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JEL Classification: E31, E50, Q54, Q43

Keywords: Co2 taxes, Carbon Pricing, inflation, monetary policy, climate change

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1 Introduction

At a recent large scale gathering of central bankers and financial market participants, Larry Fink, CEO of Black Rock, made headlines by predicting that the fight against climate change will fuel global inflation.[1] With more and more countries joining the race to decarbonize their economies, understanding the impact of climate policies on inflation becomes of first order importance to monetary policy makers. Recently, the European Central Bank has emphasized the question in its 2021 strategy review and climate action plan.[2] Rising carbon prices do raise the specter of oil price shocks and 1970-style stagflation. Since then, oil price shocks have held a special chapter in macroeconomic policy, as quintessential supply side shocks combining lower output with higher inflation. One might expect that carbon taxes have the a similar inflationary effect as a surge in the oil prices. However, this conclusion may be too hasty.

The effect of a carbon tax on inflation will depend on many factors, including the size of a carbon tax, its coverage, use of the tax revenue and the redistribution. Tax incidence may play a role: if carbon taxes are absorbed in producer's margins, the response in final energy prices may be muted, as would be the effect on energy use and emissions. And finally, the price response could also depend on the reaction of monetary policy: if the central banks do not accommodate the carbon tax shock, keeping the average price level strictly on target, increasing energy prices may have to be (mechanically) compensated by declines in other price categories. In theory, therefore, the effects of carbon prices on inflation are unclear.

Existing modelling studies on the effect of carbon taxation point to sizeable effects on inflation, based on the assumption that higher energy prices are largely passed on to consumers. For instance, McKibbin, Morris, and Wilcoxen consider a 15 US dollar carbon tax implemented in the United States, and find that it causes a rise of inflation by 0.8% during the first year of the policy. The contribution of this paper is to study the link empirically.

To the best of our knowledge, this is the first study emphasizing the impact of carbon taxes on inflation. Our analysis builds on carbon taxes implemented in Europe and Canada. Methodologically, we separately apply the synthetic control method and local projections to identify the effects on the consumer price index (CPI) and its components. Our main finding is that carbon taxes have not been inflationary and may even be somewhat deflationary. This finding is remarkably robust across different jurisdictions, for different implementation waves, controls for macroeconomic performance and monetary policy responses, as well as other sample tests. We find that relative prices changed following the implementation of a carbon tax, but increasing energy prices where compensated by decreasing prices in food, services and shelter. We then explore macroeconomic and distributional channels that could explain the finding. In particular, we study the responses of GDP, household income

[1] Bloomberg, June 18, 2021, see https://www.bloomberg.com/news/articles/2021-06-18/the-climate-change-fight-is-adding-to-the-global-inflation-scare.

[2] See https://www.ecb.europa.eu/press/pr/date/2021/html/ecb.pr210708_1~f104919225.en.html.

and wages in response to the carbon tax in the Canadian province British Columbia (BC). We also explore heterogeneous effects on households across the income distribution. With the experience of the yellow vest movement in France in mind our suspicion was that the carbon tax may have been regressive, reducing incomes and expenditures of the poorest the most. Our findings on the response of GDP are line with previous studies (Metcalf 2019; Yamazaki 2017), namely effects are mostly insignificant.

By contrast, we find that real household income, compared to other Canadian provinces, fell significantly after the introduction of the carbon tax in British Columbia. The findings is uniform across the income distribution, but most pronounced for households belonging to the top income quintile. As a result, real household expenditures also declined in the wake of the carbon tax, potentially resulting in a negative demand shock putting downward pressure on prices. The decline in expenditure is particularly pronounced for non-tradables. At least for BC, our evidence supports the thesis that falling household income contributed to the observed price dynamics.

In addition to the indirect channel through declining household income and expenditure we also find support for a complementary explanation for the relative decline in prices of non-energy prices: permanently higher energy prices should reduce the net present value (NPV) of energy-intensive durable goods, most prominently houses and cars. In British Columbia we document that not only the prices of shelter but also those of vehicles declined (relative to the control group) following the introduction of the carbon tax.

Related Literature. Our paper is related to a growing empirical literature studying the effects of climate change policies, in particular carbon taxes. Prior studies have documented that carbon taxes achieve their goal of reducing emissions (e.g. Murray and Rivers 2015, for Canada; Andersson 2019, Martin, De Preux, and Wagner 2014, Lin and Li 2011, Best, Burke, and Jotzo 2020, for Europe). Rafaty, Dolphin, and Pretis (2020) provide a survey of this literature.

Literature on the economic effects of carbon taxes are scarce by comparison. Focusing on the carbon tax in British Columbia, Metcalf (2019) and Bernard, Kichian, and Islam (2018) find no aggregate effects on GDP or employment. Yamazaki (2017) confirms the findings for aggregate employment, but finds a small, negative response of wages in British Columbia related to the carbon tax. Our study is consistent with the limited economic effects in BC, and adds evidence on the response of prices.

Metcalf and Stock (2020) study the economic effects of carbon taxes based on a sample of 15 European countries since 1990. The authors find no empirical support for a negative effect on GDP or employment. Based on the identical sample, we complement these results with the previously unexplored, monetary effects, of carbon taxes.

Finally, there is a strand of the literature that uses multi-sector, multi-country models to simulate the effects of climate change, climate policies and carbon taxes (see e.g. McKibbin, Morris, and Wilcoxen 2014; McKibbin et al. 2017; IMF 2020). Compared to the empirical counterparts, these modelling studies tend to find contractionary output effects.

Although output is at the center of these simulation studies, inflation is frequently included as an auxiliary variable. Across studies, the simulation exercises of a plausible carbon tax implementation predict an inflationary effect, that is often sizeable (e.g. McKibbin, Morris, and Wilcoxen 2014, for the United States; Andersen and Mainguy 2010, for Europe; Rahman 2011, for Australia). Much like the empirical literature on carbon taxes and aggregate output, our findings stand in contrast with the predictions from the theoretical models, emphasizing the need for future research on the topic.

The remainder of the paper is organized as follows: The next section provides background information on our sample of carbon taxes, in Canada and Europe. Section 3 presents the data and outlines the empirical strategy. In section 4, we show empirical results for the Canadian sample, including evidence on the macroeconomic and distributional effects. Section 5 provides further evidence based on the set of European countries. Finally, section 6 concludes and discusses avenues for future research.

2 Carbon Taxes in Canada and Europe

Carbon taxes have been deployed as instruments to reduce greenhouse emissions since the early 1990s. In Europe, the first countries to tax carbon were the Scandinavians, of which Sweden and Norway set an initial tax rate which continue to be among the highest globally. A second wave of adopters followed in the early 2000s (mostly in Eastern Europe and the Baltics), a third wave between 2008 and 2010 (Switzerland, Ireland and Iceland) and finally the fourth in the period 2013 – 2015, when the United Kingdom, France, Portugal and Spain introduced carbon taxes. This yields a total sample of 15 European countries which have enacted carbon taxes in addition to participating in the European Emissions Trading System (ETS).[3]

We also explore a set of Canadian carbon taxes implemented at the provincial level, with particular emphasis on British Columbia. The BC carbon tax in 2008 was a unique policy experiment during that time due to its almost universal coverage, spanning 70% of total carbon emissions. Quebec and Alberta soon followed with carbon pricing systems, as of 2019 Canada also implemented a national carbon tax.[4]

Our sample of carbon taxes is summarized in Table 1. We observe considerable heterogeneity, both in terms of initial and current tax rates, expressed in 2018 US dollars (USD), as well as in the tax base, expressed as the share of total GHG emissions covered by a tax.[5] Carbon taxes range from a negligible 0.08 USD in Poland to more than 100

[3]The ETS is a "cap and trade" system, which has been introduced in 2005. Due to design problems, free allocations and oversupply, prices of ETS fell below 5 euro and remained at that level for several years. Only in 2018, after the EU fixed some of the related issues, has the price of the ETS started to rise steadily. See https://ec.europa.eu/clima/policies/ets_en. Switzerland had a parallel cap and trade system in place since 2008, but joined the ETS in 2020.

[4]Alberta introduced a carbon tax in 2017, which was abolished in 2019. Quebec introduced a cap-and-trade system including a price floor in 2013. We use the minimum price of the cap-and-trade system analogous to a carbon tax, as it puts an effective lower bound on the price of emissions.

[5]The tax base is both dependent on the number of sectors that are included in the tax, as well as the range of fossil fuels that are covered. For instance, most taxes with a large base (e.g. Ireland) span all fossil

USD in Switzerland and Sweden. In the large European countries, the tax tends to cover around one third of total GHG emissions, on average.

Economists often advocate for Pigouvian taxes to be redistributed to the population (on a per capita basis), since the purpose of the tax is to affect consumption and internalize external effects by correcting relative prices, not to increase government revenues. Moreover, the political economy of introducing a Pigouvian tax may also suggest redistributing revenues back to households (and voters). A number of countries seem to have followed this path by introducing carbon taxes in conjunction with redistribution schemes for the tax revenues. Table C1 of Appendix C give an overview of different tax designs and redistribution schemes. Below we provide more details for two carbon taxes, British Columbia and Switzerland, respectively.

Table 1: Carbon tax sample

Jurisdiction	Date	Initial rate (USD)	2018 rate (USD)	Coverage
Finland	January 1990	3.35	76.87	0.36
Poland	January 1990	0.11	0.08	0.04
Norway	January 1991	71.87	64.29	0.62
Sweden	January 1991	75.99	139.11	0.40
Denmark	May 1992	11.94	21.45	0.24
Slovenia	January 1996	11.94	21.45	0.24
Estonia	January 2000	0.33	2.25	0.03
Latvia	January 2004	0.56	5.06	0.15
Switzerland	January 2008	13.90	100.90	0.33
Ireland	January 2010	23.26	25.00	0.49
Iceland	January 2010	9.80	35.71	0.29
United Kingdom	April 2013	8.09	25.46	0.23
Spain	January 2014	29.25	24.80	0.03
France	April 2014	10.24	55.30	0.35
Portugal	January 2015	5.80	8.49	0.29
British Columbia	July 2008	5.83	33.75	0.70
Quebec	January 2013	11.59	14.73	0.85
Alberta	January 2017	20.48	30.00	0.48

Notes: This table summarizes the carbon taxes used for the empirical analysis, for European countries and Canadian provinces. All rates are expressed in 2018 USD per ton of carbon dioxide (CO_2) equivalent (e) emissions, using the U.S. GDP deflator to convert nominal USD rates from the Carbon Pricing Dashboard of the World Bank. Coverage is the share of total greenhouse gas (GHG) emissions covered by the tax in 2019. For the United Kingdom, and Quebec, we use the price floor of the respective cap-and-trade systems as the carbon tax rate. Source: https://carbonpricingdashboard.worldbank.org/, Accessed 15.02.2021.

Two examples of carbon tax designs and redistribution schemes

Switzerland. The Swiss carbon tax has been in place for more than a decade and remains one of the worlds' highest carbon tax rates today. Recently, it regained public

fuels, whereas those with a small base (e.g. Spain) tend to only apply to a minority of fossil fuels. For more details, see the Carbon Pricing Dashboard of the World Bank.

attention, as a further increase in the tax rate was submitted to a popular vote and rejected. The referendum highlights that the taxation of carbon remains a sensitive issue also from a political economy perspective.

As an alpine country, Switzerland is highly exposed to climate change, as retreating glaciers and extreme weather events are causing droughts, floods and landslides. Moreover, since 1864 the average temperature in Switzerland has increased by about 2 degrees Celsius, more than double the global average.[6] Thus, environmental awareness is high and climate policies have been progressive, compared to bordering countries in Europe.

Switzerland has only few large, stationary emission sources (captured though an emission trading system), which leaves the carbon tax as the main climate instrument. The carbon Act was originally enacted in 2008 on the basis of the Kyoto Protocols' greenhouse gas emission reduction targets. The tax was designed with an automatic adjustment mechanism based on the attainment of a set of interim abatement targets. In case targets were not reached, it automatically increased by multiples of 12 Franks per ton of emissions to a maximum of 120 Swiss Francs.

Switzerland imports all fossil fuels, so the tax can easily be levied at border crossing. The charge covers heating oil, natural gas, hard coal and propane, leaving transport as the main exempt sector. There is a redistribution scheme in place, under which one third of tax revenues is used to pay for a building energy efficiency program and a technology fund. Two-thirds are redistributed to households on a per capita basis (as a rebate on the compulsory health insurance) and to firms, in proportion to their payroll (Hintermann and Zarkovic 2020).

In 2019 the Federal Council of Switzerland proposed a revised CO2 Act in line with its commitment to the goal of net zero greenhouse gas emissions by 2050. The revised Act proposed an increase of the carbon tax up to 210 Swiss francs that would span to the transport sector, including a charge on air plane tickets. Again, the revenues from the tax were to be redistributed to a investment fund, firms and households. The Ministry of Environment calculated that an average Swiss household (with 2 children, a car and a holiday by plane) would have to pay 97 Swiss Francs more per year, after redistribution. This seemed a relatively small price to pay in a country where median disposable income is more than 50,000 Francs per year. In addition, costs would be significantly reduced if the household decided to switch to an electric vehicle, or modernize their heating system.[7]

The law was backed by the majority of governing parties but a coalition of the right wing, populist party and various interest groups (e.g. the automobile club) fought vigorously against it, culminating in the rejection of the proposal by popular vote (held on June 13, 2021). The analysis of the voting patters shows a familiar regional divide, with cities clearly voting in favor of the higher tax and the rural population against. More surprisingly, the

[6] See Bundesamt für Umwelt, https://www.bafu.admin.ch/bafu/de/home/themen/klima/dossiers/klimaschutz-und-co2-gesetz.html.

[7] See Bundesamt für Umwelt, https://www.bafu.admin.ch/bafu/de/home/themen/klima/dossiers/klimaschutz-und-co2-gesetz/kosten-des-revidierten-co2-gesetzes-fuer-eine-durchschnittsfamilie.html.

majority of young voters also voted against the strengthened CO2 Act.[8]

This outcome was a shock especially for the incumbent government, which counted on seemingly strong public support for green policies in order to retain its status as a "model country" in the fight against climate change. The Federal Council is now forced to reconsider its climate strategy and commitments.

British Columbia. British Columbia was one of the first jurisdictions to implement a major carbon tax covering the bulk of its emissions. Though today BC's tax rate is below than that of many of its European counterparts, its coverage is higher since it includes transportation. This is particularly impressive given the apparent large degree of polarization and resistance towards carbon taxes in North America.

Canada had ratified the Kyoto Protocol in 2002, but climate policies mostly focused on education, voluntary initiatives and financial incentives. Like Switzerland, Canada is highly exposed to climate change and there is public support for mitigation policies, in principle. Unlike Switzerland, however, Canada is also an oil producer and until recently faced resistance against stringent measures at the national level. This opened the path for climate action at the provincial level (Duff 2008).

In mid 2008 British Columbia introduced a carbon tax on all fossil fuels, including gasoline, diesel, natural gas, coal, propane, and home heating fuel, levied on purchases by all business and households. At its enactment, the tax started at 10 Canadian dollars (CAD) per ton of CO2e, scheduled to increase by 5 CAD each year until 35 CAD, where it remained flat until 2018.

In principle, the design was to be revenue-neutral, but the tax credits frequently exceeded tax revenues. A complex redistribution scheme was put into place, which favors low-income households and small businesses. For instance, low-income households received lump-sum payments of 100 CAD per adult and 30 CAD per child. Additional redistribution elements are: 1. An income tax decrease for low-income households (by 2 percent (2008) and 5 percent (2009), respectively); 2. A corporate income tax decrease for small corporations (<500,000 CAD revenue) to a level of 3.5 (2008), 3 (2010), and 2.5 (2011) percent, respectively; 3. A corporate income tax decrease for large corporations (>500,000 CAD revenue) to a level of 11 (2008), 10.5 (2010), and 10 (2011) percent, respectively (see also Yamazaki 2017).

BC's carbon tax rate, as well as the redistribution scheme have been readjusted several times, and are state contingent. A previously scheduled increase of the rate was postponed in 2020 to provide emergency relief during the COVID-19 pandemic. In 2022 the rate is scheduled to increase to 50 CAD per ton of CO2e emissions. Moreover, in 2019, the Canadian federal government finally implemented a nation-wide carbon price, beginning at rate of 20 CAD and rising to 50 CAD per ton of CO2e emissions.[9] According to observers, the carbon tax in British Columbia enjoys popular support. In contrast to the Swiss tax, this has not been tested in a direct vote.

[8]For details, see https://www.admin.ch/co2-gesetz.

[9]See https://www2.gov.bc.ca/gov/content/environment/climate-change/clean-economy/carbon-tax.

3 Data and Empirical Approach

We proceed by outlining the data and empirical strategy for identifying the effect of carbon taxes on the price level in two separate samples of carbon tax jurisdictions: Canadian provinces and European countries, listed in Table 1.

3.1 Data

Our data on carbon tax rates and tax bases are retrieved from the World Bank's Carbon Pricing Dashboard[10]. All tax rates are expressed in USD, going back to 1990 when the first tax in our sample was implemented. Throughout, we compute real carbon tax rates, using the 2018 US GDP deflator.

For the sample of European countries, we use data on CPI, as well as macroeconomic aggregates. We obtain CPI data at monthly frequency from the OECD, spanning the period 1985–2019. The sample includes 32 OECD countries, and the data are dis-aggregated for food, energy and core CPI, which excludes food and energy.[11]

In addition to the monthly sample, we construct a separate sample of CPI data at annual frequency (from the OECD), spanning a similar time period. It comprises of 26 European countries with available data. Finally, we match data annual data on GDP per capita (retrieved from the OECD) and monetary policy rates, from the Bank for International Settlements.

More details on both European samples, including descriptive statistics on the CPI data are presented in Appendix B, Tables B1 and B2.

Our Canadian sample consists of monthly CPI data at the provincial level, available since 2000. For each province, data are dis-aggregated into granular consumption categories. We separately explore the series on services, shelter, energy and food in our analysis. Moving to macroeconomic aggregates, we retrieve data on GDP per capita, compensation per worker and household income per capita at annual frequency since 2000. Finally, we leverage data from the Canadian survey of household spending (SHS), which provides detailed consumption expenditure and income estimates based on surveyed households, dis-aggregated by income quintile and province, at annual frequency since 2000. All Canadian data are obtained from Statistics Canada.

3.2 Empirical approaches

Our analysis builds on two separate empirical approaches. First, we use the synthetic control method to identify the "treatment effect" of a jurisdiction implementing a carbon tax on CPI, relative to other jurisdictions without a similar tax. Second, we employ local projections to control for potential confounding factors. In case of British Columbia, we complement our analysis using a Difference-in-Differences estimator for robustness, outlined in Appendix A2.

[10] https://carbonpricingdashboard.worldbank.org/, Accessed 15.02.2021

[11] Core CPI consists mainly of non-tradables, housing, transportation and services.

The synthetic control method (SCM) proposed by Abadie and Gardeazabal (2003) and Abadie, Diamond, and Hainmueller (2010) relies on constructing a data-driven synthetic counterfactual jurisdiction that is identical to a given carbon tax jurisdiction in every way, except the carbon tax. As an example, the algorithm would construct a synthetic control to perfectly track CPI in British Columbia prior to the tax implementation, based on a weighted average of the remaining 9 Canadian provinces. By comparing the path of CPI after the implementation, we can assess the effect of implementing a carbon tax on CPI. Identification relies on the assumption, that the two evolve in the same way in the absence of a carbon tax.[12]

Each synthetic control economy is constructed using an algorithm that minimizes the deviation of CPI between the treated and counterfactual economy before the carbon tax implementation. Specifically, the algorithm assigns data-driven weights to a set of donor economies in order to match the path of CPI before the tax enactment as closely as possible. The effect of implementing a carbon tax is evaluated by observing the difference of the two groups, which we refer to as the synthetic control gap.

For each implemented carbon tax, we choose a 10 year event window around the enactment, and use the period prior to the tax for the selection of the synthetic controls. Since our data are at monthly frequency, this exercise amounts to minimizing the difference in CPI based on 60 individual observations (namely, 5×12). Throughout, we exclude countries that themselves introduced a carbon tax during the event window from the donor pool.

Specifically, for each carbon tax implementation in economy E we denote Y_e the vector of CPI in the tax country and X_e the CPI matrix for the potential counterfactual economies C, in the donor pool. The individual weights w_c^e are contained in the weighting vector W_e. The optimal vector W_e^* minimizes the following mean squared error:

$$(Y_e - X_e W_e)' V_e (Y_e - X_e W_e), \quad e = 1, ..., E \tag{1}$$

subject to $\sum_{c=1}^{C} w_c = 1$, and $w_c \geq 0 \; \forall \; e, c$. Matrix V_e is positive-semidefinite and symmetric (see Abadie, Diamond, and Hainmueller 2010).

For the sample of European countries, we seek to assess the average effect that a carbon tax has on the price level. At each point in time, we therefore follow Acemoglu et al. (2016) and Funke, Schularick, and Trebesch (2021) to take averages of CPI across all carbon tax countries, and their synthetic controls, respectively.

The decision to implement a carbon tax is potentially endogenous to the economic environment, in particular governments might be inclined to introduce and adjust carbon taxes in a pro-cyclical fashion.[13] Concerns of endogeneity are, however, less pressing

[12] SCM has been used extensively in the literature to evaluate the effect of changes in government (e.g. Born et al. 2019; Funke, Schularick, and Trebesch 2021), national tax policies (e.g. Andersson 2019; Grogger 2017) and financial policies (e.g. Billmeier and Nannicini 2013; Chamon, Garcia, and Souza 2017).

[13] For instance, British Columbia deferred the scheduled 2020 increase of its carbon tax until 2021 as a response to the COVID-19 pandemic. See https://www2.gov.bc.ca/gov/content/taxes/tax-changes/covid-19-tax-changes.

for the analysis price level compared to aggregate economic activity. The reason is that monetary policy is conducted by central banks, whereas tax policies are carried out by fiscal authorities. Nonetheless, we use the local projection (LP) method by Jordà (2005) in order to address potential confounding factors to our analysis.

Specifically, we estimate a sequence of panel (OLS) regressions,

$$\Delta CPI_{i,t+h} = \alpha_i + \Theta_h \tau_{i,t} + \beta(L)\tau_{i,t-1} + \delta(L)\Delta CPI_{i,t-1} + \gamma_t + \epsilon_{i,t} \tag{2}$$

where τ_{it} is the real carbon tax rate in economy i in year t. Θ_h is the effect of an unexpected change in the carbon tax at year t on annual CPI in h years. To control for persistence of the tax rate and CPI, we include the 4 latest lags of each variable in the regression. Unobserved heterogeneity specific to each jurisdiction or year are absorbed by a set of fixed effects, α_i and γ_t.

All dynamic impulse responses are estimated from annual data, spanning the period 2000–2018 for Canada, and 1985–2018 for Europe, respectively. We restrict our sample of European countries to 26 with available data, that are also part of the ETS.[14]

Following Metcalf and Stock (2020), we weight all carbon tax rates by their 2019 emissions coverage, postulating a greater pass-through of tax rates to the economy in case of high tax bases. Standard errors are heteroscedasticity robust ((2021)) and clustered on jurisdiction.

Our counterfactual exercise consists of a one-time permanent increase in the carbon tax by 40 USD that applies to 30% of a jurisdiction's GHG emissions. We compute dynamic impulse responses in the 5 years after a tax implementation, based on the estimated LP coefficients. Throughout, we distinguish between the contemporaneous (in year 0), short-term (in years 1–2) and medium-term (year 3–5) average effects of the carbon tax.

4 Evidence from Canada

We begin our analysis with evidence for Canada. Canadian provinces provide a neat setting to assess the economic impact of carbon taxes since they do not have their own monetary policy, which potentially reacts to higher aggregate energy prices. The Bank of Canada's mandate is for the whole of Canada, rather than stabilizing prices for individual provinces.[15]

First, we present results using the synthetic control method, comparing British Columbia to other Canadian provinces. We separately look at the aggregate price level, as well as individual sub-categories of CPI that can shed light on the heterogeneity underlying the overall effect. Second, we turn to LP-based results, focusing on BC only, and including other provinces that implemented carbon taxes before 2018. Finally, we turn to the response of

[14] Listed in Table B1 of Appendix B.

[15] We checked minutes of monetary policy announcements around the time of the carbon tax implementation in BC. We could not find any evidence of the carbon tax implementation in, or potentially increasing energy prices in BC factoring into monetary policy decisions.

macroeconomic aggregates, as well as distributional effects of the carbon tax in British Columbia, in order to uncover potential channels through which the tax affects relative prices.

4.1 Synthetic controls

We start with the results based on the synthetic control analysis. Figure 1 panel A plots the aggregate CPI in BC and its constructed synthetic control in the 5 years before and after the carbon tax enactment. Reassuringly, CPI in our estimated synthetic control (dashed line) moves in lockstep with actual CPI in BC (solid line) prior to the tax implementation. However, after the first year of the carbon tax, the inflation paths start to diverge: CPI in British Columbia now lies below that of its synthetic counterfactual. In other words, CPI increased less in BC, compared to the synthetic control. 5 years removed, the difference between the two is sizeable, at about 5 percentage points.

House prices are a substantial component of CPI and a potential factor driving our result. British Columbia and Canada more broadly experienced a housing boom in the years preceding the financial crisis. While house prices flattened drastically in BC after 2008, they kept gradually increasing in the rest of Canada. The introduction of the carbon tax could have potentially exacerbated that price reversion in BC, as higher present and future energy prices increase the servicing cost for real estate, putting downward pressure on the implied net present value.

In order to ensure that our findings are not entirely related to the house price correction, we repeat our analysis using a CPI index excluding shelter, in Panel B of Figure 1. The results remain robust, albeit smaller in magnitude. Again, we see a divergence between BC and its synthetic control after one year, that increases over time. After 5 years, CPI in the synthetic control economy is 2.5 percentage points higher relative to BC. Comparing Panels A and B, it seems that the adjustment in house and rent prices in BC are indeed part of the story, but does not explain the overall difference in CPI.

Having documented the negative response of overall prices in BC, the central question is whether the fall in prices is uniform across the CPI basket, or whether there are is heterogeneity among CPI categories. A priori, we would expect the carbon tax to put upward pressure on energy prices, and lead to an adjustment of relative prices of other goods and services.

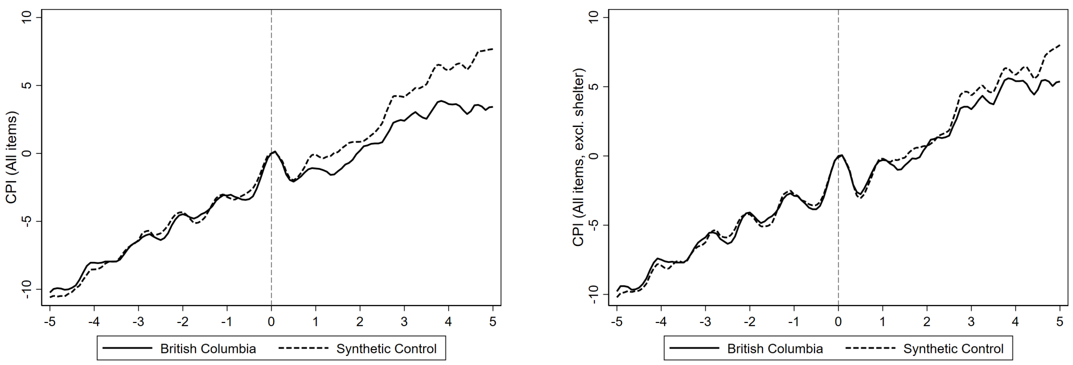
In order to more intuitively compare differences between BC and its synthetic control in each CPI category, we compute to the synthetic control gap, that is, the difference between CPI in B.C and its synthetic control (solid and dashed line respectively in Figure 1), for a set of major CPI categories.[16] Shaded gray bounds denote 90% confidence bands, based on the pre-treatment deviation between the two series.

For reference, panel A shows the gap for the overall CPI series, i.e. the mirror image of Figure 2 panel A. We follow a similar approach for the remaining CPI categories, by first

[16]We focus on the main components of the Canadian CPI basket, see https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid1810000701.

Figure 1: Synthetic controls for CPI

A. CPI *B. CPI excl. shelter*



Notes: Figure shows the path of aggregate CPI (panel A) and aggregate CPI, excluding shelter (panel B) for British Columbia and its synthetic control. Panel A constructed from Manitoba, Quebec and Newfoundland and Labrador. Panel b: Manitoba, Ontario, Prince Edward Island.

constructing synthetic controls for each sub-category, before calculating the gap. We note that throughout, our synthetic counterfactual accurately tracks CPI in BC prior to the tax, highlighted by a relatively stable gap around zero.

Panel B depicts the synthetic control gap for the CPI category energy. As expected, we see an increase in energy prices in BC compared to its synthetic control following the carbon tax enactment. Conversely, the synthetic control gap for food (panel C) shows a modest decline in prices after the carbon tax was introduced.

In panels D and E we depict the responses of non-tradables, services and shelter, respectively. In both cases, the synthetic control gap is negative and sizeable. Focusing on shelter in particular, we see a slight negative trend in the gap prior to the tax implementation, that is however dramatically accelerated afterwards. We find a similar response for energy-intensive durable goods such as vehicles, potentially lending support to the NPV channel outlined above.[17]

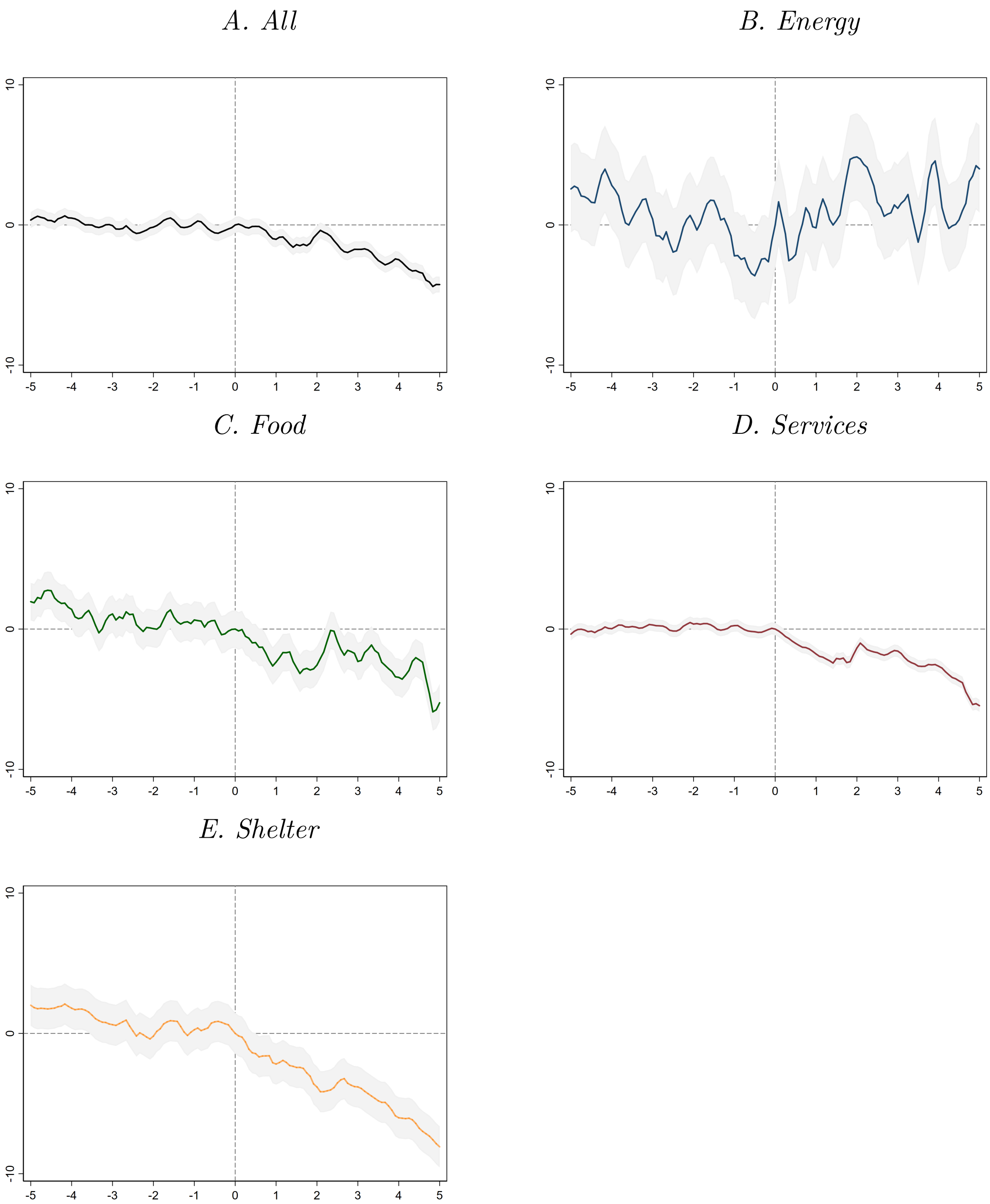
When comparing the price responses across panels, it seems that non-tradables, such as services and shelter, and to a lesser extent also food, are driving the aggregate negative response of CPI in British Columbia. Overall, the results point to an adjustment of relative prices in the aftermath of the carbon tax enactment: While energy prices slightly increased, prices of other goods and services fell.

4.2 Local projections

In this section, we complement our results by estimating local projections. The approach has two main advantages compared to synthetic controls. First, this allows us identify the effect of the tax more credibly by controlling for confounding factors occurring during the

[17] We find a simliar response when reproducing Figure 2 for the prices of energy-intensive durable goods, in Figure A2 of Appendix A.

Figure 2: Synthetic control gaps, CPI and its categories



Notes: Figures show the synthetic control gap, between British Columbia and its synthetic control, for overall CPI (panel A), as well as the CPI categories energy (panel B), food (panel C), services (panel D) and shelter (panel E). Shaded gray bounds show 90% confidence bands, based on the pre-carbon tax difference between British Columbia and its synthetic control.

time of the tax enactment. Second, compared to the event study set-up, we capture effects from the intensive margin, as well as the extensive margin.

Following Metcalf and Stock (2020), we consider a 40 USD carbon tax implementation that remains flat over time, and accrues on 30 percent of total GHG emissions. We separately analyze two samples: First, a sample that excludes Quebec and Alberta, which introduced carbon taxes in 2013 and 2017, respectively. This implies that the estimated

Table 2: Estimated price impacts

Sample	Impact in year 0	1–2	3–5	Controls	N	R2
a) BC only	-5.69^{***}	1.56^{***}	-1.75^{***}	Prov. FE	92	0.27
	(0.33)	(0.39)	(0.28)			
	-2.19^{***}	-0.77	-0.82	Economic	92	0.57
	(0.75)	(0.77)	(0.93)			
	-0.65	-1.47^{**}	-0.88	Prov. & Time FE	92	0.77
	(0.50)	(0.66)	(0.63)			
b) All	-0.17	-0.47	-0.76	Prov. FE	115	0.18
	(0.78)	(0.72)	(0.59)			
	-0.60	-0.51^{**}	-0.29	Economic	115	0.50
	(0.55)	(0.23)	(0.51)			
	-0.18	-0.28	-0.76	Prov. & Time FE	115	0.72
	(0.32)	(0.55)	(0.56)			

Notes: Table shows the dynamic impulse responses of CPI to a 40 USD carbon tax with 30% emission coverage for the Canadian sample. "BC only" (panel a) excludes Quebec and Alberta from the sample, "All" (panel b) includes them. The number of observations and R2 represent the means over the six individual regressions, respectively. Standard errors are heteroscedasticity robust. Significance levels denoted by *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

responses are entirely driven by British Columbia. In the second sample, we include Quebec and Alberta to capture the average effect from all carbon tax implementation in Canada prior to 2018.

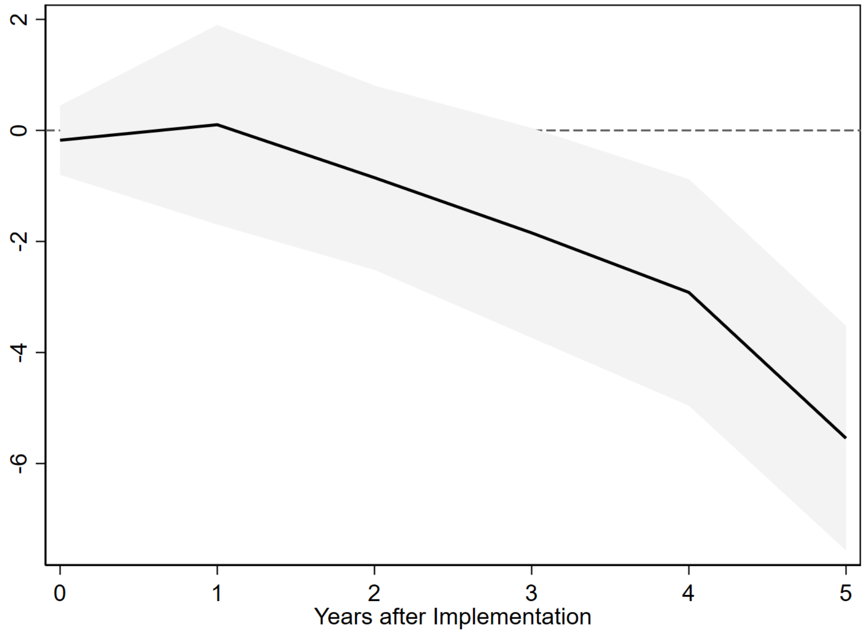
We present our baseline results for overall CPI, which are however robust to using CPI excluding shelter. Throughout, we distinguish between the contemporaneous, short-term (1–2 years) and medium-term (3–5 years) effects, by estimating the average effect over multiple years. The data are annual, spanning the period 2000–2018 and cover all provinces.

We start with the sample including only the BC carbon tax in Panel a of Table 2. The first row shows the results, when including a provincial level fixed effect and no other controls. Except for the short-term effect, the effect of the carbon tax on CPI is negative and in most cases statistically significant. In row 2, we add per capita GDP growth and the Canadian monetary policy rate, in order to control for the prevailing economic environment and monetary policy stance.[18] The impulse responses become smaller in magnitude and some lose statistical significance, but all retain their negative signs. Quantitatively, our results suggest that a 40 USD flat tax on 30% of GHG emissions implies an instantaneous fall in CPI by 2.19 index units. The average effect in years 1 and 2 after enactment fades out, at –0.77 CPI units, on average. More than three years removed, the effect on CPI remains negative at –0.82.

Our most restrictive specification includes provincial and year fixed effects (row 3).

[18] Each variable enters including 4 lags, along the lines of Equation (2).

Figure 3: Estimated cumulative response



Notes: Figures show the cumulative impulse response of CPI to a a 40 USD carbon tax with 30% emission coverage, estimated for the full (i.e. including Alberta and Quebec) Canadian sample. Shaded gray bounds show 95% confidence bands.

Again, all effects show a negative sign, that is statistically significant at the 5 percent confidence level in the 2 years following the tax.

In panel b, we include the remaining two provinces with a carbon tax, Quebec and Alberta, in the analysis. Consistent with panel a, the estimated impulse responses in rows 4-6 of Table 2 highlight the negative response of CPI. Across all our specifications, including fixed effects or economic controls the response shows a negative sign, that is however not statistically significant, in most cases.

For illustration, we plot the cumulative impulse response (assuming a parallel trends assumption) for the full Canadian sample, including province and year fixed effects, in Figure 3. Shaded gray bounds denote 95% confidence bands. The impulse response of CPI after a carbon tax implementation is economically sizeable and statistically significant: 5 years removed, CPI falls by a total of 6 points following the enactment of a 40 USD tax on 30% of GHG emissions. Overall, these results confirm the negative response of CPI in the period after a province implements a carbon tax. Moving beyond BC, the pattern seems to hold more broadly, albeit the effect is less precisely estimated.[19]

[19]The result is also robust to using a Difference-in-Differences identification strategy, outlined in Appendix A2.

4.3 Macroeconomic and Distributional effects

In this section, we turn to the macroeconomic and distributional effects of the carbon taxes in Canada, in order to understand what is driving our muted price responses. One hypothesis is that carbon taxes put downward pressure on wages (consistent with Yamazaki 2017) and thus aggregate income. Lower real income could lead households to cut expenditure and consume less goods and services at the margin, consistent with a negative demand shock.

This income channel could be further exacerbated depending on whether tax revenues are redistributed, and how this redistribution scheme is designed. In BC in particular, the redistribution is very progressive in income, going mostly to low-income households (see discussion above). As a result, high-income households which make up a large fraction of total could be the ones having to cut back on consumption. We test this hypothesis using income and expenditure data of Canadian households of various income quintiles.

Table 3: Estimated economic effects

	Impact in year					
Dep. Var.	0	1–2	3–5	Sample	N	R2
a) GDP	−0.02	0.05	0.12***	BC only	76	0.42
	(0.07)	(0.04)	(0.04)			
	0.00	0.04	0.09*	All	95	0.43
	(0.03)	(0.02)	(0.05)			
b) Income	−0.06***	0.02	0.06**	BC only	76	0.53
	(0.02)	(0.02)	(0.03)			
	0.01	0.01	0.04	All	95	0.48
	(0.01)	(0.01)	(0.03)			
c) Compensation	−0.05	0.03	0.07	BC only	76	0.47
	(0.03)	(0.03)	(0.04)			
	0.00	0.02	0.04	All	95	0.53
	(0.01)	(0.01)	(0.03)			
d) Expenditure	−0.04	0.02	0.04	BC only	76	0.27
	(0.04)	(0.05)	(0.10)			
	0.00	−0.02	0.06	All	95	0.22
	(0.01)	(0.02)	(0.06)			

Notes: Table shows the dynamic impulse responses of CPI to a 40 USD carbon tax with 30% emission coverage for the Canadian sample. "BC only" excludes Alberta and Quebec, "All" includes them. All dependent variables are real and in per capita terms. All specifications include province and year fixed effects. The number of observations and R2 represent the means over the six individual regressions, respectively. Standard errors are heteroscedasticity robust. Significance levels denoted by *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

Conceptually, we follow a similar local projections estimation strategy, but using GDP, income, worker compensation (wage) and expenditure as dependent variables in our regressions. Panel a of Table 3 shows the dynamic impulse response of real GDP per capita in the years after the carbon tax enactment. Row 1 is based on the sample excluding Alberta and Quebec, the second row includes both provinces. We see that, if anything, the response of GDP is positive. In fact, for the years 3 to 5 we find an average impulse response that is positive and statistically significant (at the 5 and 10 percent confidence level, respectively). This is consistent with prior empirical evidence on the lack of an aggregate economic effect of carbon taxes (compare e.g. Metcalf 2019).

We next turn to the response of real income per capita (panel b). In contrast to GDP, we find evidence of a negative and statistically significant contemporaneous response of income for the sample excluding Alberta and Quebec, even after controlling for province and time fixed effects. Quantitatively, the estimate implies that the carbon tax would depress real income per capita by 6 percent, on impact. This suggests that the carbon tax did in fact led to lower household income in the case of British Columbia, particularly in the early phase. We note that the effect reverses in years 3 to 5, and is absent altogether when estimated on the full sample (row 2).

Estimates in Panel c illustrate that part of the negative income response could be tied to worker compensation (in real terms). We find a a negative contemporaneous response of worker compensation for the restricted sample (row 1), albeit less precisely estimated. Similarly, the effect fades out and reverses over the short- to medium-term. For the full sample in row 2, we find small and insignificant impulse responses.

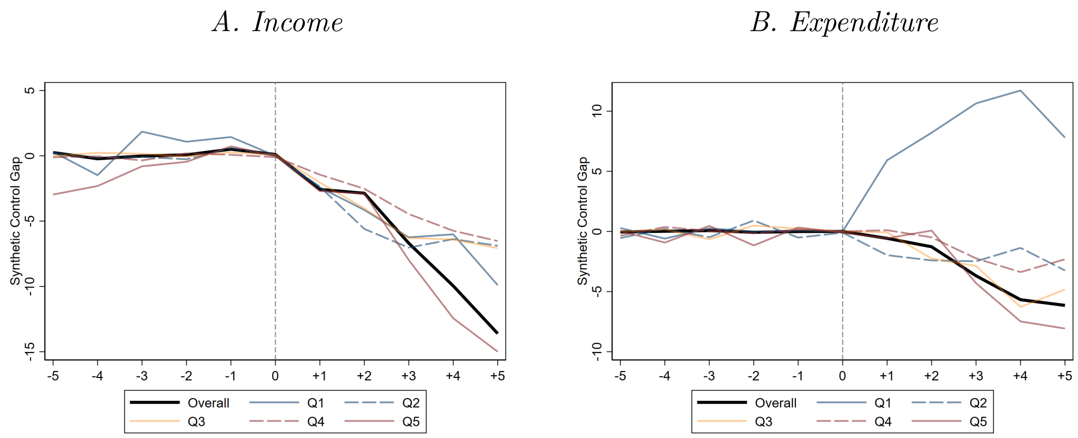
Finally, we ask how the negative impulse response of worker compensation and income feeds into consumption expenditure. Row 1 of panel d implies a negative response of expenditure per capita, on the order of magnitude of 4 percentage points, on impact. In the following years, the response turns positive. We find small, negative responses in the short-term and a positive response in the medium-term for the full sample (row 2).

In summary, it seems that following the tax enactment, British Columbia in fact experienced a negative response of household income and expenditure, while retaining overall activity. This lends support to the income channel as a potential explanation for the downward pressure on prices. This findings seems to be unique to BC, however, as we find not support for similar results for the rest of Canada.

In the absence of redistribution schemes, carbon taxes have been shown to accrue mostly to low-income households (see e.g. Wang et al. 2016). In the case of BC tax revenues are recycled and redistributed progressively with income. As a result, high-income households could be forced to shoulder the burden of the tax, potentially causing them to cut consumption more aggressively. As a result, the magnitude of the income channel outlined above could be exacerbated.

In Panel A of Figure 4, we plot the synthetic control gap for household income estimated for the average household (solid, dark line), and each income quintile separately, around the time of the carbon tax implementation in British Columbia. Once more, it confirms the negative effect on aggregate income in the aftermath of the tax, documented in Table 3.

Figure 4: Economic effects for different households



Notes: Figure shows the synthetic control gap for household income (panel A) and household consumption expenditure (panel B). All series are in real terms and were smoothed using a symmetric moving average. Solid dark line is the total response, coloured lines correspond to the 5 different income quintiles (Q1: bottom, Q5: top).

When comparing the synthetic control gap for different income quintiles, we see a fall across the income distribution. Put differently, real income of BC households falls, compared to their synthetic controls. This negative response is most pronounced for the top income quintile (solid, red line), which is driving the overall negative effect.

Turing to Panel B, we see a similar negative aggregate response for the synthetic control gap estimated on (real) consumption expenditure, in line with the results outlined in 3. Consistent with Panel A, households belonging to the top income quintile show the largest contraction in consumption expenditure, and substantially contribute to the negative aggregate fall. Conversely, households belonging to the bottom income quintile (solid blue line) in BC drastically increase their consumption expenditure compared to the synthetic control. Given that their income, including any tax credits linked to the tax itself, falls as well (compare Panel A), this pattern is somewhat puzzling.

As a final exercise, we re-estimate the synthetic control gaps by income quintiles for the various CPI categories, previously used in Figure 2. When comparing responses across categories, we find that the aggregate consumption expenditure on energy and food remains roughly flat. Instead, consumption of non-tradables, mostly services and to a lesser extent shelter are falling in BC relative to the synthetic control. Once more, it seems that high-income households are the key contributor for the overall effect. Corresponding visual evidence is shown in Figure A1 of Appendix A.

To summarize, we find some evidence in favor of an income channel operating in the case of British Columbia. In particular high-income households see their income fall following the carbon tax enactment and cut back on consumption of non-tradables. This pattern is especially pronounced for services, whose relative price also decreases most dramatically in the years following the tax.

5 Evidence from Europe

In this section we turn to the group of European countries that have implemented carbon taxes nationally, between 1990 and 2015. Methodologically, we take a similar approach as in the previous section, by first looking at an event study set-up for overall CPI and its sub-categories, before moving to LP-based results.

For the synthetic control method, we focus only on big carbon taxes with sufficiently high tax rates at the time of implementation, excluding the small eastern European taxes. One difference compared to the results from BC, is that we are interested in the average effect of a carbon tax on CPI across countries. We do so by averaging over all carbon tax countries and their synthetic controls. Along the same lines, we analyze aggregate CPI, as well as CPI categories food, energy and core CPI, which consists mostly of non-tradables, services and housing.

For the local projections, we provide separate results for the restricted sample of large carbon taxes, as well as the complete sample. For robustness, we check a number of distinct country groupings, testing for different responses depending on the implementation timing (three waves), as well as revenue-recycling policies and independent monetary policy.

5.1 Synthetic controls

Before we turn to the aggregate results for Europe, we start by showing CPI of individual carbon tax countries compared to their synthetic controls. Panels A to C of Figure 5 show the paths of CPI for Finland, Switzerland and France (solid lines) and their estimated synthetic controls (dashed lines), respectively. Note that in each case, we normalize the time dimension around the year where a particular tax was implemented. In all cases, the synthetic counterfactual tracks actual CPI perfectly prior to the tax implementation. Thereafter, however, CPI in the carbon tax economies always lies below that of their synthetic controls.

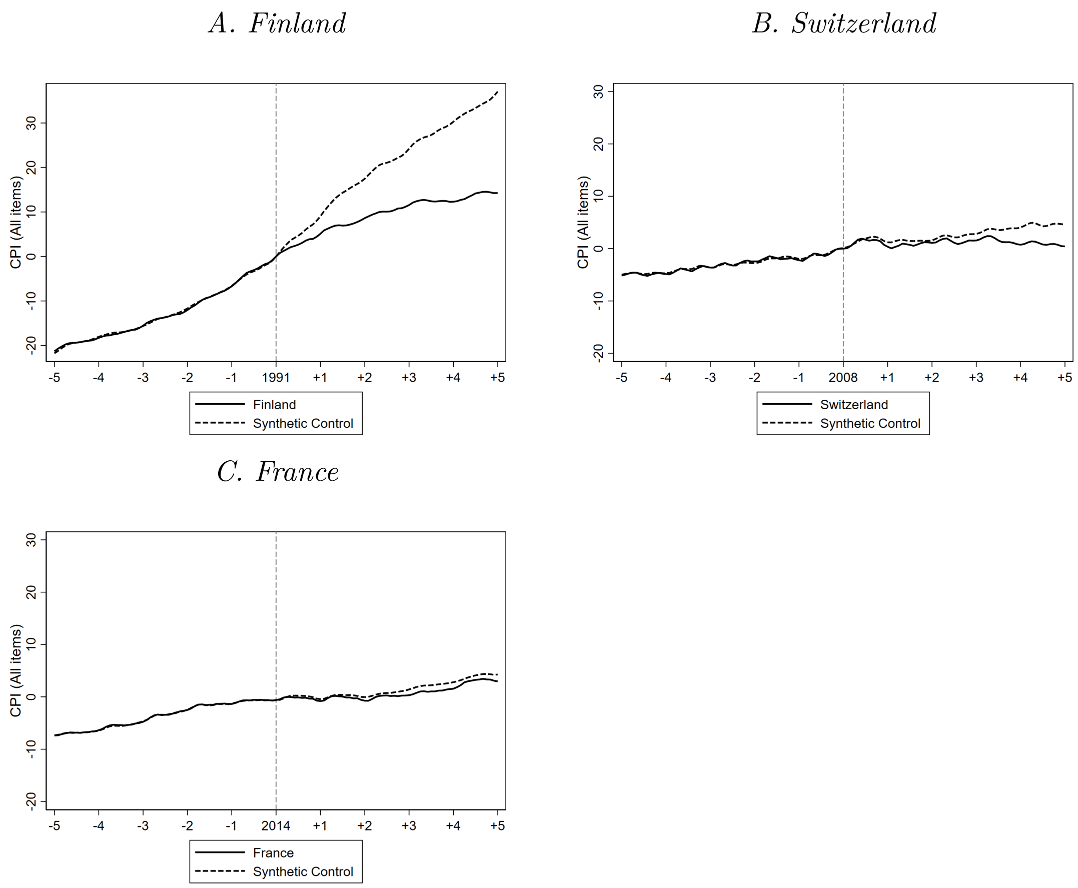
We note the substantial differences in the magnitude of response across the three taxes : While the gap in CPI between Finland and its synthetic control is in excess of 20 percentage points, we find less pronounced effects for Switzerland and France. We explore the differences in response depending on the time of implementation later on.

In the next step, we take the average over all 10 carbon tax economies (solid lines) and all synthetic controls (dashed lines), following Acemoglu et al. (2016).[20] The results are depicted in Figure 6, based on the sample of large carbon taxes, excluding only eastern European countries. Echoing the results for British Columbia, CPI moves in lockstep for the average carbon tax country and their synthetic control prior to the tax implementation. Thereafter, CPI starts to diverge rapidly. 5 years removed, the CPI in the average carbon tax country is 10 percentage points below that of their synthetic counterfactual.

Next, we turn to estimating synthetic control gaps for the average carbon tax country

[20] For reference, we list the main countries used for the construction of each synthetic control in Table B5 of Appendix B.

Figure 5: Synthetic controls for CPI, individual countries



Notes: Figure shows the path of aggregate CPI for carbon tax countries Finland (Panel A), Switzerland (Panel B) and France (Panel C) compared to its synthetic control, normalized to 0 in the month the carbon tax was implemented. The donor pool was restricted to OECD countries which did not themselves implemented a carbon tax during the 5 years before and after the implementation. More details on the construction of the synthetic control in Table B5 of Appendix B.

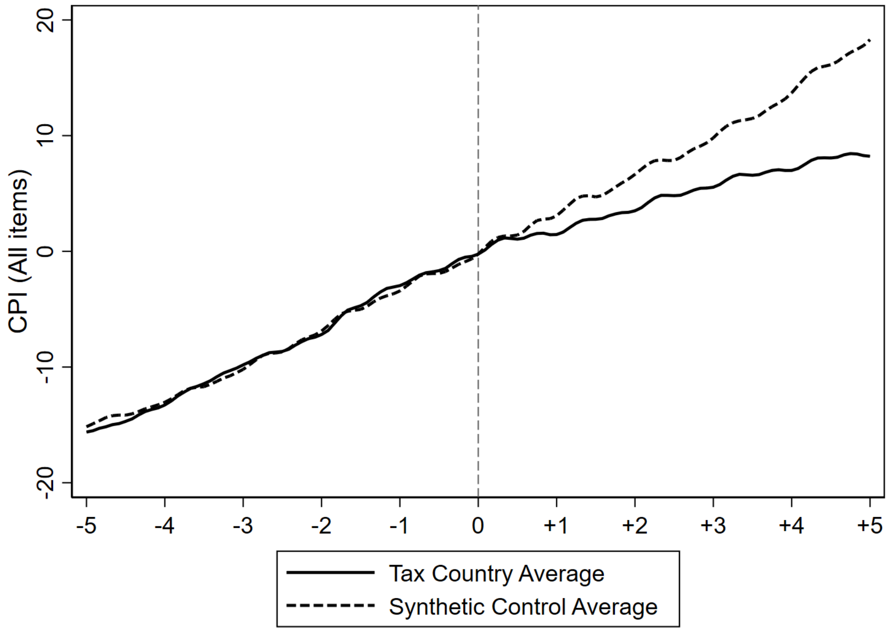
and its synthetic control, for overall CPI and its sub-categories. We begin with overall CPI (Panel A of Figure 7), which is based on subtracting the dashed from the solid line in Figure 6. The shaded gray bounds show 90% confidence bands based on the pre-carbon tax deviations. It highlights the pronounced fall in the aggregate CPI over the course of 5 years after a tax is implemented.

We repeat the same exercise for the CPI category energy in Panel B. Consistent with the Canadian results, we find that energy prices remain fairly flat in the years after the tax enactment. Only after 4 years there appears to be slight fall in energy prices in carbon tax countries, relative to their synthetic controls.[21]

Panels C and D of Figure 7 show results for the CPI categories food and core CPI (or, "non-tradables"). In both cases, the synthetic control gap is around zero before the tax implementation and falls persistently in the 5 years after. In particular, the price of food is 10 percentage points, the price of non-tradables is 6 percentage points lower in the carbon

[21] This finding is driven primarily by the Scandianvian countries. When excluding Sweden, Denmark, Norway and Finland, the response of energy prices is positive, compared to the synthetic control.

Figure 6: Synthetic controls for CPI, aggregate



Notes: Figure shows the path of aggregate CPI for the average European country with a carbon tax and its synthetic control group. Panel A includes all carbon tax countries, panel B excludes the early Scandinavian taxes. The donor pool was restricted to OECD countries which did not themselves implemented a carbon tax during the 5 years before and after the implementation. More details on the construction of the synthetic control in Table B5 of Appendix B.

tax countries, compared to the synthetic control. While this pattern of non-tradables are consistent with the Canadian evidence, the deflationary response of food prices is unique to Europe.

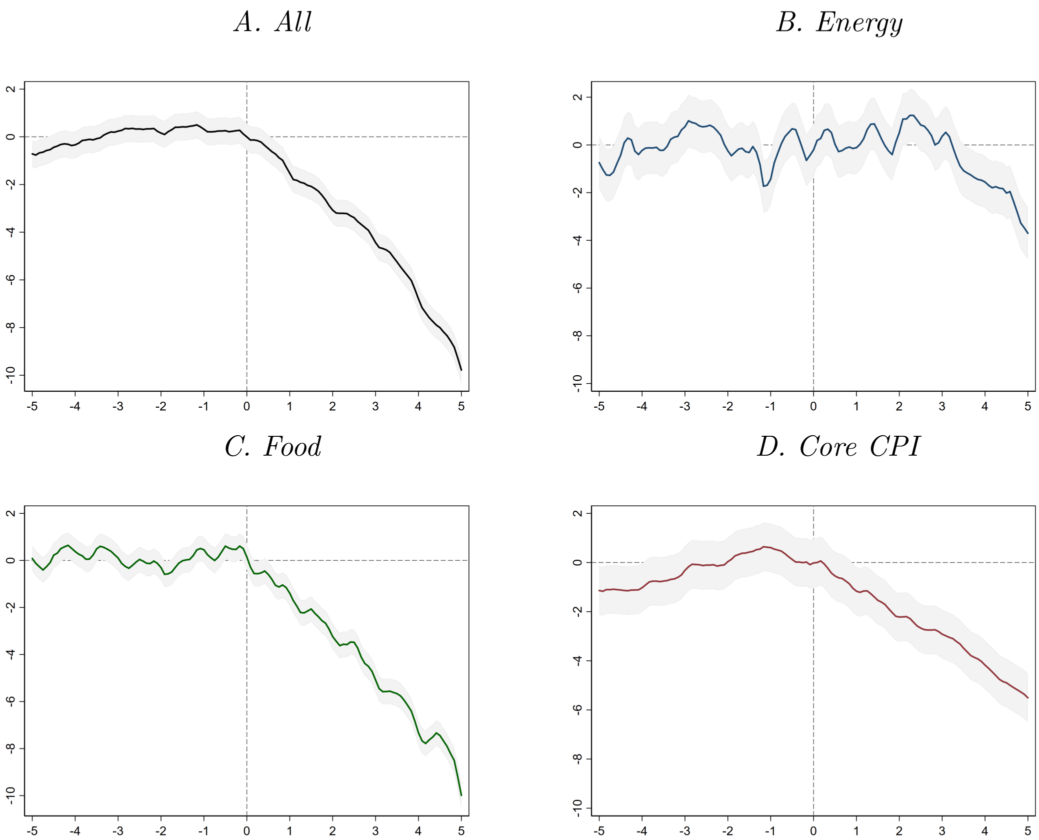
Taken as a whole, the analysis confirms the previous findings from the Canadian sample: Also in Europe, carbon taxes have a deflationary effect in the period after they are implemented. When disentangling CPI categories, it seems that the fall in prices is dictated by food and non-tradables becoming cheaper, more than offsetting the positive, or neutral response of energy prices.

5.2 Local projection

In this section, we present analogous results based on local projections. Once again, we consider a 40 USD carbon tax that applies to 30% of GHG emissions. We separately estimate impulse responses for two samples: One excluding the small taxes, the other including all 15.

The dynamic impulse responses are summarized in Table 4. Panel A starts with the sample of large carbon taxes, including only a country fixed effect (row 1). We find negative and statistically significant impulse responses both on impact, as well as for the following 5 years. Row 2 adds the domestic interest rate and real GDP growth as controls. The

Figure 7: Synthetic control gap, CPI and its categories



Notes: Figures show the synthetic control gap between the average European country with a carbon tax and its synthetic control group. Panel A is based on aggregate CPI, panel B shows energy, panel C food, panel D core CPI. Grey areas are 90% confidence bands, based on the pre-carbon tax difference between country and its synthetic control. The donor pool was restricted to OECD countries which did not themselves implemented a carbon tax during the 5 years before and after the implementation.

impulse responses remain of roughly similar size and significance.

Row 3 shows our most restrictive specification, including country and year fixed effects. Throughout we find negative impulse responses that are statistically significant at the 5 % level for the contemporaneous effect. Compared to the Canadian results, the responses are smaller in magnitude: On impact, the carbon tax implies a fall in CPI by 0.44 units, that increases to 0.46 in years 1 and 2. In the medium term (3–5 years), the response is –0.30 index units, which is however not statistically significant.

Panel B repeats the analysis for the whole sample, including the set of smaller carbon taxes. Across specifications, we find a robust pattern of negative, often statistically significant, impulse responses in CPI in the immediate and medium-term aftermath of the carbon tax implementation. Quantitatively, the results barely change when including or excluding the smaller taxes.

Figure 8 illustrates the estimated cumulative impulse response function, estimated on the full sample, including country and year fixed effects. It highlights the negative contemporaneous response of about –0.5 index points, that is statistically significant at the 5% confidence level. Thereafter, the impulse response trends upwards in the 5 years after the tax enactment. After 5 years, we document a small, negative cumulative effect on CPI, that is however not statistically significant.

Overall the European results are in line with the evidence from Canada: If anything, carbon taxes have a deflationary response on aggregate prices. Interestingly, we find that the magnitude of the effect differs tremendously, much larger in Canada and smaller in Europe. Moreover, the contemporaneous negative response is most pronounced in Europe, whereas the opposite is true for Canada. We next explore differences in timing of the tax enactment in Europe, which potentially sheds light on the heterogeneity in responses across countries.

Table 4: Estimated price response

	Impact in year					
Sample	0	1–2	3–5	Controls	N	R2
a) Big only	-0.53^{***}	-1.07^{***}	-1.27^{***}	Country FE	565	0.22
	(0.20)	(0.32)	(0.42)			
	-0.53^{***}	-0.99^{***}	-0.89	Economic	356	0.33
	(0.15)	(0.30)	(0.57)			
	-0.44^{**}	-0.46	-0.30	Country & Time FE	565	0.44
	(0.21)	(0.35)	(0.44)			
b) All	-0.55^{***}	-1.09^{***}	-1.31^{***}	Country FE	635	0.24
	(0.20)	(0.34)	(0.43)			
	-0.56^{***}	-1.02^{***}	-0.96^{*}	Economic	400	0.33
	(0.13)	(0.28)	(0.58)			
	-0.46^{**}	-0.41	-0.20	Country & Time FE	635	0.47
	(0.21)	(0.36)	(0.47)			

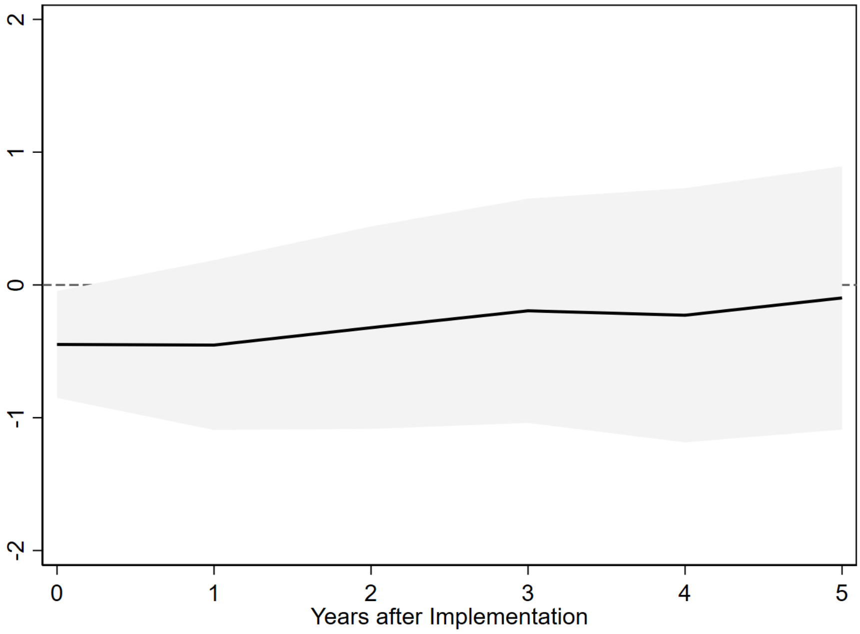
Notes: Table shows the dynamic impulse responses of CPI to a 40 USD carbon tax with 30% emission coverage for the European sample. "Big only" excludes the taxes with rates below 20 USD, and tax base of less than 20 %, i.e. excludes Estonia, Latvia, Poland, Portugal. "All" includes them. The number of observations and R2 represent the means over the six individual regressions, respectively. Standard errors are heteroscedasticity robust. Significance levels denoted by *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

5.3 Three waves of carbon taxes

Our data encompass carbon taxes implemented over a roughly 25 year span, between 1990 and 2015. In this section, we repeat our analysis by grouping countries according to when they enacted a carbon tax.

We define three waves: The first wave includes taxes implemented prior to 2000, encompassing the Scandinavian countries, Poland and Slovenia. The second wave spans the following 10-year period, including 2010 during which time Estonia, Latvia, Switzerland, Ireland and Iceland implemented taxes. The United Kingdom, Spain, France and Portugal belong to the third wave.

Figure 8: Estimated cumulative response



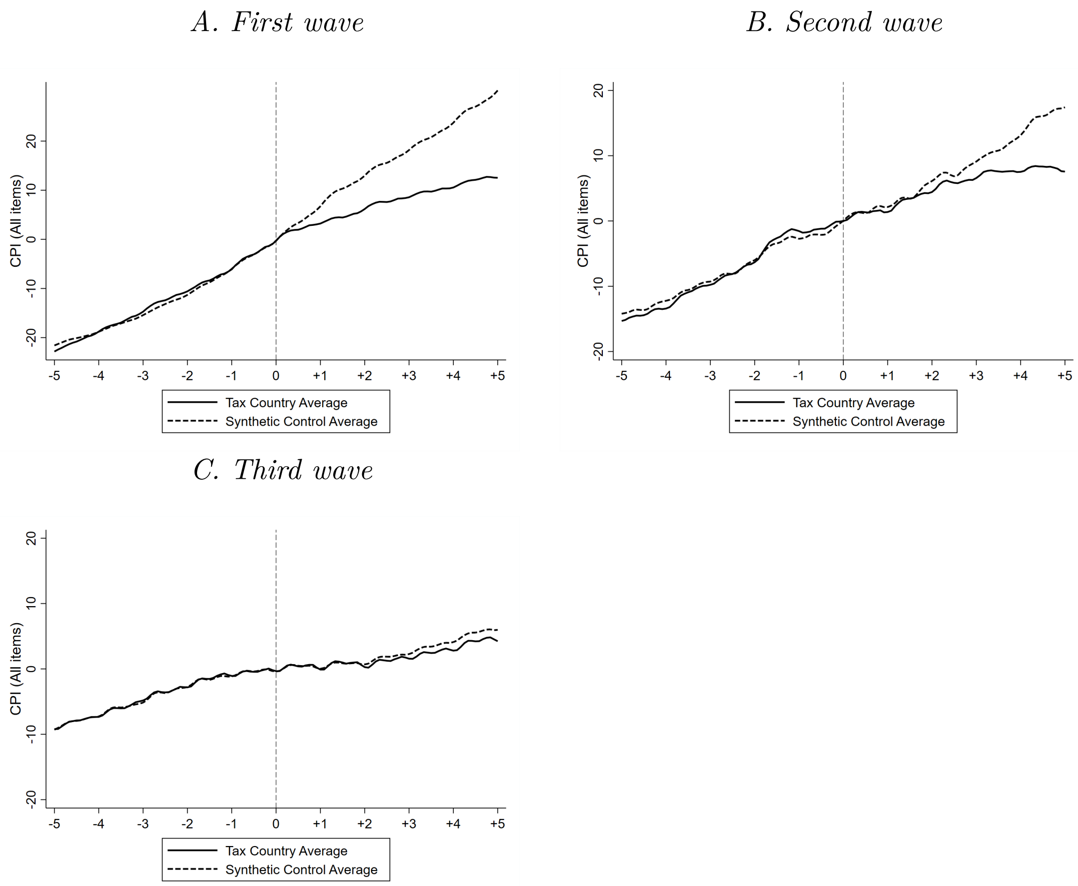
Notes: Figures show the cumulative impulse response of CPI to a 40 USD carbon tax with 30% emission coverage, estimated for the full European sample. Shaded gray bounds show 95% confidence bands.

Figure 9 shows the path of CPI for the various groups (on average), compared to their synthetic controls. There are substantial differences across the three waves. The gap between average CPI compared to the synthetic control is most pronounced for the first wave of carbon tax countries (panel A), on the order of magnitude of 20 percentage points. We find a similarly, although less pronounced differences for the countries implementing taxes in the second wave (panel B). The after-tax deviation of CPI is more subtle in panel C, for the last set of countries, at roughly 3 percentage points.

Next, we estimate local projections for the various carbon tax waves individually. We do so by excluding all carbon tax countries that do not belong to a particular wave from the analysis, e.g. excluding all taxes enacted after 2000 to estimate the response tied to the first wave of countries. Panel A of Table 5 shows results for the first wave, including country fixed effects (row 1), policy rate and GDP (row 2), as well as country and year fixed effects (row 3). Impulse responses are negative, and in most cases statistically significant. In the specification including country and year fixed effects, the carbon tax leads to a contemporaneous fall in CPI by 0.56 units, that is very precisely (1% level) estimated. In the short- to medium-term the impulse responses remain negative, but lose statistical significance.

Turning to the second wave of carbon tax countries (panel B), we find similarly negative responses, in most cases. When including country and year fixed effects, the estimates imply a negative contemporaneous effect that turns positive over the following 5 years. None of the estimates are statistically significant, however. The results are analogous for

Figure 9: Synthetic controls for CPI, three waves



Notes: Figure shows the path of CPI for pre-2000 tax countries (panel A), 2000-2010 tax countries (panel B) and post-2010 tax countries (panel C), as well as their synthetic controls, respectively. The donor pool was restricted to OECD countries which did not themselves implemented a carbon tax during the 5 years before and after the implementation. More details on the construction of the synthetic control in Table B5 of Appendix B.

the sample including only those countries that implemented taxes after 2010 (panel C). Again, dynamic responses are negative in most specifications. When including country and time fixed effects, we find a similar pattern compared to the second wave countries: a negative initial response followed by a reversion in the aftermath of the tax implementation, that are all imprecisely estimated.

Overall, the evidence points to carbon tax inducing a deflationary response, primarily in the first wave of carbon tax countries. For countries that implemented taxes since the 2000s, we find some support for an initial negative response, that reverts back in the 5 years after the introduction. One potential explanation is the higher level of inflation in the 1990s, compared to the 2000s. Nonetheless, even for the later taxes we find no evidence that is indicative of a robust inflationary response following a carbon tax.

We test a number of additional country groupings: First, we group countries depending on whether they recycle carbon tax revenues. The design of the carbon tax and how revenues are used to lower existing taxes, or for lump-sum payments potentially affects

Table 5: Estimated price effect

Sample	Impact in year 0	1–2	3–5	Controls	N	R2
a) First wave	-0.55^{**}	-1.01^{***}	-0.98^{***}	Country FE	429	0.12
	(0.24)	(0.40)	(0.36)			
	-0.50^{***}	-0.87^{***}	-0.51^{**}	Economic	271	0.34
	(0.17)	(0.24)	(0.23)			
	-0.56^{***}	-0.55	-0.36	Country & Time FE	429	0.47
	(0.23)	(0.35)	(0.43)			
b) Second wave	-0.19	-0.07	-1.63^{***}	Country FE	374	0.15
	(0.71)	(0.32)	(0.31)			
	0.20	-0.31	-1.23	Economic	214	0.28
	(1.31)	(1.00)	(0.78)			
	-0.12	0.23	0.58	Country & Time FE	374	0.51
	(0.58)	(0.90)	(0.91)			
c) Third wave	-1.37	-1.69^{*}	0.62	Country FE	410	0.13
	(0.91)	(1.02)	(1.80)			
	-1.17	-1.07	0.57	Economic	243	0.28
	(1.01)	(0.95)	(1.59)			
	-0.17	0.02	0.86	Country & Time FE	410	0.58
	(0.25)	(0.95)	(1.69)			

Notes: Table shows the dynamic impulse responses of CPI to a 40 USD carbon tax with 30% emission coverage. The analysis separately includes pre-2000 tax countries (panel a), 2000-2010 tax countries (panel b) and post-2010 tax countries (panel c), respectively. The number of observations and R2 represent the means over the six individual regressions, respectively. Standard errors are heteroscedasticity robust. Significance levels denoted by *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

the way by which a carbon tax affects the economy. In classifying countries we follow the definition of Metcalf and Stock (2020).[22] The results (see Table B3 of Appendix B) point to a negative impulse response for the revenue recycling countries. Interestingly, we do find some support for a positive response of CPI in the group of non-revenue recycling countries, when including country and year fixed effects.

Finally, we also check whether independent monetary policy plays a role in the price response following a carbon tax. Along the same lines, we separately look at two country groups: First, the Euro area countries and Denmark[23] as countries without autonomous monetary policy. Second, the set of countries not belonging to the Eurozone, with autonomous monetary policy. Our results point towards a more negative response for those countries with independent monetary policy. Conversely, we find small, positive responses

[22] We note that this simple classification might not do justice in accounting for often complex differences in tax design. For instance, France vowed to use revenues to lower the tax burden on low-income households and pensioners (see Marten and Van Dender 2019), but is classified as a non-revenue recycling country in Metcalf and Stock 2020.

[23] The Danish Krone is pegged to the Euro.

for the euro area and Denmark (see Table B4 of Appendix B).

The modest, positive responses of CPI in countries without independent monetary policy, and which do not recycles tax revenues are the only evidence from our analysis of 15 carbon taxes pointing towards potential inflationary effects associated with carbon taxes. Overwhelmingly, our results support deflationary effects. Nonetheless, it reinforces the need to better understand transmission mechanisms from carbon pricing to the price level, that could help explain cross-country differences related to recycling of carbon tax revenues and monetary policy.

6 Discussion and Conclusions

Against the backdrop of the current debate on monetary strategies and the increasing momentum of green policies, we set out to test empirically the effect of carbon taxes on inflation. Our initial intuition was in line with Larry Finks': we expected to find a positive effect and mostly wondered about its size. Would carbon taxes (and other climate related policies) have a large effect on inflation? Could it be large enough to impact monetary policy reactions and inflation targets going forward?

Our findings, instead, point the other way. Both in Canada and Europe, the evidence suggests that introducing carbon taxes had deflationary, rather than inflationary effects. This raises a series of questions for further research, which we are only partially able to to address in this paper.

The most important is clearly: why? We test a number of hypotheses but find that the empirical evidence is remarkably robust. The finding that carbon taxes are not inflationary is robust for Canada and Europe, as well as a battery of robustness checks: For Europe, it is robust for early, as well as late carbon tax adopters, although the deflationary effect is smaller for the latter group. Moreover, the result is true for countries with "high" carbon taxes. The finding also overwhelmingly holds across jurisdictions that manage their own monetary policy and those that do not (provinces in Canada or countries in the euro area). Finally, deflationary effects also dominate regardless of whether countries that are "recycling" carbon tax revenues or not.

Admittedly, we cannot fully control for other factors driving our results. Clearly, most of the carbon taxes in our sample were implemented during the great moderation – secular stagnation decades. However, these forces would apply equally to the non-carbon tax jurisdictions, which are in our control group. The same is true for the various financial crisis in the last 3 decades.

Of course, in most countries carbon taxes are only one part of a comprehensive toolkit to combat climate change. Focusing solely on carbon taxes might blur the picture when trying to understand the economic effects of climate policy more broadly. A study encompassing prices from other instruments complementary to the carbon taxes could be a promising avenue for future research.

In addition to the effects of carbon taxes on the price level, our analysis also sheds light on the adjustment of relative prices. Did they change relative (final) prices for energy versus other goods, as intended? On this score carbon taxes seem to have ”worked”: in most cases, energy prises rose in the period after carbon taxes were implemented (compared to the control group). At the same time, prices of other components of the CPI basket, mostly non-tradables, fell. Again, this finding is common for Canada and European jurisdictions.

Lastly, we tried to understand potential mechanisms explaining our results by turning to the carbon tax in British Columbia, which succeeded in reducing emissions while retaining aggregate output and employment. We test two hypothesis which may explain the (relative) decline of prices of non-tradables: Rising energy prices may have depressed household income and the NPV of energy-intensive durable goods. We find evidence for both channels: (Real) household income and consumption expenditure fell in British Columbia across income groups, compared to the the rest of Canada. The cut in consumption was most prevalent for high-income households, potentially related to the progressive redistribution scheme in BC. In addition, we find support for falling prices of real estate and energy-intensive durables, consistent with a NPV channel.

The distributional implications of carbon taxation and other climate change mitigation policies clearly merit further research both on direct macroeconomic effects, as well as indirect political economy considerations. The trajectory and credibility of future carbon prices will depend on gathering and maintaining sufficient support for climate policies. The example of Switzerland should serve as a warning that despite high public support for climate related policies, higher carbon taxes may be reject in a popular vote if they are seen as being ”expensive” by a sufficiently large number of voters.

In terms of the aggregate price level, our evidence from three decades indicates that the taxation of carbon they did not cause inflation, if anything it was deflationary. This does not mean that monetary policy should disregard this kind of shock. Deflationary effects may be equally undesirable as inflationary ones. Moreover, the absent reaction of monetary policy in most jurisdictions that introduced carbon taxes might have contributed to this outcome in the first place. Further research will be needed to draw the broader implications for optimal monetary policy reactions in response to carbon price shocks.

References

Abadie, Alberto, Alexis Diamond, and Jens Hainmueller. 2010. "Synthetic control methods for comparative case studies: Estimating the effect of California's tobacco control program." *Journal of the American statistical Association* 105 (490): 493–505.

Abadie, Alberto, and Javier Gardeazabal. 2003. "The economic costs of conflict: A case study of the Basque Country." *American economic review* 93 (1): 113–132.

Acemoglu, Daron, Simon Johnson, Amir Kermani, James Kwak, and Todd Mitton. 2016. "The value of connections in turbulent times: Evidence from the United States." *Journal of Financial Economics* 121 (2): 368–391.

Andersen, Mikael Skou, and Gaëll Mainguy. 2010. "Europe's experience with carbon-energy taxation." *SAPI EN. S. Surveys and Perspectives Integrating Environment and Society*, no. 3.2.

Andersson, Julius J. 2019. "Carbon taxes and CO 2 emissions: Sweden as a case study." *American Economic Journal: Economic Policy* 11 (4): 1–30.

Bernard, Jean-Thomas, Maral Kichian, and Misbahul Islam. 2018. "Effects of BC's Carbon Tax on GDP." *USAEE Research Paper Series*, no. 18-329.

Best, Rohan, Paul J Burke, and Frank Jotzo. 2020. "Carbon pricing efficacy: Cross-country evidence." *Environmental and Resource Economics* 77 (1): 69–94.

Billmeier, Andreas, and Tommaso Nannicini. 2013. "Assessing economic liberalization episodes: A synthetic control approach." *Review of Economics and Statistics* 95 (3): 983–1001.

Born, Benjamin, Gernot J Müller, Moritz Schularick, and Petr Sedláček. 2019. "The costs of economic nationalism: evidence from the Brexit experiment." *The Economic Journal* 129 (623): 2722–2744.

Chamon, Marcos, Márcio Garcia, and Laura Souza. 2017. "FX interventions in Brazil: a synthetic control approach." *Journal of International Economics* 108:157–168.

Duff, David G. 2008. "Carbon Taxation in British Columbia." *Vermont Journal of Environmental Law* 10:87.

Funke, Manuel, Moritz Schularick, and Christoph Trebesch. 2021. "Populist Leaders and the Economy." *CEPR Discussion Paper No. 15405.*

Grogger, Jeffrey. 2017. "Soda taxes and the prices of sodas and other drinks: evidence from Mexico." *American Journal of Agriculatural Economics* 99 (2): 481–498.

Hintermann, Beat, and Maja Zarkovic. 2020. "Carbon Pricing in Switzerland: A Fusion of Taxes, Command-and-Control, and Permit Markets." *ifo DICE Report* 18 (1): 35–41.

IMF. 2020. "Mitigating climate change." *International Monetary Fund: World Economic Outlook Chapter 3.*

Jordà, Òscar. 2005. "Estimation and inference of impulse responses by local projections." *American economic review* 95 (1): 161–182.

Lin, Boqiang, and Xuehui Li. 2011. "The effect of carbon tax on per capita CO2 emissions." *Energy policy* 39 (9): 5137–5146.

Marten, Melanie, and Kurt Van Dender. 2019. "The use of revenues from carbon pricing." *OECD Taxation Working Papers No. 43.*

Martin, Ralf, Laure B De Preux, and Ulrich J Wagner. 2014. "The impact of a carbon tax on manufacturing: Evidence from microdata." *Journal of Public Economics* 117:1–14.

McKibbin, Warwick J, Adele C Morris, Augustus Panton, and Peter Wilcoxen. 2017. "Climate change and monetary policy: Dealing with disruption." *Brookings Climate and Energy Economics Discussion Paper.*

McKibbin, Warwick J, Adele C Morris, and Peter J Wilcoxen. 2014. "The economic consequences of delay in US climate policy." *Brookings Climate and Energy Economics Discussion Paper.*

Metcalf, Gilbert E. 2019. "On the economics of a carbon tax for the United States." *Brookings Papers on Economic Activity* 2019 (1): 405–484.

Metcalf, Gilbert E, and James H Stock. 2020. "Measuring the macroeconomic impact of carbon taxes." *AEA Papers and Proceedings* 110:101–06.

Murray, Brian, and Nicholas Rivers. 2015. "British Columbia's revenue-neutral carbon tax: A review of the latest "grand experiment" in environmental policy." *Energy Policy* 86:674–683.

OECD. 2019. "Taxing energy use 2019." *Paris: OECD Publishing.*

Plagborg-Møller, Mikkel, and Christian K Wolf. 2021. "Local projections and VARs estimate the same impulse responses." *Econometrica* 89 (2): 955–980.

Rafaty, Ryan, Geoffroy Dolphin, and Felix Pretis. 2020. "Carbon pricing and the elasticity of CO2 emissions." *Institute for New Economic Thinking Working Paper No. 140.*

Rahman, Mohammad Mafizur. 2011. "The proposed carbon tax in Australia: impacts on income distribution, employment and competitiveness." *Proceedings of the International Conference on Income Distribution Theory and Policy*, pp. 2–13.

Wang, Qian, Klaus Hubacek, Kuishuang Feng, Yi-Ming Wei, and Qiao-Mei Liang. 2016. "Distributional effects of carbon taxation." *Applied energy* 184:1123–1131.

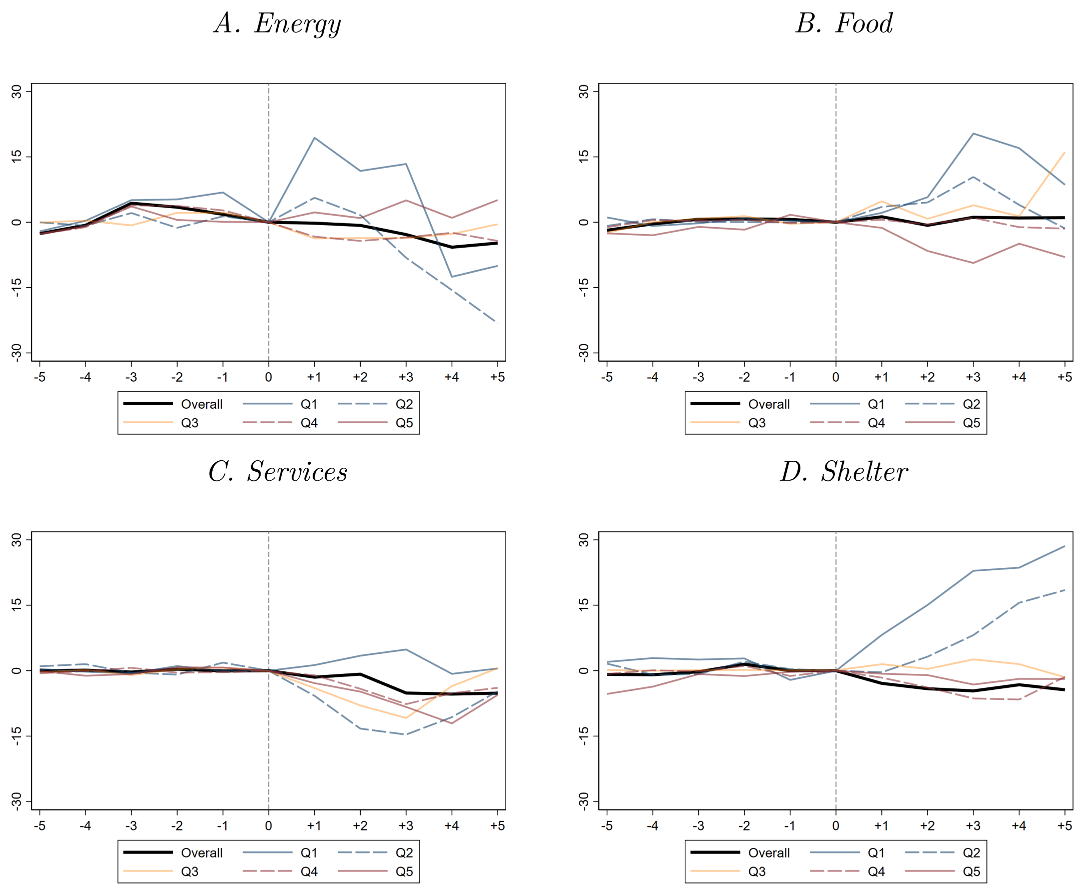
Winter, Jennifer. 2020. "Carbon Pricing in a Federal State: The Case of Canada." *ifo DICE Report* 18 (1): 13–19.

Yamazaki, Akio. 2017. "Jobs and climate policy: Evidence from British Columbia's revenue-neutral carbon tax." *Journal of Environmental Economics and Management* 83:197–216.

Appendix A Canada

A.1 Expenditure categories

Figure A1: Synthetic control gap, various CPI categories



Notes: Figure shows the synthetic control gap for household energy expenditure (panel A), food expenditure (panel B), expenditure on services (panel C) and expenditure on shelter (panel D). All series are in real term and were smoothed using a using a symmetric moving average. The solid, dark line is the total response, coloured lines correspond to the 5 different income quintiles (Q1: bottom, Q5: top).

A.2 Difference-in-Differences estimates

As a robustness check, we also estimate the effect of the carbon tax on CPI in British Columbia based on a difference-in-differences estimator. While we do not claim any causal relationship, as potential confounding events might bias the results, it does allow us to estimate the plausible effect of the tax implementation in British Columbia.

To that end, we estimate the following model:

$$CPI_{p,t} = \alpha + \beta D_{p,t} + \delta_p + \gamma_t + \epsilon_{p,t} \tag{3}$$

where $CPI_{p,t}$ is the CPI in province p in month t. D_{pt} is a dummy variable for BC after July 2008, post- carbon tax. α is a constant, δ_p and γ_t are province and year fixed effects, respectively. $\epsilon_{p,t}$ is an error term.

β captures the treatment effect of the carbon tax implemented in BC on CPI after July 2008. We present the results in Table A1, starting with the simple model without any fixed effects in column 1. The effect of the carbon tax is negative and statistically significant at the one percent confidence level. Quantitatively, we find that CPI was significantly lower (5.44) in BC relative to the remaining provinces, in the years after 2008. In columns 2 and 3, we add province and time fixed effects, respectively. Column 4 excludes Alberta and Quebec from the sample. Across all specifications, the estimated effect remains of similar magnitude and statistical significance.

Table A1: Difference-in-Differences Regression

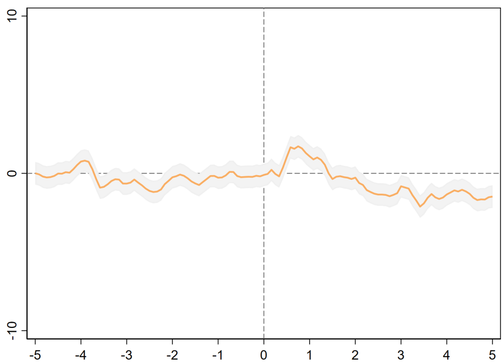
	Full sample			Excl. AL, QC
	(1)	(2)	(3)	(4)
D_{pt}	-5.44***	-5.44***	-5.44***	-5.44***
	(0.72)	(0.66)	(0.66)	(0.49)
Constant	104.55***	104.46***	95.38***	95.43***
	(0.21)	(0.32)	(0.66)	(0.50)
Observations	2,280	2,280	2,280	1,824
R2	0.71	0.71	0.96	0.98
Province FE	No	Yes	Yes	Yes
Time FE	No	No	Yes	Yes

Notes: The dependent variable is the CPI level in province p in month t. D_{pt} is a dummy variable for BC after July 2008, post- carbon tax. Columns 1-3 are based on the full sample, column 4 excludes Quebec and Alberta. All regressions include robust standard errors clustered on province. Data: monthly, 2000–2018. Significance levels denoted by *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

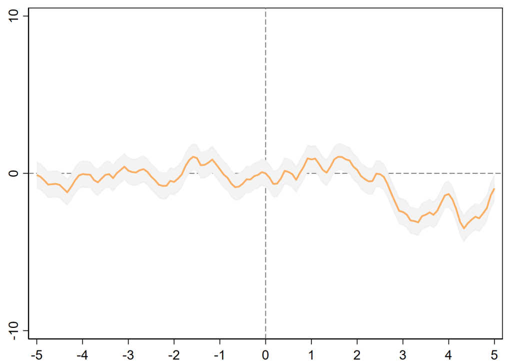
A.3 Prices of energy-intensive durable goods

Figure A2: Synthetic control gap, durable goods

A. Passenger vehicles



B. Recreational vehicles



Notes: Figure shows the synthetic control gap, between British Columbia and its synthetic control, for CPI categories passenger vehicles (panel A) and recreational vehicles (panel B). Shaded gray bounds show 90% confidence bands, based on the pre-carbon tax difference between British Columbia and its synthetic control.

Appendix B Europe

B.1 Data

Table B1: Annual sample

		CPI			
Country	First Obs.	Min	Max	Mean	SD
Austria	1985	53.33	105.05	78.10	15.69
Belgium	1985	55.11	106.28	78.96	15.74
Czech Republic	1991	32.45	105.34	77.72	21.21
Denmark	1985	50.90	102.23	78.78	15.93
Estonia	1998	55.48	107.13	82.24	17.38
Finland	1985	51.61	102.20	80.59	14.73
France	1985	58.04	103.09	82.71	13.56
Germany	1985	58.74	103.78	81.67	14.17
Greece	1985	13.29	104.08	69.53	29.70
Hungary	1985	4.16	105.68	54.58	36.23
Iceland	1985	13.38	106.26	57.70	27.88
Ireland	1985	49.48	100.91	79.14	18.14
Italy	1985	39.42	102.25	76.09	19.67
Latvia	1991	1.05	105.69	67.79	29.90
Lithuania	1991	0.35	107.49	72.34	29.13
Luxembourg	1985	54.57	103.59	77.74	16.00
Netherlands	1985	56.56	103.44	78.61	15.64
Norway	1985	44.24	108.41	77.49	17.21
Poland	1989	0.97	103.24	68.09	32.06
Portugal	1985	25.81	103.00	73.84	23.74
Slovakia	1991	24.02	103.32	71.89	26.21
Slovenia	1985	0.00	103.14	60.22	37.35
Spain	1985	35.60	103.45	74.28	21.40
Sweden	1985	49.07	104.80	83.91	15.76
Switzerland	1985	68.12	102.10	91.38	10.86
United Kingdom	1985	42.94	106.00	75.61	18.22
		36.10	104.30	75.04	21.29

Notes: Table lists the countries included in the sample with annual data. The sample starts in 1985, or the earliest available year for a given country. Columns 3-6 provide summary statistics (minimum, maximum, mean and standard deviation) for the CPI in each country.

Table B2: Monthly sample

Country	First Obs.	CPI			
		Min	Max	Mean	SD
Austria	1985m1	15.38	108.50	57.54	29.12
Belgium	1985m1	12.95	108.85	54.89	31.40
Canada	1985m1	9.56	108.56	49.61	33.58
Czech Republic	1991m1	28.46	112.60	79.61	21.61
Denmark	1985m1	10.87	104.00	61.67	29.82
Estonia	1998m1	54.14	110.69	84.33	17.88
Finland	1985m1	5.35	103.71	52.65	34.72
France	1985m1	7.31	105.19	54.78	34.49
Germany	1985m1	20.75	106.62	60.55	27.71
Greece	1985m1	0.96	105.52	39.87	40.40
Hungary	1980m1	2.97	113.84	50.71	38.84
Iceland	1985m1	0.03	113.77	36.13	36.73
Ireland	1985m1	4.20	102.47	61.52	32.70
Israel	1985m1	0.00	102.21	49.72	40.11
Italy	1985m1	3.50	103.50	46.75	37.03
Japan	1985m1	16.71	102.30	70.98	32.01
Latvia	1991m1	0.68	109.71	70.20	30.16
Lithuania	1990m12	0.16	111.50	74.38	29.48
Luxembourg	1985m1	14.51	106.73	54.45	30.51
Netherlands	1985m1	15.32	108.69	59.94	28.44
Norway	1985m1	7.17	112.90	50.71	34.49
Poland	1989m1	0.42	109.40	70.24	31.96
Portugal	1985m1	0.98	104.32	42.90	39.61
Slovakia	1991m1	20.38	108.22	73.95	26.35
Slovenia	1985m1	0.00	105.93	54.74	40.43
South Korea	1985m1	0.12	106.20	40.72	36.63
Spain	1985m1	1.78	105.09	44.75	37.41
Sweden	1985m1	7.22	107.77	54.37	36.26
Switzerland	1985m1	22.92	102.93	67.61	29.16
Turkey	1985m1	0.00	183.13	24.31	42.39
United Kingdom	1985m1	4.86	109.20	48.47	35.16
United States	1985m1	11.27	109.81	51.53	32.50
		9.40	109.81	56.08	33.10

Notes: Table lists the countries included in the sample with monthly data. The sample starts in 1985m1, or the earliest available date for a given country. Columns 3-6 provide summary statistics (minimum, maximum, mean and standard deviation) for the CPI in each country.

B.2 Robustness

Table B3: Estimated price effect, revenue recycling

	Impact in year					
Sample	0	1–2	3–5	Controls	N	R2
a) Recycling	-0.56^{***}	-0.26^{***}	-0.08	Country FE	433	0.14
	(0.23)	(0.10)	(0.10)			
	-0.57^{***}	-0.27^{***}	-0.10	Economic	308	0.22
	(0.18)	(0.13)	(0.10)			
	-0.42^{**}	-0.06	0.02	Country & Time FE	433	0.51
	(0.20)	(0.11)	(0.07)			
b) Non-recycling	0.36	0.32	-0.27	Country FE	529	0.13
	(0.56)	(1.01)	(1.92)			
	0.88	0.36	-0.07	Economic	308	0.23
	(0.78)	(0.58)	(0.85)			
	0.30	0.67^{**}	0.29	Country & Time FE	529	0.47
	(0.29)	(0.21)	(0.34)			

Notes: Table shows the dynamic impulse responses of CPI to a 40 USD carbon tax with 30% emission coverage for the European sample. Panel a) excludes non-revenue recycling countries, panel b) excludes revenue recycling countries. Revenue recycling countries include Switzerland, Denmark, Finland, Norway, Sweden and Portugal. The number of observations and R2 represent the means over the six individual regressions, respectively. Standard errors are heteroscedasticity robust. Significance levels denoted by *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

Table B4: Estimated price effect, monetary policy indepenedence

Sample	Impact in year 0	1–2	3–5	Controls	N	R2
a) Euro area & Denmark	−0.23	−0.21	−0.50	Country FE	533	0.11
	(0.28)	(0.16)	(0.33)			
	−0.20	−0.04	−0.12	Economic	301	0.25
	(0.35)	(0.24)	(0.25)			
	0.21	0.68***	0.26	Country & Time FE	533	0.51
	(0.29)	(0.22)	(0.29)			
b) Own Monetary Policy	−0.60**	−0.28**	−0.05	Country FE	455	0.16
	(0.27)	(0.13)	(0.09)			
	−0.52***	−0.29**	−0.07	Economic	298	0.20
	(0.20)	(0.13)	(0.11)			
	−0.50**	0.05	0.02	Country & Time FE	455	0.46
	(0.23)	(0.12)	(0.08)			

Notes: Table shows the dynamic impulse responses of CPI to a USD carbon tax with 30% emission coverage. Panel a excludes countries with autonomous monetary policy, panel b excludes euro area countries and Denmark. Autonomous monetary policy countries include Sweden, Norway, Switzerland, United Kingdom, Poland and Iceland. Denmark is included with euro area as the Krone is pegged to the Euro. The number of observations and R2 represent the means over the six individual regressions, respectively. Standard errors are heteroscedasticity robust. Significance levels denoted by *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

B.3 SCM donor countries

Table B5: Synthetic controls donor countries

Country	Donor countries
Finland	United Kingdom, Germany, Canada
Norway	France, Iceland
Sweden	France, United Kingdom, South Korea
Denmark	France, Iceland
Switzerland	Japan, Norway, Belgium
Ireland	Japan, Latvia, Portugal
Iceland	Turkey, Latvia
United Kingdom	Estonia, South Korea, Netherlands
Spain	Slovenia, Austria, Greece
France	Italy, Sweden, Czech Republic
Portugal	Sweden, Lithuania, Hungary

Notes: Table lists the main donor countries, with the highest weights, for the construction of a synthetic control for Figure 6. The donor pool consists of 32 OECD countries, restricted to countries that did not introduce a carbon tax in 10 year period around a carbon tax implementation.

Appendix C Tax designs

Table C1: Tax designs

Jurisdiction	Main sectors taxed	Revenue recycled
Finland (1990)	Transportation (mainly road), Industry, Residential & Commercial, Agriculture	Corporate and income tax cuts
Poland (1990)	/	/
Norway (1991)	Transportation (Road and Off-road), Industry, Residential & Commercial, Agriculture	Corporate tax cut
Sweden (1991)	Transportation (Road), Residential & Commercial, Industry	Corporate and income tax cuts
Denmark (1992)	Transportation (mainly road), Industry, Residential & Commercial, Agriculture	Corporate and income tax cuts
Slovenia (1996)	Transportation (mainly road), Residential & Commercial, Industry	/
Estonia (2000)	Industry	/
Latvia (2004)	Industry	/
Switzerland (2008)	Residential & Commercial, Industry	Climate Investment Fund, Redistribution to households, firms
Ireland (2010)	Transportation (Road), Residential & Commercial, Agriculture, Industry	/
Iceland (2010)	Transportation (Road), Agriculture, Industry	/
United Kingdom (2013)	Electricity	/
Spain (2014)	/	/
France (2014)	Transportation (Road), Residential & Commercial, Industry	Lower tax burden on low-income households and pensioners
Portugal (2015)	Transportation (Road), Residential & Commercial, Agriculture, Industry	Income tax cut
British Columbia (2008)	All sectors, tax mostly accrues to businesses and households	Corporate and income tax cuts, Rebates to low-income households
Quebec (2013)	Industry, Power, Transport and Buildings	/
Alberta (2017)	Households and small industrial emitters	Rebates to low-income households, green infrastructure investments, corporate tax cut

Notes: Table lists the European and Canadian carbon tax jurisdictions, including the main sectors the tax applies to (based on 2019 data), and details on the revenue recycling designs. Sources: Country notes of OECD (2019); Marten and Van Dender (2019) for Europe. Carbon Pricing Dashboard; Winter (2020) for Canada.