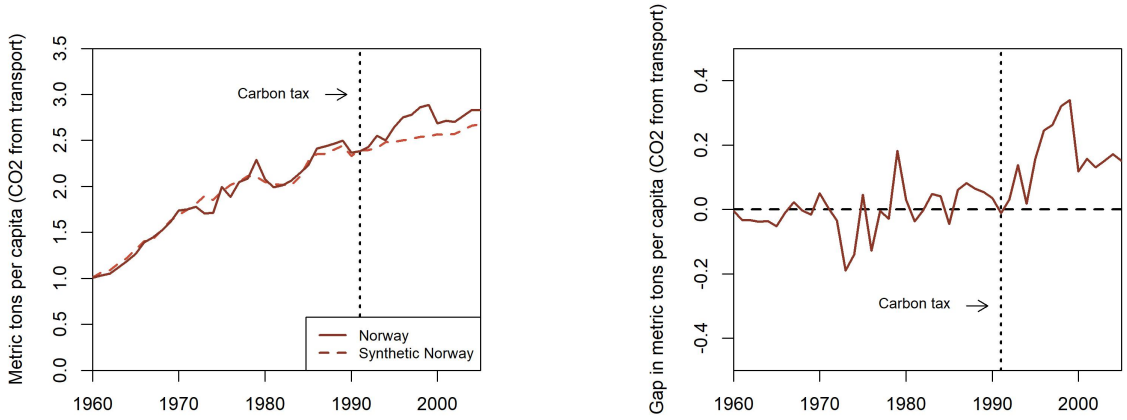
Figure 5: CO_2 emissions from transport per capita during 1960–2005: Sweden versus Synthetic Sweden

equal to 0.364 amd 0.176 respectively. Equally, this synthetic control is constructed by a combination of (in descending order by weight) Switzerland, Denmark, United States, Portugal, France, Canada, New Zealand, Poland and Greece.

Surprisingly, for the case of Synthetic Finland, GDP per capita has a weight of just 0.001. The mechanisms through which economic activity impacts emissions, gasoline consumption (with a weight of 0.202) and the fleet of motor vehicles per capita (0.068), are the observable variables with the most predictive power in this case. As will become apparent in my posterior analysis of possible confounders, Finland shows a higher ratio of emissions to GDP in comparison to its synthetic counterpart, which explains the departure from the OECD sample average in this dimension. Unfortunately, the high weights assigned to the punctual observations of CO_2 emissions (with an aggregated weight of 0.73) point to a larger explanatory power left to unobserved variables, in comparison with Sweden. This is a plausible reason for why the tracking of emissions path of this synthetic unit is not as accurate as that of Synthetic Sweden. The most relevant countries for Synthetic Finland are Belgium and Switzerland, with weights equal to 0.381 and 0.338, respectively. Belgium shares with Finland similar paths in both the size of its fleet of motor vehicles and GDP per capita, while Switzerland is the country with the most similar path in CO_2 emissions to Finland. The remaining 28.1 percent of Synthetic Finland is composed by Spain, Australia, Iceland, United States, Poland, Denmark and France (in descending order by weight). Table 3 presents the summary statistics of the key predicting variables for the Finnish case. In comparison to the unweighted average of OECD countries, Synthetic Finland gets significantly closer to Finland in terms of the most relevant predicting variables, namely, gasoline consumption, the number of motor vehicles and the special predictors (the CO_2 observations).

Figures 5 to 8 display historic data on CO_2 emissions per capita from the transport sectors of Sweden, Norway, Finland, and their respective synthetic controls. Panel A of each figure shows the paths of emissions in levels, while Panel B shows the gap in emissions of each country with respect its counterfactual.

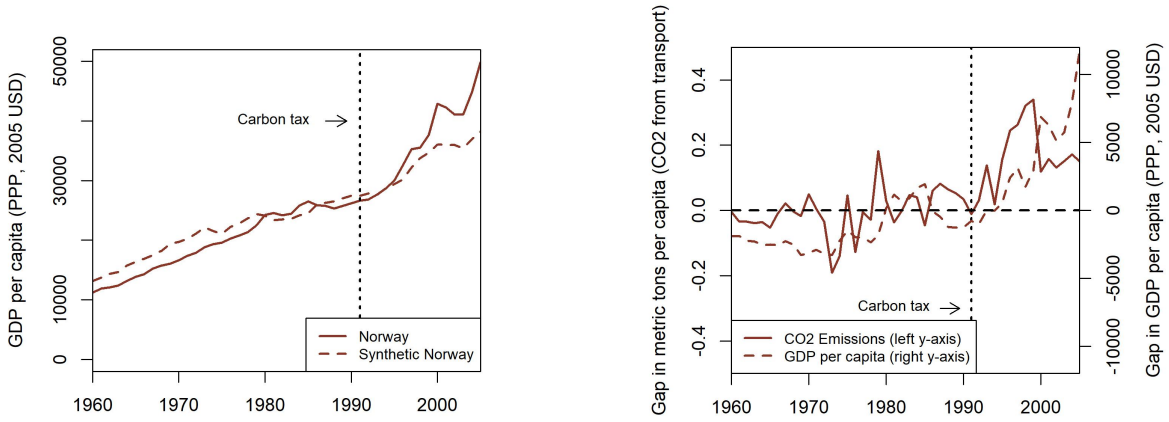
Synthetic Sweden's goodness of fit for the predictor variables translates into a good tracking of the CO_2 emissions of Sweden, as can be seen in Figure 5. Before 1990, the distance in emissions between Sweden and Synthetic Sweden is never larger than 0.081, in absolute value. Equally, the mean squared prediction error (MSPE) for the pre–treatment period is equal to 0.0013. In comparison, a clearly negative gap appeared between Sweden and its synthetic counterpart after the treatment, indicating an effect of the introduction of the VAT and the gradual increases of the carbon tax. By 2005, CO_2 emissions per capita of the transport sector in Sweden are 0.36 metric tons, or a 12.8 percent, below the counterfactual. The average yearly reduction in emissions for the whole post treatment period is equal to 0.28 metric tons, equivalent to 10.6 percent of the control scenario. Aggregating for the total population, this sums up to a reduction of 3.28 million tons of CO_2 in 2005, and 2.48 million



Panel A. Path plot

Panel B. Gap in emissions

Figure 6: CO_2 emissions from transport per capita during 1960–2005: Norway versus Synthetic Norway



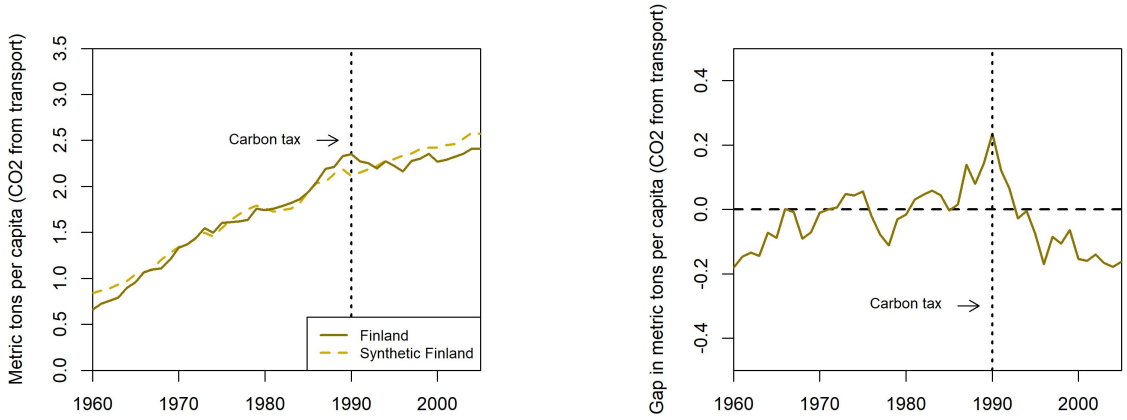
Panel A. Path plot

Panel B. Gap plot

Figure 7: GDP per capita during 1960–2005: Norway versus Synthetic Norway

tons in the average post–treatment. The total estimated emission reduction for Sweden in the period 1990–2005 is of 39.68 million tons of CO_2.

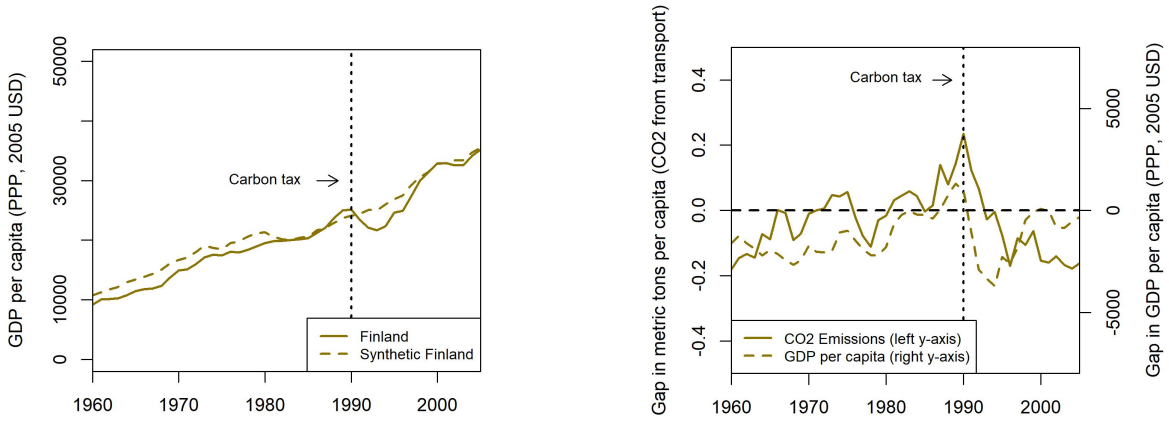
Figure 6 compares the evolution of Norway with Synthetic Norway. The counterfactual tracks well the path of emissions, with punctual deviation coinciding with the oil crises of 1973–1974, when crude oil still accounted for less than 1 percent of the total value of Norwegian exports, and 1979, when crude oil accounted for 20 percent (Statistics Norway, 2020). Overall, the pre–treatment MSPE of Synthetic Norway is equal to 0.0048. Nevertheless, the most remarkable feature of this graph is the clearly positive post–treatment gap in emissions. On the average year during the period 1992–2005, Norway emits 0.16 metric tons of CO_2 per capita more than Synthetic Norway, an extra 6.3 percent. Obviously, to interpret this as the effect of the tax reforms incurred throughout the treatment period defies any economic intuition. Hence, an analysis of possible confounders reveals that there is a divergence in trends between Norway and most OECD members, including those in the pool of donors for Synthetic Norway. As can be seen in Figure 7, Norway experienced an extraordinary growth during the 15 years following the carbon tax imposition. While during 1960 to 1990 the GDP per capita of Norway was on average 8 percent below that of Synthetic Norway, from 1991 to 2005, Norway had a mean GDP per capita 10 percent higher. By 2005, this difference was of 31



Panel A. Path plot

Panel B. Gap in emissions

Figure 8: CO_2 emissions from transport per capita during 1960–2005: Finland versus Synthetic Finland



Panel A. Path plot

Panel B. Gap plot

Figure 9: GDP per capita during 1960–2005: Finland versus Synthetic Finland

percent. This exceptional growth was driven mainly by the oil industry exploiting the recent findings of large reserves of oil (see e.g., Larsen, 2005, Jiménez-Rodríguez and Sánchez, 2005), an event of which carbon taxes have no causal effect, obviously. Norway's real GDP per capita grew 90 percent in the post–treatment period, while no country in its economic environment with a similar starting point got even close to that pace of growth. This is an idiosyncratic economic shock difficult to account for within the framework of this paper. Unfortunately, sensitive adjustments to the sample and/or set of key predictor can not solve for the biases of this gap in GDP per capita between Norway and the attempted synthetic controls. Nevertheless, this finding underlines the risk of bias on quasi–experimental estimations with countries as a unit of analysis, and raises caution in the interpretation of previous findings using DiD strategies (see Lin and Li, 2011).

Figure 8 compares the paths in CO_2 emissions of the transport sector of Finland and Synthetic Finland. The MSPE of this counterfactual for the period 1960–1990 is 0.0067. Therefore, the pre–treatment fit in this case is not as precise as for the previous two countries. This is driven mostly by deviations at the beginning of the sample and around 1990. By design, Synthetic Finland prioritizes resembling Finland in the observations closer to the treatment than those before. Notice that the distance in terms of the predictor variables is measured from the average of the 10 years previous to

the treatment. Besides, the observations of the CO_2 emissions themselves are for years 1970, 1980 and 1989. Additionally, the specially marked boom and bust cycle experienced by Finland around the early 1990's recession make for a temporary confounder in our analysis (Honkapohja and Koskela, 1999). As can be seen in Figure 9, Finland grows vigorously between 1985 and 1989, a total 22.7 percent within 4 years. Equally, the economy suffers a marked recession from 1990 to 1993, with a decrease in the real GDP per capita of 13.8 percent. In comparison, the swings of most developed countries were not as marked, and the GDP of Synthetic Finland follows a modest path of growth throughout this time. Even though this divergence adds noise to the counterfactual, there is reasons to consider this a temporal confounder rather than a permanent one. Firstly, the GDP per capita of Finland comes back to be slightly below the control soon after the depression. Already in 1995, Finland is just 8.5 percent below Synthetic Finland, as in the average pre–treatment year. Secondly, the average post–treatment difference in GDP per capita is just -4.6 percent, so the risk of a downward bias stemming from this recession is small, assuming emissions react to economic activity with small delay. In summary, albeit being a less accurate counterfactual than the reference for this thesis, Synthetic Sweden, the control unit for Finland should still be precise enough for this study purposes.

On an average post–treatment year, the estimated effect of the Finnish fuel taxation is a reduction of 0.07 metric tons of CO_2 per capita, equivalent to a 2.8 percent decrease from the counterfactual. Looking at the final period starting in 1996, when real fuel taxation reached a plateau (around 0.80 euros per liter for gasoline), CO_2 emissions were 5.7 percent, or 0.14 metric tons, below the control unit on average. The absolute reduction in emissions for the aggregate of the Finnish population in those last 10 years would be 7.2 million metric tons of CO_2. Nevertheless, this estimate would be just 5.6 millions if the first 6 years of treatment were included, given the mentioned positive gap opened around 1990.

The size of the estimated effects of the tax reforms in Finland is relatively small, even for the years where the gap with respect to Synthetic Finland is larger and the confounding effect of GDP divergences less plausible. From 1996 to 2005 the size of the estimated treatment effects is still 3 times smaller than for Sweden. In the next subsection I will further explore the validity of this estimates by performing several placebo tests. Therefore, for the remaining of this section the analysis will be focused on the study case of Finland, taking the case Sweden as a comparative reference.

B. Placebo Tests

To further test the significance of the estimates for Finland, I perform a set of placebo tests, namely, "in–time", "in–space" and "leave–one–out". The in–time test assigns the treatment to a period free of the environmental taxation, in my case 1980–1990. In consequence, the synthetic control is constructed from data of the period 1960–1979. The aim of this test is to compare the size of the placebo effect to the actual treatment effect. The rationale is that if these two are similar in magnitude, we cannot rule out that the effects represented in Figure 8 could be found by chance. Figure 10 shows that there is actually a divergence in the path of emissions after the fake treatment. The effect of the placebo treatment on an average year is 0.24 tons of CO_2 per capita. The post–treatment MSPE is 0.0257 and its ratio with respect to the pre–treatment MSPE is 29. All of this indicators are larger for the placebo treatment than for the actual treatment. Nevertheless, these could be exaggerated by the unusual growth in GDP per capita of the late eighties, as mentioned in the previous subsection. Hence, the remaining placebo tests can help to reach a definitive conclusion.

The in–space placebo test constructs a synthetic control for each of the countries in the pool of donors with the same specifications used for Finland. Again, comparing these placebo effects to the estimates for Finland can give an idea of how significant the effects of the fuel taxation were.

Panel A of Figure 11 compares the gap in emissions for ten countries with pre–treatment mean squared predicted errors (MSPE) less than 4 times those of Finland. Finland presents a sustained negative gap unlike most of the other countries. This is clearly represented in Panel A of Figure 13, that displays the average post–treatment gaps. Panel B of that same figure compares the ratio of MSPE before and after the treatment, a measure of how significant the treatment effect may be in comparison to pre–treatment noise. The higher the ratio, the more significant the treatment effect. According to this measure, Finland is on the bottom half in terms of treatment significance. Furthermore, the filter in the countries considered for this test can be relaxed, including countries with up to 20 times the pre–treatment MSPE of Finland (as Andersson, 2019 did). This makes all of the control countries, with the exception of the US, to make it into the comparisons. Panel B in Figure 11 represents the gap in emissions of each of these countries with their respective synthetic

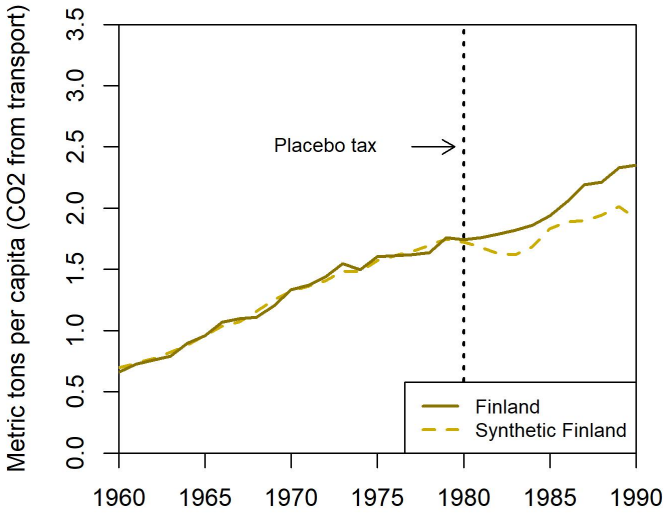
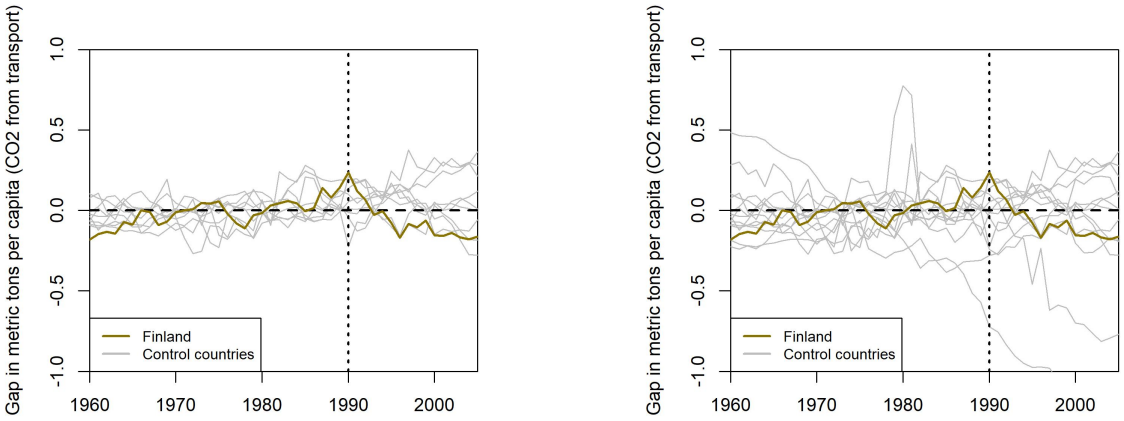


Figure 10: Placebo in–time test

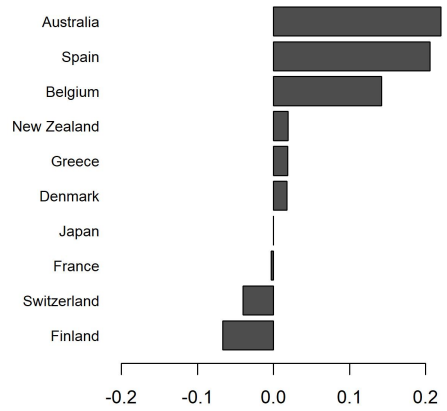


Panel A Panel B

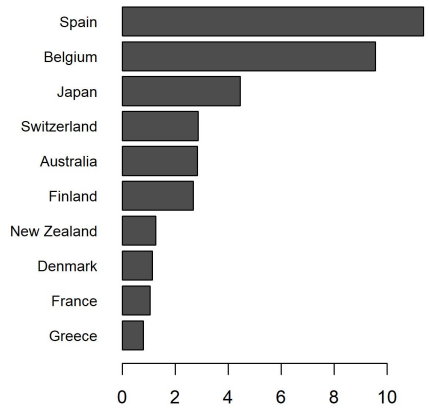
Figure 11: Permutation test: Per capita CO_2 emissions gap in Finland and placebo gaps for the control countries

Notes: Panel A shows per capita CO_2 emissions gap in Finland and placebo gaps in nine OECD control countries (those with a pre–treatment MSPE less than 4 times that of Finland). Panel B shows per capita CO_2 emissions gap in Finland and placebo gaps in thirteen OECD control countries (those with a pre–treatment MSPE less than 20 times that of Finland).

controls. Finland is not clearly among the countries with the most negative post–treatment gaps, anymore. Finally, Figure 15 compares once again the average treatment effect and the ratio of pre and post treatment MSPE. This time the graphs include thirteen control countries plus Finland and Sweden. There is two untreated countries, Iceland and Poland, with a larger mean negative effect and a greater MSPE ratio than Finland. Moreover, Finland is still in the lower half of the countries in terms of the ratio of post–treatment to pre–treatment MSPE. In conclusion, the estimated effects on CO_2 emissions of the increases in transport fuel taxation throughout the 1990–2005 period in Finland are insignificantly different from the estimated effects observed in an untreated country.



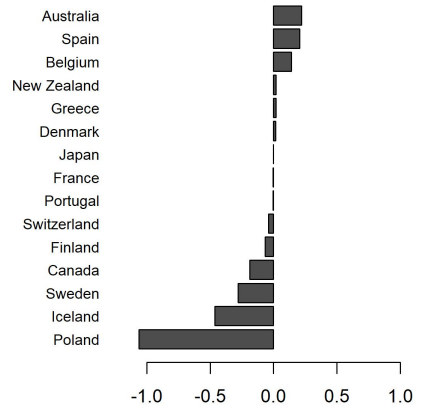
Panel A. Mean predicted error



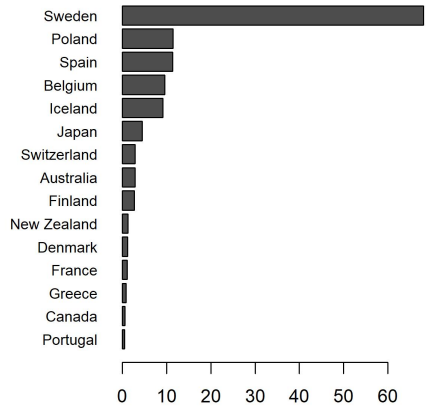
Panel B. Post–treatment/Pre–treatment MSPE

Figure 13: Post–treatment mean gap in per capita CO_2 emissions and ratio of post–treatment MSPE to pre–treatment MSPE

Notes: Panel A shows the mean post–treatment gap in CO_2 emissions between each country and its synthetic control unit for Finland and other nine OECD control countries (those with a pre–treatment MSPE less than 4 times that of Finland). Panel B shows the ratios of post–treatment MSPE to pre–treatment MSPE.



Panel A. Mean predicted error



Panel B. Post–treatment/Pre–treatment MSPE

Figure 15: Post–treatment mean gap in per capita CO_2 emissions and ratio of post–treatment MSPE to pre–treatment MSPE

Notes: Panel A shows the mean post–treatment gap in CO_2 emissions between each country and its synthetic control unit for Finland, other thirteen OECD control countries (those with a pre–treatment MSPE less than 20 times that of Finland) and Sweden. Panel B shows the ratios of post–treatment MSPE to pre–treatment MSPE.

For the final robustness check, the "leave–one–out" test (Abadie et al., 2015), I iteratively leave one country out of the pool of donors to construct different versions of Synthetic Finland. Comparing these counterfactuals to the original Synthetic Finland can help to discern if my estimates are heavily driven by the inclusion of any single country in the control group. There is six countries with a weight in Synthetic Finland equal to or larger than 0.001. Hence, for this test I construct six new versions of Synthetic Finland, leaving one of these countries out each time. Conclusively, the results do not change significantly for any of these alternative counterfactuals.[5] If anything, leaving these countries out of the sample reduce the magnitude of the estimated reduction in carbon emissions.

[5]See Figure 19 in the Appendix.

IV. Carbon Tax Demand Elasticity

Despite a large and sustained increase in the Finnish taxation of fuels, its estimated impact on CO_2 emissions is insignificant. This contrasts with the study case of Sweden, where estimates point to a reduction of carbon emissions of more than 10 percent in the 1990–2005 period. This is surprising given the total tax rate for gasoline, for example, was greater in Finland than in Sweden for most years after 1995 (IEA, 2019c). Nevertheless, there is a major difference between the tax reforms of these two countries: the relative weight of the carbon tax. The initial carbon tax rate per ton of CO_2 in Finland was below 2 USD and showed little growth in the considered period, meanwhile, the initial nominal rate in Sweden was 41 USD and was increased to over a 100 USD by 2005. As a result, on the average post–treatment year only 3.2 percent of the retail price of gasoline belonged to the carbon tax in Finland, in comparison to 12.5 percent in Sweden.

There is now numerous studies pointing to a larger behavioral response to gasoline taxes, and particularly carbon taxes, than to other price shocks (Davis and Kilian, 2011; Li et al., 2014; Rivers and Schaufele, 2015; Antweiler and Gulati, 2016). At the same time, Andersson (2019) found the carbon tax elasticity of gasoline demand was three times higher than for other price drivers, and propose this as a possible explanation of the large effect of the Swedish tax reform. Hence, as a complementary analysis, I'll test the consistency of my estimates for Finland and this hypothesis. With that aim, I use annual data of the consumption and real price of gasoline for 1978–2011. I divide the retail price of gasoline, measured in euros per liter, into its carbon–tax–exclusive component, $p_t^v = (p_t + \tau_{t,excise})VAT_t$, and the carbon tax, $\tau_{t,CO_2}^v = (\tau_{t,CO_2})VAT_t$. Then, I estimate the parameters of the following log–linear model:

$$ln(x_t) = \alpha + \beta_1 p_t^v + \beta_2 \tau_{t,CO_2}^v + \beta_3 D_{t,CO_2} + X_t\gamma + \varepsilon_t, \tag{3}$$

where x_t is gasoline consumption per capita; D_{t,CO_2} is a binary variable that takes value 1 for the post–treatment years (1991–2005) and zero otherwise; X_t is a vector of controls (GDP per capita, urbanization, unemployment rate, and a time trend), and ε_t is a random error term.

According to the estimates from the OLS estimation of this log–linear model, presented in columns 1 to 4 of Table 4, the carbon tax elasticity is about 3.8–6.8 times the size of the (other components) price elasticity. This difference is statistically significant across all the specifications. The estimated coefficients through a log–linear model are commonly referred to as semi–elasticities. In consequence, taking the estimates of column 4 as a reference, we see that a 1 euro cent (0.01 units) change in the carbon tax component is associated with changes in gasoline consumption of 2 percent. Meanwhile, an equivalent change in the carbon–tax–exclusive component is associated with changes of just 0.3 percent.

These estimates are subject to bias concerns because of the endogeneity of gasoline prices or anticipatory behavior. Intuitively, endogeneity is less of a concern in a small economy as Finland, as crude oil prices are determined in global markets and the impact of Finland in the world prices is negligible. Nevertheless, local providers of transport fuel, at the retail and refinery level, could adjust their profit margin as a response to local demand changes and therefore affect the final gasoline price. With the aim of addressing this potential source of bias, I use crude oil prices as an instrument for the carbon–tax–exclusive price component. The result of this IV regression is presented in column 5 of Table 4. Estimates in columns 4 and 5 are remarkably similar. Besides, the Durbin–Wu–Hausman test indicates the carbon–tax–exclusive price component is exogenous in fact. Furthermore, the Stock and Yogo (2002) for weak instruments indicates crude oil price is a strong instrument.

Anticipatory behavior (e.g. consumers purchasing oil before a tax change) has also been considered a potential source of bias (Coglianese et al., 2017). Nevertheless, the inclusion of leads and lags had little influence in my estimates for demand elasticities.

The tax incidence analysis of Section I estimated tax changes are fully borne by consumers, hence our estimated elasticities can be seen as demand elasticities. The results in column 4 of Table 4 imply a price elasticity of demand of -0.31 and a carbon tax elasticity of demand equal to -2.09.[6] Hence, the estimated demand elasticity to carbon tax changes is 6.7 times the elasticity to other price changes.

[6]Elasticity of demand is given by $\varepsilon = (dY/dX)(X/Y)$, and our model is log linear: $log(Y) = a + bX$, and thus the elasticity is $\varepsilon = be^{a+bX}(X/Y) = bY(X/Y) = bX$. Here, X is the real price of gasoline at its sample mean: 1.05 euros. The price elasticity of demand is hence given by $-0.294 \times 1.05 \approx -0.31$ and the carbon tax elasticity: $-1.991 \times 1.05 \approx -2.09$.

Table 4: Estimation Results From Gasoline Consumption Regressions

	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) IV
Gas price with vat	-0.511	-0.525	-0.305	-0.294	-0.346
	(0.033)	(0.039)	(0.048)	(0.067)	(0.026)
Carbon tax with vat	-1.939	-2.059	-1.898	-1.991	-1.966
	(0.457)	(0.265)	(0.195)	(0.223)	(0.198)
Dummy carbon tax	0.176	0.193	0.147	0.169	0.173
	(0.036)	(0.041)	(0.014)	(0.027)	(0.026)
Trend	0.002	-0.000	-0.025	-0.018	-0.016
	(0.002)	(0.006)	(0.005)	(0.008)	(0.007)
GDP per capita		0.003	0.012	0.005	0.005
		(0.006)	(0.002)	(0.006)	(0.004)
Urban population			0.046	0.041	0.036
			(0.008)	(0.010)	(0.008)
Unemployment rate				-0.005	-0.005
				(0.004)	(0.003)
Constant	6.217	6.175	2.477	2.988	3.380
	(0.036)	(0.069)	(0.647)	(0.805)	(0.678)
R^2	0.847	0.849	0.917	0.922	0.920
Instrument F-statistic					46.663
Observations	34	34	34	34	34

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 Euros. GDP per capita is measured in 2005 USD. Urban population is measured as percentage of total population. Unemployment is measured as percentage of total labor force. Column (5) uses the brent crude oil price as instrumental variable for the carbon tax-exclusive gasoline price. Newey-West standard errors in parentheses; heteroskedasticity and autocorrelation robust. Standard errors are calculated using 16 lags, chosen with the Newey and West (1994) method.

Source: Data on unemployment was obtained from Federal Reserve Bank of St. Louis (2020).

My estimate of the price demand elasticity is in line with previous studies using yearly data and static models, (Dahl and Sterner, 1991).[7]

Using the estimated carbon tax and price elasticities from column 4, we can use a simulation approach to estimate the impact of the Finnish tax reforms on CO_2 emissions of transport through its influence in gasoline demand. This is a partial estimation of the effect of carbon and excise taxes on emissions, as it does not account for the impacts of these on alternative fuels (mainly diesel) and other long–term adjustments (the model assumes gasoline demand reacts only to contemporaneous shocks). Nevertheless, this approach comprehends the effects on the most prevalent fuel at the time of the treatment, with an agreed upon sign of the effects of fuel taxation.[8]

Figure 17 compares the emission reduction estimated via simulation (red dashed line) with the synthetic strategy gaps for Finland and Sweden. The simulation measures the reduction in emissions with respect an alternative scenario where the carbon tax rate is equal to zero and the excise tax on gasoline is maintained at its 1989 level throughout the post–treatment period. The simulated gap in emissions for Finland has an average value for the 1990–2005 period of -0.10 metric tons of CO_2 per capita, and seems to bound from below the synthetic gap, which has an average value of -0.07. Nevertheless, both estimated gaps in emissions converge towards the end of the treatment period. In 2005, the simulated reduction in CO_2 emissions is 0.19 metric tons, against the 0.16 of the synthetic

[7]The literature review by Dahl and Sterner (1991) considers 22 studies with yearly data and static models, mostly from OECD countries, and finds an average demand elasticity of -0.53. 5 of those studies had estimates just around 0.3.

[8]The impact of fuel taxation on diesel is ambiguous, as substitution effects and correlation in tax rates with gasoline can make diesel tax increases be associated with higher diesel demand (Figure 4 suggests this is the case for Finland). Equally, Dahl (2012) finds more than a quarter of static models estimated positive price elasticities for diesel. Therefore, the simulation estimates here presented are likely an upper bound to the treatment effect (in absolute value).

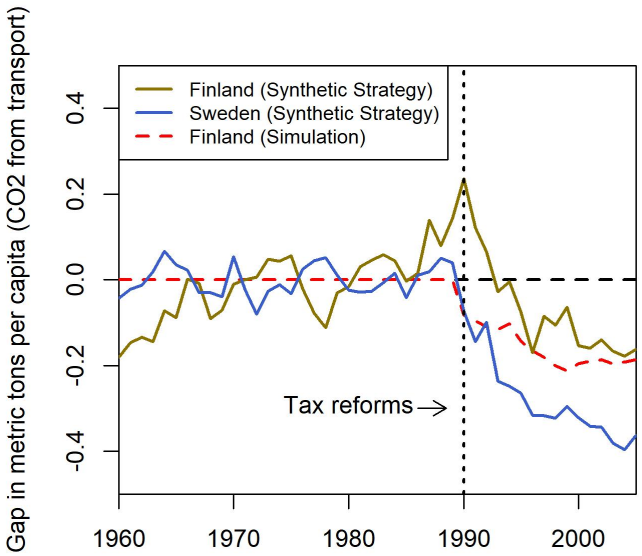


Figure 17: Tax elasticities simulation

Notes: Graph shows per capita CO_2 emissions gap in Finland and Sweden estimated via the synthetic control strategy and the gap for Finland obtained through a simulation based on gasoline demand elasticities.

strategy.

The simulated reduction in emissions is therefore not considerably larger than the one obtained through Synthetic Finland. It still has a lower absolute value than the 1980 placebo treatment effect and some of the in–space placebo effects. The synthetic units for Belgium and Spain, for example, presented lower pre–treatment MSPE than Synthetic Finland and post–treatment placebo effects 40 and 100 percent larger than the simulated gap in emissions. At the same time, This simulated reductions in emissions are roughly half the size of the estimates for Sweden, both through the synthetic strategy and through previous simulations (Andersson, 2019). This does not imply, however, that an effect of the carbon and other fuel tax reforms can be completely ruled out. The demand elasticity simulation estimate points to a modest effect via gasoline demand adjustments. Hence, an improved empirical counterfactual, more precise than the Synthetic Finland here presented, could potentially detect an effect of this size. Nevertheless, the evidence suggests that the considered fuel taxation reforms in Finland achieved reductions in CO_2 emissions per capita from the transport sector of less than 10 percent during the 1990–2005 period.[9]

V. Discussion

My findings for Sweden can be compared to those of Andersson (2019), who also implemented the synthetic control strategy to the study case of Sweden. My results find almost identical carbon emission reductions resulting from the Swedish carbon tax reforms, demonstrating this estimates are robust through a direct replication.

These results contrast with those found by the Swedish Ministry of the Environment and Energy (2009) in the fifth national report on climate change. In this report, the estimated reduction of CO_2 emissions from the transport sector by 2005 is 1.7 million tons, in comparison to a scenario where Sweden had maintained taxes at the 1990 rates. This estimate is obtained through a simulation of gasoline consumption adjustments and is significantly lower than my empirical estimate of 2.48 million tons of CO_2. This remarkable difference can partially be explained by the price elasticity of

[9] 10 percent, or roughly 0.23 metric tons of CO_2 per capita, is the size of the treatment effect needed to be larger than the considered placebos and overcome temporal confounding effects (e.g. the specially strong growth of Finland's economy in the late eighties, which resulted in a positive post–treatment gap in emissions of 10 percent).

demand assumed, -0.8, which is derived from several European studies (Edwards, 2003). Nevertheless, Andersson (2019) found a carbon tax elasticity of -1.57 for Sweden, while I estimated this to be -2.09 for the neighboring Finland. This comparison can illustrate how simulation analyses may underestimate the effectiveness of CO_2 taxation.

An empirical study with similar scope to mine is Lin and Li (2011), which applies a DiD approach to estimate the effects of carbon taxes in Sweden, Norway, Finland, Denmark and the Netherlands. Curiously, the only case they find a significant effect for (at a 10 percent significance level) is Finland, with a 1.7 percent reduction in the CO_2 per capita growth rate. This differs from my results. Out of the two valid synthetic control strategies run, Finland is the one with non–significant estimated effects, in contrast to Sweden. However, Lin and Li (2011) consider control countries with worrying characteristics, namely, Austria, Ireland and Luxembourg (see Section IIA above). They also consider CO_2 emissions of the economy as a whole as their outcome variable, which therefore includes untreated (meaning, not covered by the carbon tax nor subject to excise tax increases) sectors. This contravenes the necessary assumptions for causal inference in a DiD setting and bias the estimates, most probably. Equally, some of the covariates used, like urbanization level, industry structure and energy prices, are influenced by carbon taxes and therefore endogenous. Including this variables as independent variables will likely bias the estimates. Besides, this DiD approach can not account for idiosyncratic confounders that may apply to particular countries and violate the parallel trends assumption. This way, the authors conclude Norway's "carbon tax actually has not realized its mitigation effects", citing the oil drilling and natural gas exploitation sectors as responsible of the CO_2 emissions increase. Nevertheless, the growth of these sectors is determined by the exogenous shock of the relatively recent discovery of large crude oil reserves (Larsen, 2005), a phenomenon that makes the "parallel trends assumptions" unfeasible. Additionally, my attempt to recreate a Synthetic Norway indicates the spillovers of the crude oil and gas sectors affected the GDP as a whole and parallel trends are likely unfeasible even for sectors outside the fossil fuels extraction, like transport (see Figure 7 for a graphical illustration).

Apart from the empirical estimate of a non–significant effect of the Finnish fuel taxation reforms, this study presents evidence of a larger gasoline consumption response to carbon tax changes than to equivalent carbon–tax–exclusive price adjustments. This result is consistent with the literature on carbon and road fuel taxes (Davis and Kilian, 2011; Li et al., 2014; Rivers and Schaufele, 2015; Antweiler and Gulati, 2016). This is, however, the first study to analyze the gasoline market of Finland in this regard, and offers a first comparative reference to the estimate of Andersson (2019) for the neighboring Sweden, the only other estimate for a European country. Nevertheless, the estimated carbon tax elasticity for Finland should be taken carefully in terms of its external validity. One of the more plausible reasons behind this larger behavioral effect is tax changes are associated with a more prominent media coverage and public awareness than equivalent crude oil shocks, for example (Li et al., 2014). Therefore, a small carbon tax, like the one imposed in Finland, likely has a high ratio of media coverage per monetary value. This means, on average, an increase of 0.01 euros in the Finnish carbon tax is associated with several times the media coverage a 0.01 euros increase in the carbon–tax–exclusive component. This may be the reason in Finland the carbon tax elasticity of demand for gasoline is 6.7 times larger than the carbon–tax–exclusive price elasticity during the 1978–2011 period. Given that, a carbon tax elasticity of -2.09 is unlikely to remain consistent for larger tax rates. Nevertheless, Sweden, currently the country with the highest carbon tax per ton of CO_2, has shown a carbon tax elasticity of -1.57. Hence, evidence points there is still room for Finland, and similar countries, to effectively increase their carbon taxation on transport fuel. At the same time, this indicates the effects of the Finnish fuel taxation reforms could have been significantly larger if the carbon tax component had been the main driver of fuel tax increases.

VI. Conclusion

Via the Paris Agreement, national governments have taken a stance in favor of addressing the shared challenge of addressing climate change. With the aim of meeting the emission reduction objectives announced by each member of the deal, it is key to rely on effective economic instruments.

This study empirically estimates the CO_2 emissions reduction of tax reforms that imposed carbon taxes on transport fuels for two countries: Sweden and Finland. The identification approach implemented is the synthetic strategy, which carefully constructs a control unit that resembles the pre–treatment paths of emissions of the treated countries through a weighted average of untreated countries in their economic environment.

Through the imposition of a carbon tax and the coverage of the transport fuels by the VAT, Sweden reduced its yearly emissions by 10.6 percent on average. At the same time, Finland imposed its own environmental taxation and continuously increased the excise taxes on transport fuels. Nevertheless, the causal effects I found for this policy were not significant. Through a secondary analysis, I find differences in the size of carbon taxes might be a plausible reason for the contrasting results of these two series of tax reforms. In Finland, gasoline consumption, arguably the main channel through which fuel taxation impacts carbon emissions of the transport sector, shows a sensitivity to carbon tax changes 6.7 times greater than to equivalent carbon–tax–exclusive price adjustments. However, throughout the considered treatment period, 1990–2005, only 3.2 percent of gasoline prices belonged to the environmental tax. This relatively high carbon tax elasticity of demand for gasoline has been shown to also apply to Sweden (Andersson, 2019), which sat a carbon tax rate that made 12.5 of the gasoline price on average. Therefore, my findings suggest carbon taxes would be more efficient than other fiscal instruments to curb CO_2 emissions from the transport sector. At the same time, this evidence points to a potential underestimation of carbon tax effects by previous studies, which generally used regular elasticities of gasoline demand for their simulation approaches.

Additionally, this paper presents an attempt to apply the synthetic control strategy to Norway, which also implemented its own carbon tax reform in 1991. However, the extraordinary growth of the country during the 1991–2005 period makes for an idiosyncratic economic phenomenon that bias the estimates and renders the synthetic control method unfit for the task. However, this exercise sets light on the identification issues of previous empirical studies with Norway as a study case. Mainly, the violation of the parallel trends assumption needed for Difference–in–Difference approaches.

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Appendix

Table 5: Country weights in Synthetic Sweden

Australia	0.000	Greece	0.000
Belgium	0.189	Iceland	0.147
Canada	0.000	Japan	0.000
Switzerland	0.368	New Zealand	0.000
Denmark	0.000	Poland	0.000
Spain	0.091	Portugal	0.114
France	0.000	United States	0.091

Table 6: CO_2 Emissions Predictor Weights of Synthetic Sweden

	Weights
GDP per capita	0.114
Urban population	0.166
Gasoline consumption per capita	0.010
Motor Vehicles (per 1000 people)	0.095
CO2 from transport per capita 1989	0.188
CO2 from transport per capita 1980	0.414
CO2 from transport per capita 1970	0.014

Table 7: Country weights in Synthetic Norway

Australia	0.000	Ireland	0.000
Belgium	0.000	Iceland	0.000
Canada	0.012	Japan	0.000
Switzerland	0.614	New Zealand	0.001
Denmark	0.190	Poland	0.001
Spain	0.000	Portugal	0.076
France	0.028	United States	0.077
Greece	0.001		

Table 8: CO_2 Emissions Predictor Weights of Synthetic Norway

	Weights
GDP per capita	0.176
Urban population	0.003
Gasoline consumption per capita	0.364
Motor Vehicles (per 1000 people)	0.043
CO2 from transport per capita 1989	0.122
CO2 from transport per capita 1980	0.250
CO2 from transport per capita 1970	0.042

Table 9: Country weights in Synthetic Finland

Australia	0.099	Greece	0.000
Belgium	0.381	Iceland	0.013
Canada	0.000	Japan	0.000
Switzerland	0.338	New Zealand	0.000
Denmark	0.001	Poland	0.001
Spain	0.160	Portugal	0.000
France	0.001	United States	0.006

Table 10: CO_2 Emissions Predictor Weights of Synthetic Finland

	Weights
GDP per capita	0.001
Urban population	0.000
Gasoline consumption per capita	0.202
Motor Vehicles (per 1000 people)	0.068
CO2 from transport per capita 1989	0.077
CO2 from transport per capita 1980	0.256
CO2 from transport per capita 1970	0.397

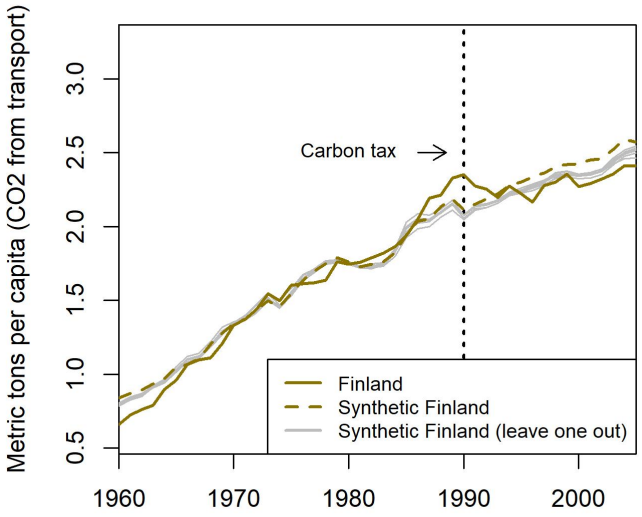


Figure 19: Leave-one-out: Distribution of the synthetic control for Finland