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Pricing for a Cooler Planet: An Empirical Analysis of the Effect of Taxing Carbon

Abstract

Finland introduced the planet's first carbon tax in 1990 to experiment with, to most economists, the best policy to reverse carbon emissions. I estimate the causal effect of taxing carbon on Finnish emissions using the Synthetic Control Approach (Abadie, 2021). The results suggest that taxing carbon reduces emissions by big margins. Finnish emissions are 16% lower in 1995, 25% lower in 2000, and 30% lower in 2004 than emissions in the counterfactual consistent with carbon taxes whose value increasing by 20 fold in 1990 - 2005. The estimates suggest that the carbon tax's abatement elasticity is about 9%.

JEL-Codes: C210, C230, H230, L910, Q540, Q580.

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1 Introduction

Slowing climate change and limiting its adverse effects is the most pressing challenge at a planetary level. Pricing carbon is the most effective approach to slow climatic changes and to transform the world economy according to a century of research in economic theory (Pigou, 1920; Dales, 1968; Montgomery, 1972; Weitzman, 1974; Stern, 2007; Nordhaus, 2019; Pindyck, 2019; Stavins, 2020). Thus, most economists unite behind Pigou's insight of pricing pollution to limit pollution externalities.

Recently, Economic Experts Panel members of the Chicago Booth School of Business gave about 80% confidence-weighted votes in favor of carbon taxes as a better way to implement a climate policy than cap-and-trade schemes.[1] Despite the conceptual foundation behind using a carbon tax to reverse carbon emissions being strong, its empirical foundation remains arguably weaker. The foundation substantiating carbon taxes reduce emissions ex-post is weaker mainly due to a lack of sufficient evidence.

The supporting evidence for the effectiveness of taxing carbon is missing, first, because few countries have taxed carbon: even fewer empirical studies of the causal effect on emissions as Sterner (2015) notes. And, no country has imposed carbon tax until Finland begun in 1990 (World Bank, 2020). Besides, in the countries that have taxed carbon, the policy-induced data generating process has been too complex to lend itself to causal identification. Green (2021, p. 17) conducts a comprehensive review of the literature, including those outside Economic Sciences, regarding the ex-post evidence of carbon tax's effectiveness and concludes that "we know relatively little about its ex-post performance..." In this article, I examine the causal effect on carbon emissions of the Finnish taxes and offer complementary evidence to advance evidence-based climate policies.

What is the causal effect on CO_2 emissions of the Finnish taxes on carbon? One can think about this question and identify the causal effect by conducting a randomized control trial: some regions, chosen randomly, tax carbon while the remaining regions serve as a control group. Yet, countries tax carbon in all regions let alone with randomization. One thus needs a second-best alternative to randomization: the synthetic control approach to estimate the causal effect of the Finnish carbon tax since 1990 (Abadie and Gardeazabal, 2003; Abadie et al., 2010; Abadie, 2021). The approach is most suitable for the current task on the following grounds (e.g., Athey et al., 2018). First, there is a single unit treated with a carbon tax in which the variable of interest involves emissions at a national level. Second, the synthetic control method adopts a data-driven approach in choosing the best comparison unit and allows falsification tests in assessing its sensitivity. Third, the output – in transparent visuals of the pre and post-treatment matching for both the estimates of causal impact and diagnostic tests – is lucid.

[1] http://www.igmchicago.org/surveys/climate-change-policies

In estimating the effect of the Finnish carbon tax using synthetic control, I focus on emissions from the transportation sector for the following reasons. First, there is a problem of ruined-control in the countries without a carbon tax. The problem arises when Finland imposes the carbon tax, some inputs can be imported from (or exported to) other countries. In other words, the aggregate emissions in nations without a carbon tax could be affected by the Finnish carbon tax when such countries trade with Finland. This is a concrete problem, for example, when it comes to per capita emissions, which is a contaminated measure for a small open economy like Finland. However, transportation services are internationally non-tradable, the ruined-control effect due to international trade is limited. Besides, Finland is a small open economy that cannot affect global oil prices suggesting the ruined-control issue is arguably less serious in transportation activities. Second, the structure of energy production and use in transport activities is similar across countries. This eases the task of constructing a valid comparison unit to Finland from the set of other countries. The similarity contrasts with the heterogeneity in other activities (e.g., the power or housing sector), which involve vast differences in the energy mix. Third, I focus on the transport sector due to the availability of data for predictors that allow comparability across countries.

To estimate the effect on emissions of taxing carbon, I assemble national-level data of CO_2 tax, CO_2 emissions from transportation activities per capita, and determinants of such emissions.[2] In the main specification, I focus on member countries of the OECD since the early 70s that never imposed a carbon tax as potential comparison countries (donor pool). I use emissions from such countries to construct a plausible counterfactual trajectory of Finnish emissions without a carbon tax.

The estimated gap between the actual and the counterfactual emissions implies that the carbon tax reduces emissions considerably. Finnish emissions are 16% lower in 1995, 25% lower in 2000, and 31% lower in 2005 relative to the counterfactual. Rising impact over time goes in line with the increasing intensity of the CO_2 tax per ton of CO_2 over time (i.e., increased by 20 fold in the treatment period). The estimated emissions reductions came from stabilizing the Finnish emissions at the 1990 level relative to sharply rising emissions in the countries lacking a carbon tax. The estimated emissions reductions are consistent with the decline in Finnish gasoline, and diesel, consumption after 1990. Moreover, Finnish passenger transport activities and the number of vehicles have decreased to a new trend after 1990. Next, I estimate the carbon tax elasticity of emissions reductions directly by using the real carbon tax data and its estimated impact. The geometric mean of the annual carbon tax elasticity of emissions reduction values is -9%. Finally, I take advantage of the fuel tax reforms Finland undertook to estimate the effect of implicit carbon prices in addition to the impact of carbon taxes. Limiting the donor pool to the subset of countries without a carbon tax having no substantial fuel

[2]In the following, I use emissions to mean CO_2 emissions from transportation activities for brevity.

tax reform, I estimate a comparable effect of implicit carbon prices on Finnish emissions.

In examining the effect of the planet's first carbon tax, the article contributes to the small but growing literature advancing evidence-based climate policies. Mideksa and Kallbekken (2012) examine the effect of a carbon tax on emissions in Norway using the synthetic control identification strategy. Similarly, Andersson (2019) examines the effect of a carbon tax on emissions in Swedish transportation sector. The recent literature includes Martin et al. (2014), Abrell, Kosch, and Rausch (2019), Metcalf (2019), Bretscher and Grieg (2020), Fernando (2019), Leroutier (2019), Pretis (2020;), Metcalf and Stock (2020), and Rafaty, Dolphin, and Pretis (2020). Green (2021) provides the latest and comprehensive summary of the literature. Specifically, the article advances this literature as follows. First, this article contributes to enriching external validity and presents complementary evidence from a new case study based on the Finnish experience to the literature examining ex-post effectiveness of carbon taxes.[3] This aspect can be useful to the extent that the effect of carbon taxes can be different in different countries and periods. Second, in addition to estimating the impact, the article digs deeper to examine the underlying drivers behind the estimated impact. To this end, it examines passenger transport, vehicle ownership, and consumption of gasoline and diesel in Finland before and after 1990. Third, the results suggest a high estimate of carbon tax elasticity of annual emissions reduction. This contrasts with indirect estimates from variations in fuel prices based on *expectations, salience, and signals* different from the same relative prices due to random variations in fuel prices. Fourth, the article examines the additional effect of implicit carbon prices on emissions by studying from several legislation-data regarding motor fuel tax reforms and limiting the donor pool to the subset of countries that avoided changing motor fuel taxes substantially in the treatment period. What are the data, and their sources, behind these results?

2 The Finnish Carbon Tax, Data, and Donor Pool

Nachmany et al. (2015) offer comprehensive coverage of climate change legislation in 99 countries, including Finland. They report that Finland has been a progressive player in the march for de-carbonizing the global economy. After imposing the carbon tax in 1990, it has signed the UNFCCC in 1992 and adopted it in 1994. It has ratified the Kyoto Protocol and has participated in the European emissions reduction initiatives. These suggest that there is some element of concern for the climate behind Finnish carbon taxes.

The Finnish Carbon Tax. The World Bank (2021) reports the evolution of the Finnish carbon tax since 1990, expressed in the US\$/tCO_2e. The tax value starts with US\$ 1.75

[3]This perspective follows the influential literature studying the unemployment effect of minimum wage.

in 1990 and grows to US$ 16.43 in 2000 before reaching US$ 23.39 at the end of the treatment period in 2005. While the initial amount is arguably small, it increases sharply, for example, by almost 20 fold by 2005 relative to 1990.

Data Source. The data for the Finnish carbon tax comes from the World Bank (2021). To convert the carbon tax to a constant price, I use the CPI data with 1990 as a base year using data from the Official Statistics of Finland (2021). Regarding emissions, I use annual country-level panel data for the period 1970 – 2005. The sample starts in 1970 because of the data of fossil CO_2 emissions, which come from the EDGAR dataset, version 5.0 FT2018 (Crippa et al., 2019), starts in 1970. The sample period ends in 2005 to avoid contamination of the control regions from the European-wide carbon pricing scheme through the EU ETS that began in 2005. The definitions of sectors in the EDGAR dataset are categories consistent with the guidelines from the IPCC for emissions inventories.[4] Thus, emissions from 'Transport' include emissions from all transportation activities, which is measured in tons. I use population data from the World Development Indicators to calculate the per capita CO_2 emissions. Following Andersson (2019), I use GDP per capita, the number of motor vehicles, gasoline consumption per capita, and the percentage of urban population as predictors of emissions. To examine the mechanisms behind the main result, I obtain the Finnish data of passenger transport from OECD(2021) as well as gasoline and diesel consumption in kg per person from the IEA (2020a).

Donor Pool. A valid comparison unit is crucial to estimate the trajectory of Finnish emissions in the counterfactual scenario of no carbon tax. The donor pool contains a list of countries, without a carbon tax, whose emissions I use to construct the emissions of a plausible comparison unit. In the main model, the pre-1971 OECD countries, without a carbon tax, constitute the donor pool. World Bank (2020, p. 11) reports countries with carbon tax before 2005: Finland and Poland in 1990, Norway and Sweden in 1991, Denmark in 1992, Slovenia in 1996, Estonia in 2000, and Latvia in 2004. This leaves Australia, Austria, Belgium, Canada, France, Germany, Greece, Iceland, Ireland, Italy, Japan, Luxembourg, Netherlands, New Zealand, Portugal, Spain, Switzerland, Turkey, United Kingdom, and the United States as a donor pool.

The countries in the donor pool adopt arguably similar transportation technologies as Finland. Limiting the donor pool to countries whose emissions are driven by a similar structural process as that of Finland serves as a reasonable potential comparison unit. I examine if there is an objective ground to trim the donor pool further using emissions or determinants of emissions – as Rosenbaum (2010) suggests – before the treatment period. This choice avoids the problem of conditioning on post-treatment outcomes: the problem arising when one uses information after the treatment time, 1990, about the

[4] `https://themasites.pbl.nl/tridion/en/themasites/edgar/documentation/definitions/index-2.html`

emissions and the main predictors. As an objectively rigorous approach of determining units with a similar structural process of a given variable is an open research area, I estimate an autoregressive model of emissions from each country to confirm a similar structural process both in Finland and countries in the donor pool using the parameter stability test.

Using members of the OECD countries as a donor pool for an OECD member is standard in the literature (e.g., Mideksa, 2013; Abadie et al., 2015; and Andersson, 2019). Besides, choosing countries based on international classification as the donor pool, instead of countries handpicked by a researcher, prevents hidden bias from contaminating the choice. In the section describing robustness tests, I drop an emissions-predictor at a time. Also, I trim the donor pool step-by-step, without replacement, to remove a group of countries with a major role (i.e., each having at least 15% weight) in constructing synthetic Finland. I trim the donor pool all the way to considering the least number of members of the OECD countries as a donor pool that allows me to estimate the impact, in this case only four countries.

3 Analysis

Conceptually, carbon taxes induce emissions reductions by incentivizing emitters to reduce costs. Costs of reducing emissions are uncertain ex-ante (Weitzman, 1974). The uncertainty could be due to unpredictable technological shocks, business cycles, contingencies that cannot be foreseen and contracted upon, etc. When firms face a carbon tax, they choose their abatement by balancing the marginal abatement cost of each firm with the economy-wide marginal cost of abatement (i.e., the carbon tax). If the tax level is high, firms deliver more abatement and when the tax level is low, firms deliver less abatement. Similarly, other things held the same, carbon taxes deliver relatively higher abatement during recessions and shrinking economic activities than during times of boom and growing economic activities. In times of low economic activities, firms find it very cheap to reduce emissions instead of paying carbon taxes. In times of boom and higher demand, firms find it expensive to reduce emissions, and paying the carbon tax instead of reducing emissions can minimize cost. From an ex-ante perspective, when shocks to the cost of emissions reductions cannot be predicted, the amount of emissions reductions carbon taxes deliver *ex-post* is uncertain. It is possible that a carbon tax can fail to meet national and global abatement targets. Thus, it is essential to estimate the effect of carbon taxes on emissions ex-post and infer the rate at which emissions decrease in response to carbon taxes.

To infer a causal estimate about the effect of the Finnish carbon tax on emissions, one has to estimate a valid trajectory of counterfactual emissions based on the best comparison unit. In the synthetic control approach, the best trajectory of counterfactual emissions is a convex combination of the trajectory of emissions of potential comparison countries without a carbon tax. Often, the best counterfactual fares better than individual countries in reproducing the trajectory of emissions in Finland in the years without the carbon tax. Thus, the evolution of emissions of the best comparison unit serves as an approximation of the evolution of counterfactual emissions in the years Finland has imposed carbon tax.

To clarify the mathematics of generating the optimal weights behind synthetic Finland, let N represents the number of countries in the donor pool. Let v represents the number of variables that explain emissions. Let X^D be a $v \times N$ matrix representing the data of determinants of emissions of countries in the donor pool and X^F is a $v \times 1$ vector of values of determinants of Finnish emissions, both before Finland imposed the carbon tax. With $\omega = (\omega_1, \ldots, \omega_N)^T$ as a vector of weights on the donor pool countries in constructing synthetic Finland, the vector of optimal weights is defined by $\omega^* = \arg\min_{\omega} \left[X^F - X^D\omega\right]^T S \left[X^F - X^D\omega\right]$ subject to the constraints $\omega_i \geq 0$ and $\sum_N \omega_i = 1$. Note that S is any $v \times v$ diagonal matrix with non-negative elements suggesting that the weights need to be chosen to fit the pre-treatment emissions of synthetic Finland with the observed emissions in Finland. Since the optimal weight depends upon the diagonal matrix ($\omega^* = \omega(S)$), the value of S minimize the discrepancy between the emissions of Finland and its synthetic counterpart during the pre-treatment period. Technically, $S^* = \arg\min_S \left[E^F - E^D\omega(S)\right]^T S \left[E^F - E^D\omega(S)\right]$ subject to the condition that $\|S^*\| = 1$ and thus the optimal weights are generated according to the rule $\omega^{**} = \omega(S^*)$. Let T_A represent the number of time units on and after treatment and E_A^D represents a $T_A \times N$, a matrix representing the values of emissions of countries in the donor pool after treatment. Then, the values of emissions in synthetic Finland after Finland imposed the carbon tax E_A^{SF} is given by $E_A^{SF} = E_A^D\omega^{**}$, which is a $T_A \times 1$ vector. For details, I refer the reader to Abadie (2021).

3.1 Basic Results

Using the synthetic control approach together with the data described before, the counterfactual trajectory of emissions emerges as a convex combination of emissions of six countries. These countries, with corresponding weight in a bracket, are the United Kingdom (43.20%), Turkey (18.40%), New Zealand (15.90%), Luxembourg (10.20%), Switzerland (9.40%), and the United States of America (2.90%). While the weights assigned to various countries in constructing synthetic Finland change with robustness tests, the trajectory of emissions of synthetic Finland remains surprisingly robust. Before discussing results from robustness tests, let me describe the central results.

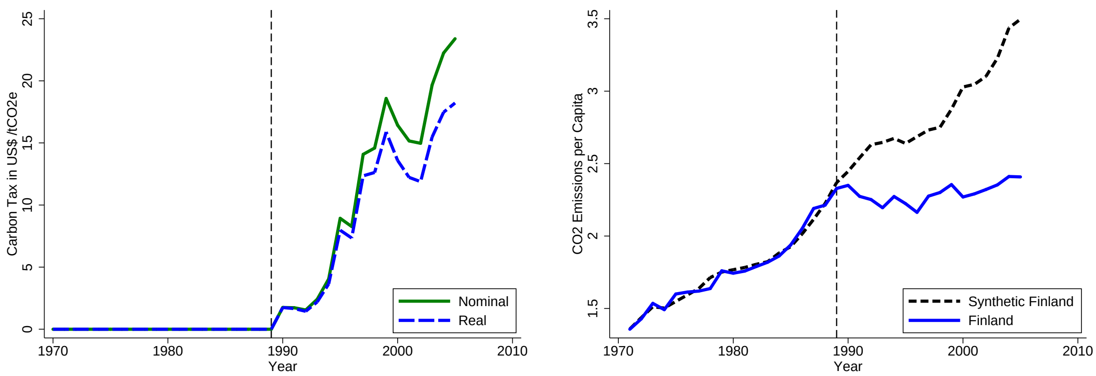
Table (1) and Figure (1) contain the summary of the main results. The comparison of predictors emissions in Finland and synthetic Finland in Table (1) suggests that synthetic Finland gives an arguably close estimate of the predictors of emissions in the period without the carbon tax (e.g., relative to the average based on the entire donor pool). In each variable, the average value in Synthetic Finland is much closer to the values in Finland relative to the average values from the donor pool. Figure (1a) reports the evolution of both the nominal carbon tax and the one adjusted for the consumer price index (CPI) at 1990 prices. While the value of the real carbon tax is less than or equal to the value of the nominal carbon tax, both graphs tell qualitatively a similar story – the Finnish carbon taxes have increased throughout the treatment period despite starting at a small amount. Similarly, figure (1b) exhibits emissions in Finland and synthetic Finland before and after 1990. Emissions in Finland and synthetic Finland increase together from 1970 to 1990. However, the trajectories of emissions in Finland and synthetic Finland depart from each other after 1990, when the carbon tax increases.

Table 1: CO_2 Emissions from Transport Predictor Means before 1990

Predictors	**Actual Finland**	**Synthetic Finland**	**OECD Average**
Percentage of Urban Population	71.35	71.30	73.10
GDP per Capita (PPP)	16722.56	16730.78	21793.98
Gasoline Consumption per Capita	285.80	374.64	418.94
Motor Vehicles (per 1,000 people)	291.67	314.59	421.76

Note: Gasoline Consumption is in kilograms of oil equivalent. Following Abadie et al. (2010) and Andersson (2019), we control for lagged outcome variable in 1975, 1980, 1985, and 1989 as additional predictors.

With the identifying assumptions under the synthetic control approach, trajectories in Figure (1a) and (1b) suggest that carbon taxes reduced emissions in 1990 – 2005 considerably. Relative to the counterfactual emissions, Finnish emissions are 14% lower in 1992, 16% lower in 1998, and 27% lower in 2003.



(a) CO_2 Tax in Finland.

(b) CO_2 Emissions from Transportation Activities.

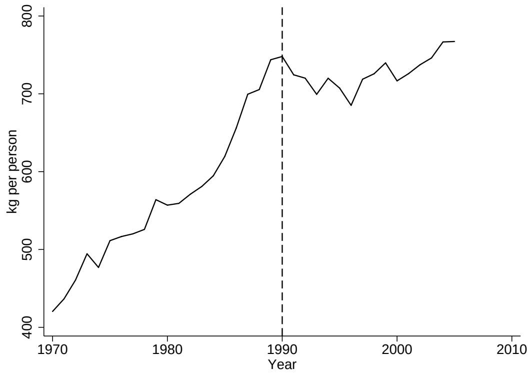
Figure 1: Carbon Tax and the Impact on Emissions in 1970 – 2005.

Much of the gains in emissions reductions come from the stabilization of emissions in Finland relative to the sharply-rising emissions in synthetic Finland. The carbon tax is smaller during the early years relative to the tax in the later years. Similarly, the gap between the two trajectories of emissions during the early years is smaller relative to the gap during the later years. The growing intensity of carbon tax per ton of CO_2 is consistent with approximately stable emissions in Finland in contrast to the growing emissions in synthetic Finland after 1990.

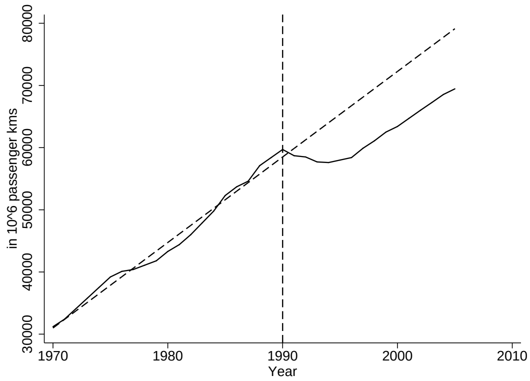
3.2 Some Driving Mechanisms

To shed light on the underlying drivers behind the observed emissions reductions, I examine how some determinants of transport emissions evolved in Finland during 1970 – 2005. To this end, I focus on the volume of gasoline and diesel consumption, the number of vehicles, and the volume of passenger transport.

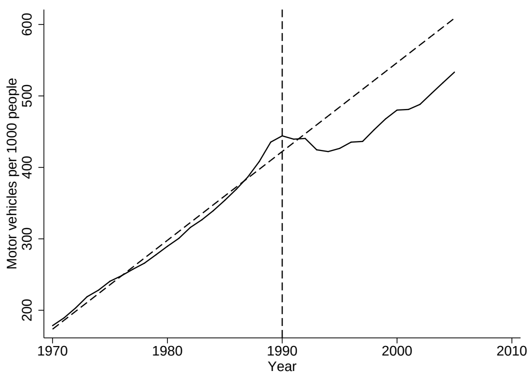
(a) Consumption of Gasoline (solid line) and Diesel (dashed line)



(b) Gasoline plus Diesel



(c) Passenger Transport



(d) Number of Vehicles Per 1000 People

Figure 2: Some Mechanisms Behind the Observed Emissions Reductions. The dashed lines in (c) and (d) are predicted outcome on the basis of trend before treatment period.

Figure (2a) exhibits the consumption of gasoline and diesel per capita before and after Finland imposed carbon taxes, using data from IEA (2020a). The figure suggests that gasoline consumption per capita declined after 1990 in contrast to an overall increase in the period before 1990. At the same time, the consumption of diesel has been increasing although there is some temporary decrease in the early 1990s. Figure (2b) shows that the total gasoline plus diesel consumption per capita in Finland increased before 1990 and became relatively more stable after 1990. In fact, Figure (2b) has a similar path as emissions per capita in Finland reported in Figure (1b). The decrease in gasoline consumption with a moderately increasing diesel consumption is arguably a central mechanism behind the estimated post-1990 decrease in emissions.

In addition to energy consumption, the volume of passenger transport activities and the number of vehicles suggest a similar story. Figure (2c) exhibits the flow of passenger transport (in 10^6 passenger-kilometers) in Finland.[5] One can witness from (2c) that the passenger transport activities have decreased permanently to a parallel path. Similarly, from Figure (2d), one can infer that the number of vehicles permanently declined after 1990 to a parallel path. While the number of vehicles increases after 1990, it increases in a path with lower quantities, in a similar way to the volume of passenger transport. Thus, the data of gasoline and diesel consumption, passenger transport, and vehicle ownership exhibit a permanent reduction, and in this sense, collectively, they shed some light in explaining the estimated decrease in emissions Figure (1b) suggests.

3.3 Carbon Tax Elasticity of Emissions Reductions

So far the values of the carbon tax are not used in estimating its causal impact, except for the introduction date. Relating the trajectories of the estimated impact and carbon taxes, one observes the co-evolution of the variables in the spirit of a dose-response test (e.g., Abadie and Gardeazabal, 2003 and Mideksa, 2013). Comparing the trajectory of the estimated impact of carbon taxes and carbon taxes, the two variables co-evolve positively with the Pearson correlation coefficient greater than 80%.

A useful parameter to summarize the effect of carbon tax is elasticity. Since the number of observations is very small, the OLS based estimation of elasticity is sensitive and its application is conceptually questionable. Thus, the annual elasticity value is computed directly using the midpoint formula (Mankiw, 2009, pp. 91-92). That is, it is the (absolute value of) percentage change in carbon tax impact (i.e., actual emissions - counterfactual emissions) over the percentage change in tax. Figure (3a) reports the carbon tax elasticity of emissions abatement per year. The initial values of annual elasticity are higher consistent with abundant possibilities of low-hanging abatement options. While the values of annual elasticity oscillate, the arithmetic and geometric mean values are 0.099 and 0.086 respectively – statistically different from zero at 95% and 99% confidence intervals. Note that the estimated value of 0.086 is slightly higher than the indirect elasticity values one infers from fuel demand (e.g., Coglianese et al.,

[5] The OECD (2021) defines passenger transport as "the total movement of passengers using inland transport on a given network. Data are expressed in million passenger-kilometres, which represents the transport of a passenger for one kilometre."

2017; Levine, Lewis, and Wolak, 2017; Knittel and Tanaka, 2019). While the direct relative price effect has to be similar, carbon taxes carry a different set of information than random fluctuations in gasoline prices. First, in democratic countries such as Finland, taxes are enacted after thorough public deliberations. Thus, carbon taxes are more salient than temporary variations in fuel prices. Second, people expect taxes to be permanent and long term while variations in fuel prices could be short-term. In response, people adjust both on the intensive and the extensive margins when facing carbon taxes whereas mostly on intensive margins for temporary fluctuations in gasoline prices. Third, carbon taxes carry a signal from a society that urge for reducing carbon emissions, a signal absent in temporary variations in gasoline prices. The decrease in ownership of vehicles (i.e., Figure (2d)) and decreased consumption of gasoline and diesel are consistent with this explanation.[6] To sum up, Finnish carbon taxes have sharply increased in 1990 – 2005. So does the predicted emissions reductions in the same period with a high estimate of the carbon tax elasticity of emissions reductions.

(a) Carbon Tax Elasticity of Abatement. (b) Finnish Industrial CO_2-Emissions.

Figure 3: Carbon Tax Elasticity of Abatement and Finnish Industrial CO_2-Emissions.

The Finnish recession in 1990 – 1993 is a unique recession, to some it was the Finnish great depression (e.g., Gorodnichenko, Mendoza, and Tesar, 2012). Can the recession be behind the observed emissions reductions? A way to infer the consequence of the recession is to examine emissions in sector where its expected impact is the highest – the industrial sector. If the Finnish recession affects emissions in the two sectors similarly, one observes a similar effect in both activities. While outputs of and inputs for activities are internationally tradable, and thus suffer from the control-treatment problem, one can observe if the recession has resulted in emissions break around 1990. Figure (3b) suggests that the secular trend in emissions from industrial activities has not changed around 1990.

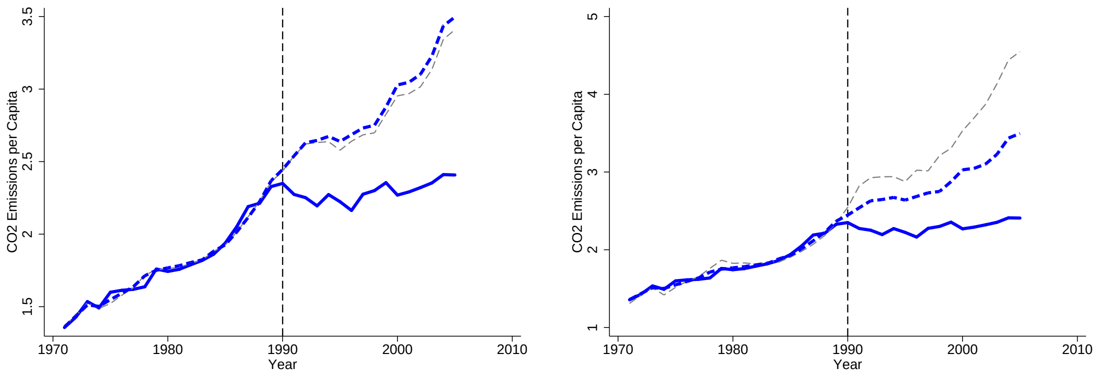
[6] I am indebted to Geoffrey Heal for suggesting these explanations.

3.4 The Effect of Implicit Carbon Prices

The identifying assumption underlying the synthetic control approach is that emissions in synthetic Finland serve as a valid counterfactual. For example, if countries price carbon indirectly through energy and fuel taxes, the identifying assumption calls for a similar evolution of such variables both in Finland and synthetic Finland. When it comes to energy prices, energy taxes, and fuel taxes, this can be too strong an assumption on two grounds. First, if governments of the countries in the donor pool tax fuel and energy and these taxes have an effect on emissions, emissions in the donor pool countries would be lower than those they would have experienced in the absence of those taxes. Under these circumstances, the counterfactual trajectory of synthetic Finland emissions after 1990 would be closer to the actual time path of emissions in Finland, downward biasing the impact estimates. Thus, the estimates presented in Figure (1) would be a lower bound on the actual unbiased estimates. In other words, if units in the control group are also treated, there should be no differences in the outcome between arms. When one finds some differences, despite some of the control units are also treated, the impact estimates are downward biased, so the actual unbiased estimates would be even larger. Second, if Finland taxes fuel and energy in addition to the carbon tax and these taxes have an effect on emissions, counterfactual emissions based on the donor pool countries – lacking both a carbon tax and the fuel and energy taxes affecting emissions – would be higher than the counterfactual emissions based on the donor pool of countries lacking lacking only the carbon tax. Thus, the estimates presented in Figure (1) correctly identify the effect of the carbon tax per se.

To examine the sensitivity of the main result, I conduct two exercises. First, I collect end-use energy price indices that take into account the end-use price, including total tax by drawing data from the IEA (2020b). Using end-use energy price indices as an additional predictor to the ones stated in table (1), I re-estimate the trajectory of emissions in synthetic Finland. The outcome of this exercise is reported in figure (4a) together with our main result from figure (1b). The bold lines in figure (4) are from figure (1). As can be witnessed from the graph, the estimated trajectory of emissions in synthetic Finland is arguably similar to the one estimated in the main result and reported in figure (1b).

Second, to address the effect of implicit carbon prices other than a carbon tax, I examined fuel tax reforms in countries without carbon taxes. Even before the concern about CO_2 emissions, countries have been imposing fuel taxes to raise revenues, reduce accidents, and address congestion of traffic. Since fuel consumption is linearly associated with carbon emissions, fuel taxes serve as indirect carbon taxes as Sterner (2007) notes. Thus, a substantial fuel tax reform changes the implicit price of carbon. While identifying a donor pool for estimating the impact of explicitly-declared carbon taxes is relatively easier, the task of identifying the donor-pool for estimating the impact of implicit carbon



(a) Controlling for end-use Energy Prices.

(b) Donor Pool based on Implicit and Explicit Carbon Prices.

Figure 4: The Effect of Energy Prices and Implicit Carbon Prices.

prices is considerably harder. The dearth of a group of countries that avoid imposing fuel taxes makes clean identification impossible, leaving one with only crude approximations.

To take into account implicit carbon prices, I exclude countries that have raised their fuels taxes from the donor pool based on weekly data on gasoline unit taxation from the Weekly Oil Bulletin of the European Commission.[7] These data cover 1994 – 2005, and thus the first few years of the treatment period are not covered. After deflating the data by CPI, I consider deviations of the taxes from the average for the entire period. I consider any country of which the tax series deviates by more than 20% in absolute value from the average in 1994–2005, at any point, as having conducted implicit carbon tax reform. Due to fuel tax data availability in 1990 – 1994, I exclude all countries which have either imposed explicit carbon taxes or conducted major 'implicit carbon tax' reforms in 1994 – 2005. In the end, I remain with countries of Austria, Belgium, France, Germany, Italy, Luxembourg, Netherlands, and Spain as a donor pool for both explicit carbon tax and implicit carbon prices to estimate the effect of carbon prices on emissions. Using these countries as a donor pool, I re-estimated the trajectory of emissions in synthetic Finland to identify the effect of other components of the carbon price. I report the outcome of this exercise in figure (4b) together with the main result from figure (1b). As can intuitively be expected, accounting for the implicit price of carbon through motor fuel taxes raises emissions reductions further in addition to the one estimated for explicit carbon taxes.

To sum up, I have estimated both the impact of explicitly-declared carbon taxes and the effect of taking into account implicit carbon prices via fuel taxes. The above *approximation* is based on a some-what ad-hoc criterion to capture significant motor fuel tax reforms in the post-1990 period. With caveats in proper identification, the estimated effect suggests that implicit carbon prices raise emissions reductions in addition to the

[7]The Weekly Oil Bulletin data are from `https://ec.europa.eu/energy/data-analysis/weekly-oil-bulletin_en`.

one from explicitly-declared carbon taxes in line with the intuition from economic theory. To examine the main result's robustness, I carry out several tests, including the tests that Abadie (2021) recommends.[8] First, I perform a back-dating test by introducing hypothetical carbon taxes in 1986, 1987, and 1988. Besides, I drop one predictor at a time to re-estimate emissions in synthetic Finland. I find that the results are robust to such tests. Second, I examine the main result's robustness to the unavailability of data, particularly from countries in the donor pool. Abadie (2021) recommends conducting the leaving-out test and examining the effect of dropping a country constituting the synthetic unit from the donor pool. The result remains robust to this test in all cases with a satisfactory pre-intervention fit. Moreover, I adopt a stricter test of excluding countries with weights above 15% in synthetic Finland *simultaneously* to construct a counterfactual trajectory of emissions from the remaining ones.[9] I do this in several rounds *without replacement* until it becomes impossible to estimate the impact. In the first round, I exclude countries with a total weight of 77.5% in the construction of synthetic Finland from the donor pool simultaneously. In the second round, I exclude countries with a total weight of 86.9% in the construction of synthetic Finland from the donor pool. Subsequently, I excluded countries with a total weight of 77.5%, 40.3%, 74.7%, and 89.4% to finally end up with four countries as the last remaining members of the donor pool: Iceland, Ireland, Luxembourg, and the United States of America. Again, the central result remains qualitatively robust even to these extreme exclusion tests.

Third, I conduct a permutation test by imposing a hypothetical carbon tax on the countries in the donor pool in 1990 and examining the chance of arriving at estimated impacts like the one in Finland (Abadie, 2021). The permutation test suggests that, limiting the comparison to the countries whose optimal comparison unit replicates the pre-1990 emissions well, observing emissions reductions like that of Finland is highly unlikely. Fourth, I relate the annual estimated impact with the annual carbon tax to discern how the trajectories of the two variables evolve. I find that the two variables co-evolving with the Pearson correlation above 80%.

Together, these tests suggest that the main result – that the Finnish carbon taxes have reduced carbon emissions – survives at least the conventional diagnostic tests. The results suggest that some force has stabilized Finnish emissions since 1990 relative to the sharply rising emissions in similar countries without a carbon tax. The observed outcome is consistent with the expected effect of a carbon tax with growing intensity over time.

[8]In the interest of space, I describe only the results leaving the details in the Appendix.

[9]The 15% cutoff is chosen based on the minimum cutoff to maintain a decent pre-treatment fit.

4 Concluding Remarks

This article has taken the synthetic control approach seriously to contribute towards answering an urgent question. The results suggest that something has stabilized Finnish emissions since 1990. The stability is more pronounced when compared with the sharply rising emissions in other similar countries lacking a carbon tax. Without a randomized-control trial, it seems that the story of a carbon tax with increasing intensity is a plausible story consistent with the estimated emissions reductions. At a minimum, the evidence does not lend support to the idea that carbon taxes do not reduce emissions in a sector that many consider having an inelastic demand. Where do the results leave us?

While learning from the Finnish experience with carbon taxes is crucial, the evidence is far from being the last word about the issue. Since the results are intuitive and necessary for public policy, it would be great to see further work in the area. For example, while one recognizes that the Finnish recession in 1990 – 1993 could have played some role in reducing emissions, it is unclear if the recession is the central explanation for the observed emissions reductions in 1993 – 2005. Similarly, the high elasticity estimates may reflect the low-hanging fruits. With these clearly stated, this article provides plausible evidence that a carbon tax can deliver meaningful emissions reductions. By doing so, it shows that taxing carbon has been crucial in leveling off emissions from transport and ensuring a partial decoupling of emissions from economic growth.

The case for a carbon tax, when compared with auctioned quotas, is far from unanimous. The reservation goes back, at least, to Buchanan (1969, p. 175) – who aimed at contributing the project of "dismantling of the Pigovian tradition in applied economics, defined here as the emphasis on internalizing externalities through the imposition of corrective taxes and subsidies." The current concerns include the difficulty of meeting a given emissions target (Harris and Pizer, 2020) and the ramifications for risk externality (Mideksa, 2020), the political difficulty of imposing a tax and changing it over time (Slemord and Bakija, 2017), the challenge of enforcing a tax and avoiding evasion in countries with a weak fiscal capacity (Acemoglu, 2005; Besley and Persson, 2009), the ease for allowing exceptions and loopholes and for undermining a tax through subsidies to complementary inputs, and other factors covered in Sterner and Coria (2012) and Stavins (2020). These factors, in addition to carbon leakage, can explain why there was no break in the trend of Finnish industrial CO_2 emissions around 1990.

The Finnish experience is valuable, at least, when it comes to the concern against carbon taxes, relative to auctioned quotas, due to the uncertainty of meeting emissions targets (Harris and Pizer, 2020). Focusing on political economy considerations, Brooks and Keohane (2020, p. 20) explain the point as follows. "In general, the environmental community is focused on ensuring emissions reductions, while the regulated industry is focused on limiting costs. The former's strong preference for such *environmental certainty* helps to explain why existing market-based climate policies are overwhelmingly quantity-based; the latter's insistence on some degree of *cost certainty* helps to explain why these policies generally also include price containment mechanisms."[10] Emissions target can be unmet due to the uncertainty from business cycles or MIT shocks like pandemics. Other things being the same, carbon taxes deliver higher abatements during recessions and lower abatements during booms, relative to auctioned quotas. In times of recessions, firms find it very cheap to reduce emissions instead of paying carbon taxes. In times of boom and higher demand, firms find it expensive to reduce emissions, and paying the carbon tax instead of reducing emissions minimizes cost. Since economies tend to have more periods of a boom than periods of a recession (e.g., see Figure 2 in Rebelo, 2005), some stakeholders (e.g., environmentalists that Brooks and Keohane (2020) refer to) worry that taxes can fail to meet emissions targets. Nevertheless, the Finnish experience in 1990 – 2005 suggests something else: a well-crafted carbon tax induces meaningful emissions reductions both in booms and recessions in the early phases of decarbonization. Thus, the Finnish experience does not support the idea that carbon taxes are excuses to continue emitting more.

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Appendix: Robustness Tests

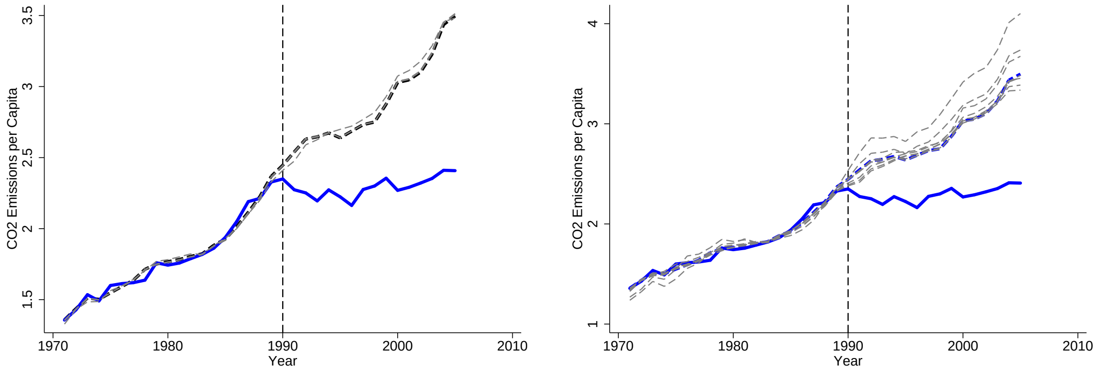
It is essential to conduct several diagnostic tests of the main results to obtain valid estimates of the impact of a carbon tax on emissions. Abadie (2021) recommends the standard tests for a causal estimate based on the synthetic control method. The goal is to know the sensitivity of the results in response to various diagnostic tests.

Back-dating Test and Leaving-out Predictors Test

The core concern is about the consequences for emissions reductions if one were to estimate Synthetic Finland with data before 1990. For example, one's confidence in the reliability of these results becomes weaker if one could observe emission reductions relative to the counterfactual before 1990. To address this issue, I conduct the back-dating test that Abadie (2021) recommends. I conducted three experiments and assigned hypothetical carbon taxes in 1986, 1987, and 1988. Figure (5a) reports a summary of the outcome of the back-dating test. The set of countries, and the corresponding weights for, constituting synthetic Finland change in response to the back-dating test. The graphs suggest that the trajectory of synthetic Finland for hypothetical carbon taxes in 1986, 1987, and 1988 is almost identical to the trajectory of synthetic Finland. Thus, there are no emissions reductions in the period without carbon tax even if I assign a placebo carbon tax in years before the actual implementations of the carbon tax. Yet, the predicted emissions reductions in the periods with the tax remain similar. In addition, I examine the consequences of dropping one of the predictors at a time. While this test is crucial to examine the robustness to missing data of one of the predictors, it is extreme in the sense of using a comparatively sub-optimal model to estimate the trajectory of emissions without carbon tax with less information on a predictor. Figure (5b) presents the outcome of this experiment, which suggests the qualitative results remain robust in the sense of being a lower-bound in response to dropping a predictor.

Leaving-out Countries Test and Permutation Test

Robustness to missing data is a great quality for a reliable result. One should carefully examine results that change dramatically without reducing the pre-treatment fit in response to minor changes in the donor pool in addition to changes in predictors, say

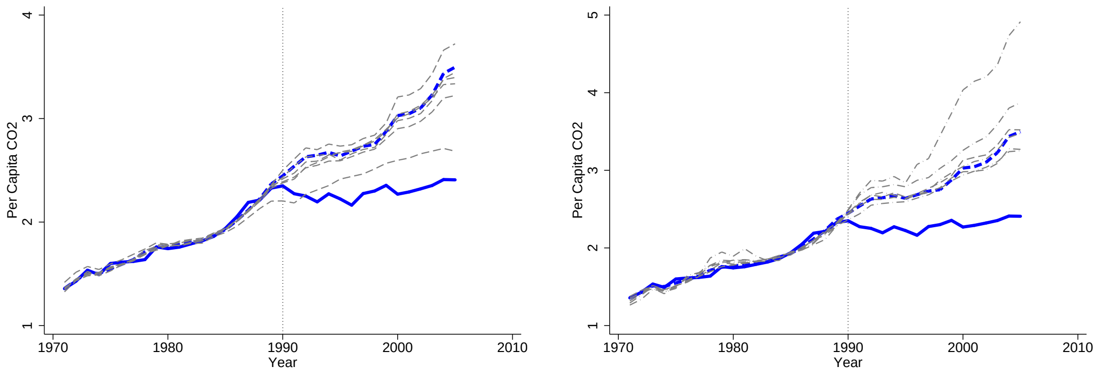


(a) Placebo Carbon Taxes in 1986, 87, or 88.

(b) Dropping a Predictor Test.

Figure 5: Back-dating Test and Leaving-out a Predictor Test

due to missing data that may occur by chance.[11] Even the accounting of emissions data may be incomparable with the accounting of the rest of the world. In this regard, the Paris Climate agreement had to negotiate to establish harmonized monitoring, reporting, and verification of emissions across countries. Thus, for any reason, if a country's data is missing, it will not play a role in the construction of synthetic Finland. Understanding how the results are sensitive, to changes in the members of the donor pool, becomes useful. To address this concern, Abadie (2021) recommends a test of leaving-out only a country with a positive weight from the donor pool at a time. As can be seen from Figure (6a), the result is qualitatively robust to removing the countries with a positive weight, whenever the pre-treatment fit is satisfied.



(a) Leaving-out a country with a positive weight from the donor pool.

(b) Leaving-out all countries with a weight above 15% simultaneously from the donor pool in multiple rounds, without replacement.

Figure 6: Leaving-out Countries Diagnostics.

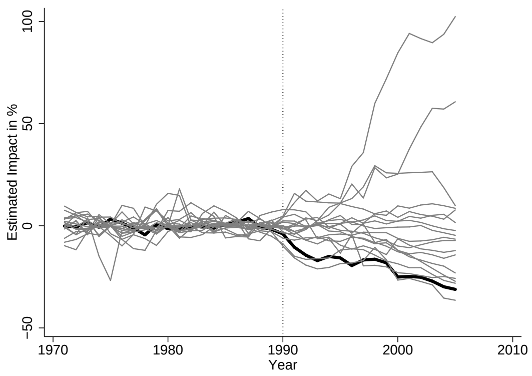
[11]This important because this can happen for any reason. For example, countries undergo various political transformations, and new nations emerge (Alesina and Spolare, 2005).

One can consider the results in Figure (6a) as possibilities. If the pre-treatment fit in all cases of Figure (6a) is acceptable, the estimated effect of carbon taxes with the poorest pre-treatment fit (i.e., when I drop Luxembourg from the donor pool) serves as the lower bound of the effect of carbon taxes. In this particular case, relative to the counterfactual emissions, Finnish emissions are 5% lower in 1993, 13% lower in 2000, and 11% lower in 2004. Even when assuming equal likelihood, this possibility arises in one out of six possibilities.

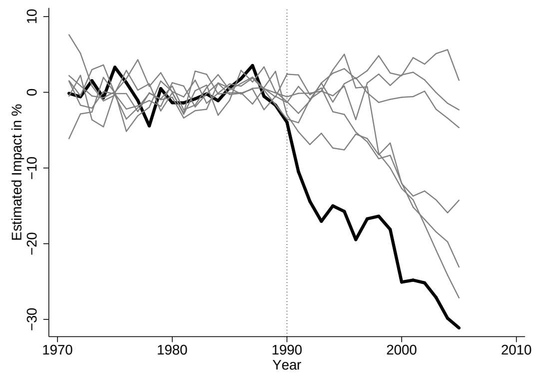
As additional tests, motivated by the case of the poorest pre-treatment fit in Figure (6a), I conduct an extreme test of excluding all the countries with nice pre-treatment fit *simultaneously* from the donor pool. Note that Abadie (2000) does not suggest this extreme test and is unseen in the synthetic control literature. Figure (6b) presents the outcome of the experiment for several rounds without replacement. In the first round, countries having a weight higher than 15% (i.e., the United Kingdom, New Zealand, and Turkey) *all at once* were removed.[12] This experiment called for removing countries with a total weight of 77.5% in the construction of synthetic Finland from the donor pool simultaneously. In the second round, the experiment called for removing countries with a total weight of 86.9% in the construction of synthetic Finland from the donor pool. Subsequently, the experiment called for removing countries with a total weight of 77.5%, 40.3%, 74.7%, and 89.4% to finally end up with four countries as the last remaining members of the donor pool: Iceland, Ireland, Luxembourg, and the United States of America. The outcome from these tests suggests that Luxembourg is essential for replicating Finland's emissions before 1990. Finally, I conducted two additional tests. I exclude *all* countries with positive weight from the donor pool, and I limited the donor pool to the one Andersson (2019) used when examining the effect of Swedish carbon taxes. In both cases, the outcome is qualitatively similar but the quality of the fit of emissions in the pre-treatment period becomes very poor. Together, these experiments suggest that the central estimate remains robust in the sense of being a lower-bound of the impact of carbon taxes.

The last class of tests I conduct, in addition to the robustness to missing data tests, is what Abadie et al. (2010) call the permutation test. That is, I iteratively assign a hypothetical carbon tax in 1990 to each country in the donor pool and estimate the placebo effects in each iteration. Figure (7a), presents the estimated distribution of outcomes from placebo treatment in each country. Panel b does the same only for countries with a comparable pre-treatment fit to that of synthetic Finland. I assume that a country has a similar pre-treatment fit with that of synthetic Finland when the maximum value of its root-mean-squared prediction error (RMSPE) less than 25% above the level of synthetic Finland. As can be seen from the picture, the observed effect of the carbon tax in Finland (i.e., a thick solid line) represents the maximum reduction of emissions in the permutation

[12]The 15% cutoff is chosen based on the minimum cutoff to maintain a decent pre-treatment fit.



(a) Placebo treatment in 1990 to countries in the donor pool



(b) Placebo treatment in 1990 in countries with good pre-treatment fit

Figure 7: Permutation Test.

distribution. Abadie et al. (2010) report that the ratios of post/pre-treatment RMSPE to calculate the implied p-value if one were to assign the intervention at random in the data, which in this case is $1/20 = 0.05$.