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The effect of a carbon tax on per capita dioxide emissions: evidence from Finland

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The effect of a carbon tax on per capita carbon dioxide emissions: evidence from Finland*

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Abstract

This paper is a quasi-replication of Andersson (2019). I use the synthetic control method to estimate the effect of a carbon tax starting at \$ 1.41 per tonne of CO_2 and increased through successive reforms to \$20 by 2011. The results show that, one year after the intervention, the tax reduced CO_2 emissions from transport by around 10% relative to the synthetic counterfactual, composed from the weighted average of OECD countries. Five years after the intervention, the effect increases to almost 20% and in 2005, the last year of the dataset, the estimated effect is of around 48%. After some robustness checks, the estimated effect is a 15% reduction in 2005. My results are consistent with Andersson (2019), who finds a 12.5% reduction at the end of his studied period. My paper contributes to the thin literature analyzing the the effect of a carbon tax ex post, providing new evidence of the effectiveness of these instruments.

Keywords: Carbon pricing; Emissions reduction; Environmental tax; Greenhouse gas emissions; Synthetic control method.

JEL Codes: H23, Q54, Q58.

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1 Introduction

A consensus has been reached among scientists about the importance of limiting the temperature increase to 1.5°C above pre-industrial levels (IPCC, 2018) and thus finding policies to reduce greenhouse gases emissions is important. Market-based instruments, such as taxes and marketable permits, can in theory be a more cost-efficient approach than command-and-control regulation. In the population however, carbon pricing mechanisms are not as widely accepted and people tend to doubt that carbon pricing will be effective at reducing emissions (Carattini et al., 2018), which may explain why carbon taxes are rarely implemented (Klenert et al., 2018). Furthermore, empirical analyses evidence on the causal effect of such interventions is really scarce; empirical research essentially focus on simulation models (e.g. Gupta et al., 2019; Fremstad and Paul, 2019; Berry, 2019). New (ex post) empirical evidence is therefore paramount to demonstrate the impact a CO_2 tax can have on CO_2 emissions.

In this paper I employ the approach of Andersson (2019) and use the synthetic control method to quantify the impact of the Finnish carbon tax on per capita CO_2 emissions from the transport sector[1]. In 1990, Finland was the first country to implement a carbon tax on many carbon emitting sources of energy: all transport fuels (gasoline, diesel, jet fuel, aviation gasoline, light and heavy fuel oil), as well as coal and natural gas (Lin and Li, 2011). Even though the tax mainly covered transportation, it was also applied to energy used for heating and the production of electricity (Bavbek, 2016). The tax was originally relatively low, equalling \$1.41 per ton of CO_2 and was gradually increased to amount between \$62 and \$66 per tonne of CO_2, depending on the source (Bavbek, 2016).

In order to estimate a synthetic counterfactual for Finland I use data for 24 OECD countries from 1965 to 2005. Since it is crucial to have only untreated units in the set of countries used in the estimation, the donor pool (see Abadie et al., 2010), countries that had simi-

[1] The synthetic control method (Abadie and Gardeazabal, 2003; Abadie et al., 2010) provides a data-driven counterfactual, composed from the weighted average of untreated units, also called the donor pool (Abadie et al., 2010). The synthetic control mimics the pre-treatment outcome of the treated unit, and uses the same weights obtained in the pre-treatment period to estimate the outcome in the post-treatment period. The causal effect is then estimated as the difference between the synthetic control and the treated unit in the post-treatment period.

lar interventions are dropped, which leaves a donor pool of 17 countries[2]. Data ranges from 1965, the earliest year fossil fuel consumption data is available and I end the studied time period in 2005 because it is the year the European Emissions Trading System (EU ETS) started (Anderson and Di Maria, 2011). To match the oucome, I use following predictors: GDP per capita, fossil fuel consumption per capita, the number of vehicles per 1,000 inhabitants, the percentage of urban population and three lagged years of CO_2 emissions.

I present three sets of results. Firstly, I show that an unweighted average of the donor pool does not fit the outcome of Finland in the pre-treatment. Secondly, synthetic Finland provides a satisfactory counterfactual. In the pre-treatment, from 1965 to 1989, the outcome of Finland and synthetic Finland are almost indistinguishable. Thirdly, given my data and estimation strategy, one year after the intervention CO_2 emissions from transport are reduced by approximately 10%, or 0.233 metric tons per capita, relative to synthetic Finland. Five years after the the tax was introduced, CO_2 emissions per capita are reduced by almost 20% compared to synthetic Finland. At the end of the post-treatment period, in 2005, the reduction is of about 1.166 metric tons (48%). The magnitude and the trend of the effect can be explained by the fact that Finland introduced the tax early. As seen above, even though the tax started at a low level, it was gradually increased. Today, Finland's carbon price is one of the most expensive in the world (Ramstein et al., 2019).

To test whether the results are obtained by chance or show an actual causal effect (Abadie et al., 2010), I provide a range of placebo tests. In the first placebo test, the "in-time" placebo, I run the same model but assign the treatment to a date before the actual treatment occured, in 1975. The 1975 placebo tax shows no effect, meaning that my results are robust to this test. The second placebo test is an "in-place" placebo. In this case, I assign the treatment to untreated units and check whether they show an effect. Because they had no intervention, none of the untreated units should display a reduction in emissions. To evaluate Finland's effect in comparison to the placebo effects, I also calculate the ratio of post-treatment mean squared predictor error (MSPE) to pre-treatment MSPE (Abadie et al., 2010). A large post-treatment

[2] The donor pool is composed of following countries: Australia, Austria, Belgium, Canada, Denmark, France, Greece, Iceland, Ireland, Japan, Luxembourg, New Zealand, Portugal, Spain, Switzerland, Turkey and the United States.

gap only displays a causal effect if the placebo is able to correctly mimic the pre-treatment outcome. Finland has the largest ratio. The in-place placebo creates a distribution of estimated effects (one true effect and several placebo effects). It is then possible to compare the effect of the treated unit (Finland) to a pool of placebo effects and test whether Finland's effect is unusually large. If the treatment was assigned randomly in the sample, the probability of getting a ratio as large as Finland would be 1/18 = 0.056, which is, given my sample size, the smallest possible p-value. Andersson (2019) proceeds in the same manner and also finds the smallest p-value possible, given his sample-size (1/15 = 0.067).

The last placebo test I perform is called "leave-one-out", where one control unit is dropped iteratively from the donor pool and the weights re-estimated. This is done to test if the result is pushed by one control country. In the leave-one-out placebo test, placebo synthetic Finland is close to synthetic Finland for the whole donor pool, except when Luxembourg is left out. My intial results are therefore robust to the majority of leave-one-out placebos. Without Luxembourg, leave-one-out placebo synthetic Finland is lower than the other synthetic controls. The placebo without Luxembourg provides a lower bound, a more conservative result: Five years after the tax, emissions are estimated to be 12% lower. In 2005, the estimated effect is around 15% compared to the synthetic counterfactual.

My paper contributes to the literature on carbon taxes and the more recent literature that estimates the effect of carbon taxes econometrically. My paper is a quasi-replication of Andersson (2019), who uses the synthetic control method to estimate the effect Sweden's carbon tax had on CO_2 emisisons from transportation. Sweden started a carbon tax in 1991 at $30 per tonne of CO_2. It was later increased and is now the highest in the world, equalling almost $130 per tonne of CO_2 (Ramstein et al., 2019). Transportation was one the main impacted sectors. The outcome variable is thus p.c. CO_2 emissions in this sector. The predictors are also really similar to those of my paper: GDP p.c., vehicles per 1,000 people, gasoline consumption p.c., the ratio of urban population and three lagged years of p.c. CO_2 emissions. Over the studied post-treatment period (1990-2005), Andersson (2019) finds an annual average reduction in emmissions per capita of 10.9%.

The remaining literature researching the effect of carbon taxes econometrically mainly uses difference-in-differences (DiD) estimators. Lin and Li (e.g. 2011) study the carbon taxes in Denmark, Finland, the Netherlands, Sweden and Norway applying the DiD method. Although they find that the taxes reduced carbon emissions in all these countries except Norway, only Finland's coefficient is statistically significant.

Yamazaki (2017) analyses the effect of the 2008 British Columbia (BC) carbon tax on employment. He uses the DiD method and industry-level data to estimate how environmental taxes affect employment during the years 2001-2013. His results show that the effect on employment depends on the type of industry. Indsutries that are energy-intensive, trade exposed (EITE) see a reduction in employment while clean service industries experience an increase in employment. Yamazaki (2017) also estimates the aggregate effect on employment, which equals the job creation in some industries minus the job destruction in others. Over the 6 years post-treatment period (2008-2013), he finds a 4.5 percent increase in employment.

Another paper analyzes the effect of the BC carbon tax on employment, this time using individual-level data (Yip, 2018). This allows him to estimate the overall effect on employment, but also potential heterogeneity between workers. Unlike Yamazaki (2017), he finds an overall unemployment increase of 1.3 percent. Employment outcomes after the carbon tax is implemented differ, depending on the socio-economic characteristics of the individuals. Low-educated people are more affected by the tax (2.4 percent increase in unemployment) than high- (0.6 percent increase) and medium-educated (1.4 percent increase). Low-educated individuals also suffer from unemployment in the longer run, while medium-educated people's unemployment is mostly temporary after the tax. Interestingly, Yip (2018) replicates the results found in Yamazaki (2017) and confirms the same results found in the latter. However, he emits some concerns about the common trend assumption and shows that it is likely violated in Yamazaki (2017).

The rest of the paper proceeds as follows. Section 2 presents the empirical strategy and the data. In Section 3, I expose the results and Section 4 concludes.

2 Empirical method and data

In this Section, the synthetic control method is briefly presented. The interested reader can find a formal description of the model in Abadie et al. (2010) and Abadie et al. (2015).

The synthetic control method is appropriate when investigating the effect of a policy at an aggregate level when the number of observable units is limited (Abadie et al., 2015). At the end of this Section, the data I use and their sources are described.

2.1 Empirical method

In the synthetic control method, units (in the case of this paper, countries) are observed during T years, indexed by t. Let T_0 be the number of pre-treatment years and T_1 the number of post-treatment years, with $T = T_0 + T_1$. In a sample of $J + 1$ units, only one (j_1 = Finland) is treated. Accordingly, there are J untreated countries, which form the donor pool. It is assumed that j_1 is exposed to the treatment only in the years $T_0 + 1, ...T$, not before[3]. Another important assumption of the model is that the untreated units are not influenced by the treatment (no spillover effect). The outcome of country j at time t is denoted Y_{jt}. The causal effect we want to estimate, α_{1t}, is given by following difference:

$$\alpha_{1t} = Y_{1t}^{I} - Y_{1t}^{N} , \tag{1}$$

where Y_{1t}^{I} is the outcome of unit 1 (Finland) in period t under treatment and Y_{1t}^{N} is the outcome of unit 1 in period t under non-treatment. However, only one of the two is observed, namely the treated outcome of the treated unit. The (potential) untreated outcome of the treated unit is not observed after the intervention. It is therefore required to construct a theoretical counterfactual that credibly estimates what *would have happened* to the treated unit in the absence of the intervention. The construction and implementation of the synthetic control, the counterfactual in this method, are described in the following paragraphs.

The synthetic control is a weighted average of the J untreated countries. Indeed, the treated unit's pre-intervention characteristics can be better estimated with a combination of control units (rather than a single one) (Abadie et al., 2015). Synthetic Finland is hence constructed by a $(J \times 1)$ vector of weights $W = (w_2, \ldots, w_{(J+1)})'$. The country weights w_J

[3] Note that due to anticipation effects, it is possible that pre-treatment periods are also (partially) treated. Abadie et al. (2010) suggest that in these cases, T_0 is redefined as the first year the outcome is affected by the treatment.

are positive or null and add up to 1. Each different W represents a different synthetic control. X_1 is a $(k \times 1)$ vector that contains the observed values of pre-treatment characteristics of country J. Similarly, X_0 is a $(k \times J)$ matrix that contains the observed values of the same variables, but this time for the donor pool. Abadie et al. (2015) indicate that W is chosen so that it minimizes the pre-treatment difference between the treated unit and the donor pool on decisive predictors. In other words, the method selects a W^* that minimizes $X_1 - X_0 W$.

Concretely, the method is implemented in the following way. For $m = 1, \ldots, k$, X_{1m} is the value of the m-th variable for Finland and X_{0m} a $(1 \times J)$ vector that contains the values of the same variable for the donor pool. W^* is chosen so that it minimizes:

$$\sum_{m=1}^{k} v_m - (X_{1m} - X_{0m} W)^2 , \tag{2}$$

where v_m is the weight of the m-th variable when the difference between X_1 and X_0 is measured. Predictors that are more important receive a larger weight. There are several ways to obtain the matrix of predictor weights, denoted V. Andersson (2019) mentions some of them like using empirical results available in the literature, cross-validation, and the one he uses: choosing the V and W matrices simultaneously such that the mean squared predictor error (MSPE) of the dependent variable is minimized over the entire pre-treatment period. In this paper, I use the last method as well.

Y_1 is a $(T_1 \times J)$ vector that containes the post-treatment values of the treated unit's outcome and Y_0 is a $(Y_1 \times J)$ matrix that collects the values of the outcomes for the donor pool. The effect of the intervention is given by the difference of the post-treatment outcome of the treated unit and the post-treatment outcome of the non-treated unit (the synthetic control): $Y_1 - Y_0 W^*$. The causal effect of the intervention in period t, α_{1t}, is obtained by the difference of the (observed) outcome of the treated unit in period t and the synthetic control's outcome in the same period:

$$\alpha_{1t} = Y_1 t - \sum_{j=1}^{J+1} w_j^* Y_{jt} \tag{3}$$

The method also provides different placebo tests to check whether the results are obtained by chance or show an actual causal effet (Abadie et al., 2010). It is a way to test the results' validity. At the end of Section 3, I present three placebo tests: "in-time" placebo, "in-space placebo", and "leave-one-out placebo".

2.2 Data

In 1990, Finland was the first country to implement a carbon tax on many carbon emitting sources of energy: all transport fuels (gasoline, diesel, jet fuel, aviation gasoline, light and heavy fuel oil), as well as coal and natural gas (Lin and Li, 2011). The tax covered not only transportation, but also energy used for heating and the production of electricity (Bavbek, 2016).

The tax was originally relatively low, equalling \$1.41 per ton of CO_2 (Bavbek, 2016) and was gradually increased to amount today, depending on the type of fuel, to \$70 (transport fuels) or \$60 (other types of fuels) per ton of CO_2 (Ramstein et al., 2019). To protect key sectors from international competition, a few exceptions were put in place (Ekins and Speck, 1999). Some energy sources were partially (peat and natural gas) or completely (wood) exempted from the tax (Vourc'h and Jimenez, 2000).

The tax mainly concerns the transport sector. The outcome variable is therefore per capita CO_2 emissions from the transport sector. As predictors, I use GDP per capita, fossil fuel consumption per capita, the number of vehicles per 1,000 inhabitants and the percentage of urban population. Three lagged years of CO_2 emissions are also included. Data comes from different sources, although the data set is almost identical to Andersson (2019). Data on p.c. CO_2 emissions from transport, GDP p.c., urban population and vehicles per 1,000 people come from his data. The original sources of Andersson (2019) are the World Bank for CO_2 emissions and urban population, Feenstra et al. (2015) for GDP p.c, Dargay et al. (2007) for vehicles per 1,000 people. Data on fossil fuel consumption per capita was retrieved from the *Our World in Data* website, whose source is the BP (2019) Statistical Review of World Energy.

The full initial sample is constituted of the 24 OECD countries in 1990: Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Japan, Luxembourg, the Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. It is crucial to have only untreated units in the donor pool (Abadie et al., 2010). Thus, from the full sample, countries that had similar interventions are dropped: The Netherlands, Norway, Sweden and Italy (carbon taxes in 1990, 1991, 1991 and 1999, respectively), as well as Germany (ecological taxation started in 1999) and the United Kingdom (climate change tax in 2001) are dropped out of the sample. The other countries remain and form the donor pool. This leaves 17 countries in the donor pool: Australia, Austria, Belgium, Canada, Denmark , France, Greece, Iceland, Ireland, Japan, Luxembourg, New Zealand, Portugal, Spain, Switzerland, Turkey and the United States.

My panel data ranges from 1965 to 2005. 1965 is the earliest year fossil fuel consumption per capita is available and I stop the time series in 2005 because the European Union Emissions Trading System (EU ETS) started that year (Andersson, 2019). This, and the fact that many countries started their own carbon pricing mechanisms, leaves almost no untreated units after 2005. The panel data consists of 26 pre-treatment and 15 post-treatment periods.

3 Results

This Section presents the results of the econometric analysis. First, I present synthetic Finland and show that it is a more credible counterfactual (Section 3.1). Then, I present the results on the effect of the carbon tax (Section 3.2). Finally, I perform three placebo-tests to check the robustness of my results (Section 3.3).

3.1 Synthetic Finland

To create a credible counterfactual, it is important that synthetic Finland resembles actual Finland. Table 1 shows the predictors means for the treated unit (Finland), the mean of the control sample, and the weighted average of synthetic Finland in the pre-treatment period (before 1990). This table is important, because the SCM forces the researcher to show that the treated unit and the synthetic control are similar (Abadie et al., 2010). Synthetic Finland, the counterfactual of this comparative case study, is systematically closer to Finland's average. The discrepancy between Finland's and Synthetic Finland's averages is less than 1% except for the number of vehicles per 1,000 inhabitants. The closeness of the predictors' means is promising.

Table 1: Predictors means before the treatment

Variable	Finland	Synthetic Finland	OECD sample
GDP per capita	15,245.3	15,244.7	16,389.5
Fossil fuel consumption per capita	39,788.0	39,906.2	40,893.9
Vehicles per 1,000 people	241.9	256.2	303.5
Urban population	68.2	67.9	70.8
CO_2 from transport p.c. (1989)	2.3	2.3	2.5
CO_2 from transport p.c. (1980)	1.7	1.7	2.1
CO_2 from transport p.c. (1970)	1.3	1.3	1.5

Notes: The values are rounded to 1 decimal. The variables are averaged over the period 1971-1980, except the lagged CO_2.

Table 2: Weights of the countries in synthetic Finland

Country	Weight	Country	Weight
Australia	0	Japan	0
Austria	0	Luxembourg	.109
Belgium	0	New Zealand	.136
Canada	0	Portugal	0
Denmark	.323	Spain	.001
France	0	Switzerland	.012
Greece	.060	Turkey	.298
Iceland	.001	United States	.058
Ireland	0		

Notes: The w_j weights are between $0 \leqslant w_j \leqslant 1$ and $\sum w_j = 1$. Weights $w_j < 0.001$ are reported as 0 in this table.

Every predictors receive a weight, the V weights of the method. The predictors weights are following: GDP per capita (0.1), fossil fuel consumption (0.055), vehicles per 1,000 people (0.002), urban population (0.002), CO_2 emissions per capita in 1989 (0.621), CO_2 emissions per capita in 1980 (0.164) and CO_2 emissions per capita in 1970 (0.057). Each country in the donor pool is also given a weight (W weights), reported in Table 2. Synthetic Finland is constructed from a combination of following countries, in decreasing order: Denmark, Turkey, New Zealand, Luxembourg, Greece, the United States and Switzerland. The other countries receive a zero or insignificant weight. Denmark, probably due to the socio-economic, as well as geographical similarities with Finland, obtains the largest weight. Note that Denmark also receives the biggest weight in Andersson (2019).

Figure 1: Path plots of CO_2 emissions from transport

(a) (b)

Notes: Panel (a) shows the path of per capita CO_2 emissions from transport in Finland and the unweighted average of control units. Panel (b) shows the same path for Finland and synthetic Finland.

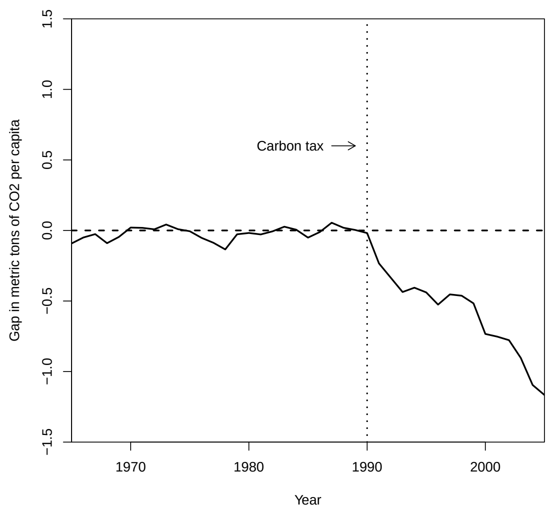
3.2 The effect of the carbon tax

The results are best described graphically. Panel (a) of Figure 1 shows the path of per capita CO_2 emissions from the transport sector of Finland and of the unweighted average of the donor pool. Panel (b) of Figure shows the same path for Finland and synthetic Finland. The weights obtained in Section 3.1 are used to create synthetic Finland.

The fit of the unweighted average is poor. In the pre-treatment period, it is constantly higher than Finland's outcome. Even though one can guess a slight divergence after 1995, it is impossible to assess that the carbon tax had a causal effect, let alone to estimate it. On the other hand, synthetic Finland provides a good counterfactual. Globally, synthetic Finland is great at mimicking actual Finland. The two paths somewhat deviate in the late 1970's but overall the fit is very satisfying. As can be seen on panel (b) of Figure 1, the carbon tax had a significant impact on the level of CO_2 emissions per capita from transport in Finland.

The gaps between synthetic Finland and Finland are given by Figure 2. The carbon tax resulted in greater and greater gaps in the post-treatment period. One year after the inter-

Figure 2: Gaps between CO_2 emissions of Finland and synthetic Finland



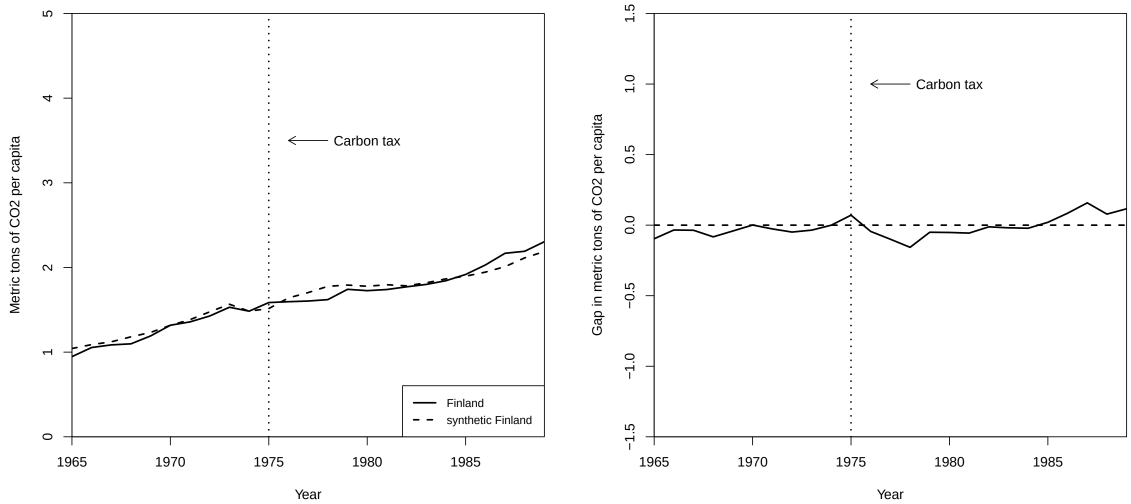
vention, carbon emissions are reduced by around 10%, or 0.233 metric tons per capita. In 2005, the last post-treatment period, the reduction in absolute terms is 1.166 (48%). The estimated effect is really large. For example, Andersson (2019) only finds a reduction of 12.5% in 2005 for the 1991 introduced Swedish carbon tax. An effect as large as mine can be corroborated by Lin and Li (2011). They find a reduction in p.c. CO_2 emissions in both Finland and Sweden. Yet, Finland's coefficient was significant, Sweden's not. Further inquiry is necessary to test the validity of this colossal effect, and some preliminary tests will be performed in Section 3.3.

3.3 Placebo tests

As mentioned in Section 2, placebo tests are often used with the synthetic control method in order to assess whether the results are obtained by chance or show an actual causal effect (Abadie et al., 2010). It is a way to test the results' validity. I perform three different placebo tests, exposed in this subsection: "in-time", "in-space" and "leave-one-out" placebo tests.

In the first placebo test, I run the same model as in Section 3.2, but assign the treatment to a date prior to the actual treatment date. This model evaluates the effect of a placebo carbon tax implemented in 1975. I use the same predictors and change the lagged CO_2

Figure 3: Path plot and gaps plot of the in-time placebo



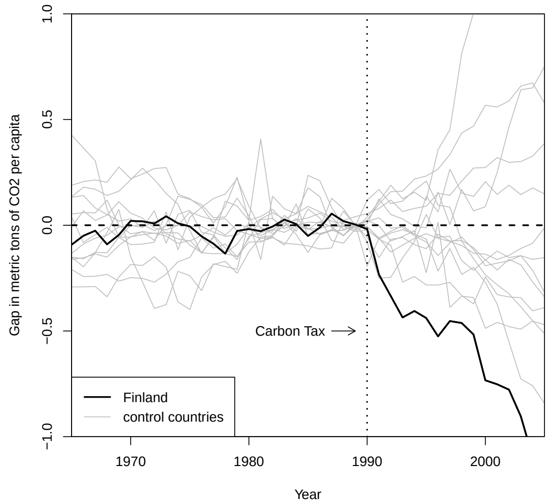
(a) (b)

Notes: Panel (a) shows the path of CO_2 emissions in Finland and in-time placebo for 1975. Panel (b) shows the gap in CO_2 emissions between Finland and synthetic Finland.

emissions accordingly. A divergence in the paths of Finland and placebo synthetic Finland would undermine the results obtained above. If the paths diverge in the same way as in Figure 1, the carbon tax cannot have been the cause of the reduction in emissions. The graphical result of the "in-time" placebo is shown in Figure 3. Even though the paths diverge very slightly, there seems to be no effect.

A second placebo test often used in the literature with synthetic controls is the so-called "in-space" placebo. The idea is to assign the intervention to unaffected units. In practice, it means to rerun the same model changing the treated unit every time, iteratively assigning the intervention to every country of the donor pool. This creates a distribution of estimated effects, with which it is possible to compare the effect of the treated unit to a pool of placebo effects. One can then control whether the effect of the treated country is abnormally large (Abadie et al., 2010, 2015). Figure 4 depicts the path of Finland (black line) and the control countries that were assigned the placebo treatment (grey lines). It is encouraging to see that none of the control unit has an effect as large as Finland's.

Figure 4: Per capita CO_2 emissions gaps in Finland and placebo gaps in control units

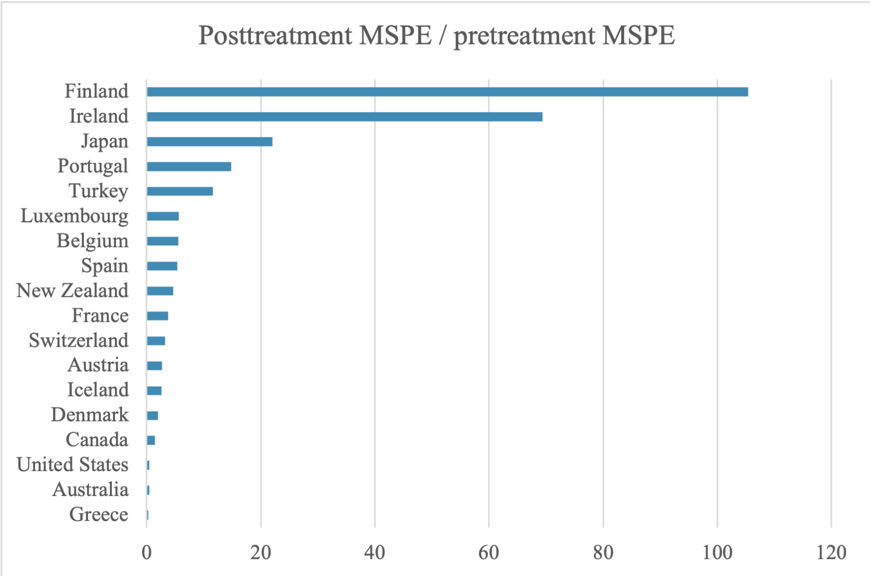


Nonetheless, the magnitude of the post-treatment gap shown in Figure 4 is not sufficient to assess the size of the effect. Indeed, a large gap only suggests a large effect if the synthetic control is able to scrupulously imitate the pre-intervention outcome. To test this, Abadie et al. (2015) propose to use the ratio of post-treatment MSPE to pre-treatment MSPE. A large ratio for Finland and small ratios for the others would consolidate the results obtained in Section 3.2. Figure 5 shows these ratios for Finland and the control countries.

It is reassuring to see that Finland has the largest ratio. Yet, Ireland's considerable ratio is somewhat troubling. Does it undermine the validity of the results? Ireland experienced an important increase in GDP per capita in the 1990's, more than doubling it during the post-treatment period (Andersson, 2019). CO_2 emissions per capita followed the same path (an increase). It is worthy to note that Andersson (2019) excluded Ireland of his sample for this reason. Additionally, Abadie et al. (2015) also obtained a few large ratios in their paper. Indeed, what really matters is that Finland's ratio is unmatched by far. If the carbon tax was assigned randomly in the sample, the probability of getting a ratio this large would be 1/18 = 0.056.

The last placebo test is called "leave-one-out". As its name indicates, one control country is dropped ("left out") from the donor pool and the weights re-estimated to test whether the

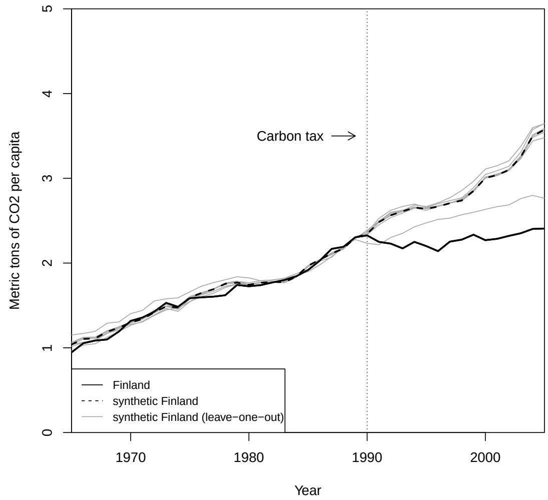
Figure 5: Ratio of post-treatment to pre-treatment MSPE for Finland and the control countries



result is pushed by one control unit. I perform this test for every country with a W weight higher than 0.001. Figure 6 shows the results of this placebo test.

Leave-one-out placebo synthetic Finland is close to synthetic Finland for the whole donor pool, except when Luxembourg is dropped. Then, synthetic Finland is lower than the other synthetic controls, however still higher than Finland. The important weight this unit gets in synthetic Finland (over 10%) is a potential explanation. What does it mean for my results? For the great majority of leave-one-out placebos, the effect remains virtually unchanged. Luxembourg seems to be a major driver of this effect. The main result is the same (the tax reduced the level of p.c CO_2 emissions), but the magnitude of the effect is lower. This placebo provides a lower bound of the effect, a more conservative result. Without Luxembourg, five years after the tax, emissions were 12% lower. At the end of the post-treatment period, the effect is only around 15%, whereas the initial estimated reduction was of 48% percent. This result is closer to what Andersson (2019) estimates for Sweden (a 12.5% reduction in 2005).

Figure 6: Leave-one-out distribution of the synthetic control for Finland.



4 Conclusion

Climate change is the biggest market failure humanity has encountered (Stern, 2008). Economists prone the use of pricing mechanisms to internalise externalities (Hepburn et al., 2020). In the case of greenhouse gases, a typical pigouvian instrument is carbon pricing, for instance in the form of a tax. This paper analyses such a tax econometrically and answers following question: What was the effect of the 1990 Finnish carbon tax on the level of per capita CO_2 emissions from transport?

The majority of the literature on the subject focuses on simulations and only a few papers estimate the effect of carbon taxes ex post. This paper is only the second to use the synthetic control method in this context, the first to analyse the effect for Finland. In this paper, I use the synthetic control method and data on OECD countries and show that the 1990 carbon tax significantly reduced the level of CO_2 emissions from the transport sector. Five years after the intervention, the effect amounted to around 12% to 20% compared to the counterfactual.

It is appropriate to issue a certain caveat regarding my results. One single country drives synthetic Finland's path upward. When Luxembourg is dropped out of the donor pool, synthetic Finland is significantly lower. The discrepancy between the counterfactual that includes Luxembourg and the one that does not gets even larger later in the post-treatment period.

The lower bound seems therefore more cautionary and maybe slightly more plausible. Indeed, it is closer to estimates found previously in the literature (e.g. Andersson, 2019). The effectiveness of the tax is nonetheless proven, given the method and data I use.

Even so, another issue remains. The effectiveness of the tax can be debated. If my results show that per capita emissions *from transport* have indeed declined significantly, the *overall* level of per capita CO_2 emissions in Finland kept rising after the implementation of the carbon tax and started to decline only in 2003. This upward trend in the 1990's can be partly explained by the exceptions that were added a few years after the implementation and by the fact that the tax was relatively low at its inception. It was then highly increased in 1997 and 2011 (Bavbek, 2016). These tax increases are likely to explain the declines in total emissions observed after these dates. Note that the rise in the nineties does not necessarily mean that the tax had no effect on the overall level of emissions. It may well be that emissions rose *less* than what would have been without the tax. Future research is welcome to test this hypothesis.

This paper shows the importance of ex post analyses and brings evidence that carbon pricing can be an important and useful tool to reduce CO_2 emissions. Future research is needed to assess the effectiveness of other carbon taxes in order to build a wider literature using econometric approaches. Further investigation on the overall level of carbon emissions, at country level, but also globally is also welcome.

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