WORKING PAPER | VERSION 0.1 | NOVEMBER 2026

Carbon Prices Cut Emissions

Evidence from Ten Natural Experiments in Fuel Taxes, Carbon Pricing and Subsidy Reform

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ABSTRACT

Finance ministries weighing a carbon tax need to know what it will do to emissions, and most of the numbers they are given come from models. This paper collects ten natural experiments in which a carbon tax, a fuel tax rise, an emissions trading price, a subsidy cut or a market shock raised fuel prices, and in which researchers later measured emissions or fuel use against a credible counterfactual. For each case it reports the fuels and sectors covered, how far the measure raised retail prices over time, the carbon price or its equivalent in dollars per tonne of carbon dioxide, and the estimated cut. Every case shows a cut. In road transport and home heating, prices of 20 to 125 dollars a tonne cut emissions from the covered fuels by roughly 5 to 15 percent over five to fifteen years, about 1 to 2 percent for each 10 dollars. Where power plants could switch from coal to gas, the cut per dollar was five to ten times larger: Britain's carbon price floor cut power-sector emissions by about a fifth a year. Taxes moved demand more than equal market price changes, and exemptions and offsetting tax cuts weakened the effect. Models used for policy advice should be tested against these cases.

Keywords: carbon tax, natural experiment, ex post evaluation, fuel prices, emissions trading, fossil fuel subsidy reform
JEL codes: Q54, Q58, H23, Q41

Working paper, version 0.1, November 2026. Stephen J. Stretton, writing in a personal capacity. The views expressed are the author's own and do not represent those of any institution with which he is or has been affiliated. Companion to papers 5.3 (validating the Climate Policy Assessment Tool) and 5.4 (its price elasticities).[1]

[*]Writing in a personal capacity.

[1]Every estimate reported here is the work of the authors cited. Conversions to dollars per tonne and to percentages of retail prices are the author's, from the sources and conventions in Appendix A. Errors are the author's own.

1 Executive summary

Carbon prices are usually judged by models; this paper judges them by what happened. Since 1990, governments and markets have raised fuel prices in ways that researchers could later evaluate as natural experiments, comparing emissions afterward with a credible estimate of what would have happened otherwise. This paper collects the ten best-documented cases and reports four facts for each: the fuels and sectors covered, the rise in retail prices over time, the carbon price or its dollar-per-tonne equivalent, and the measured cut in emissions or fuel use.

The ten cases span road transport, buildings, industry and power on three continents, at prices from about 11 to 800 dollars a tonne. They are Sweden (motor fuels from 1991, heating fuels 2001–2004), Germany (road fuels 1999–2003, the 2022 gas shock), United States state gasoline taxes, British Columbia, Switzerland's heating levy, the European Union Emissions Trading System, Britain's carbon price floor in power and Indonesia's subsidy reform (Table 1).

Every case shows a cut. Swedish transport emissions were about 11 percent below a synthetic counterfactual on average over 1990–2005, about 6 percent from the carbon tax alone; German transport emissions were 11 to 16 percent lower by 2005; Swiss heating-fuel emissions 4 to 10 percent lower by 2015; emissions at plants in the EU trading system about 10 percent lower by 2012; and Britain's power-sector emissions 20 to 26 percent lower a year in 2013–2017. One synthetic-control study of British Columbia finds no cut, against several studies of the same province that do.

In transport and heating the response is about 1 to 2 percent for each 10 dollars a tonne, building up over five to fifteen years. Germany's eco-tax, worth about 65 euros a tonne by 2003, added the equivalent of 22 percent of the 1998 petrol price and cut transport emissions by 11 to 16 percent: an implied price elasticity of about −0.4 to −0.7. Switzerland's heating levy and British Columbia's tax on natural gas imply elasticities of about −0.15 to −0.45.

Where a cleaner substitute was already standing by, the response per dollar was five to ten times larger. Britain's carbon price floor, at a total carbon price of 14 to 36 dollars a tonne, raised the fuel cost of coal-fired power by 39 to 141 percent and of gas-fired power by only 7 to 30 percent. Coal's share of generation fell from 39 percent in 2012 to 9 percent in 2016 and 2 percent in 2019. Plants in the EU trading system cut 10 to 16 percent at allowance prices averaging about 14 euros, more per dollar than any transport or heating case.

Design changed the result as much as the price did. Taxes moved demand two to three times more than equal market price changes, though buying ahead of announced rises explains part of the gap. Sweden offset its 2001–2004 motor-fuel tax rise with energy-tax cuts, and its transport gap barely widened. British Columbia's tax cut transport emissions but not, measurably, total emissions. Germany's 2022 gas shock cut gas use by 23 percent but national emissions by only about 2 percent, because power stations burned more coal and some industry moved abroad.

What to do. Plan on a sustained, broad carbon price cutting covered emissions by about 1 to 2 percent per 10 dollars a tonne in transport and buildings within a decade, and by much more in power where coal can give way to gas. Avoid offsetting tax cuts and exemptions, and publish a credible path. Modelers should back-cast these cases: on this evidence the long-run gasoline elasticity in the Climate Policy Assessment Tool (−0.64) is about right and its residential gas elasticity (−0.70) looks high (Section 7).

2 Introduction

A finance ministry that asks what a carbon tax will do to its emissions is usually given a model's answer, and the size of that answer rests mostly on assumed responses to price. The Climate Policy Assessment Tool (CPAT), which the International Monetary Fund and the World Bank use for this purpose, turns a carbon price into an emission cut through a table of price elasticities. Varying those elasticities by two standard deviations moves its estimated cut in G20 emissions from a US$75 tax from 29 percent to anywhere between 7 and 39 percent (Stretton 2026a). A model is only as good as the response it assumes. The ex post literature, which measures what happened after real price changes, is the natural test, and paper 5.3 in this series recommends validating CPAT against it case by case (Stretton 2026b).

This paper asks a simple question: when governments or markets have raised fuel prices, what happened to emissions, and how much per dollar? The answer, from ten natural experiments, is that emissions from the covered fuels fell in every case. In road transport and buildings the cut was roughly 1 to 2 percent for each 10 dollars a tonne, building up over five to fifteen years. In power, where coal could be replaced by gas already on the system, it was five to ten times larger per dollar. Taxes moved demand more than equal market price changes, exemptions and offsetting tax cuts weakened the effect, and very large short-run shocks produced small cuts per dollar.

The contribution is a case-level evidence base in one consistent format. The two closest pieces of work are reviews. Green (2021) reviews 37 ex post studies and concludes that carbon pricing has cut aggregate emissions by 0 to 2 percent a year. Döbbeling-Hildebrandt et al. (2024) pool 483 effect sizes from 80 causal evaluations of 21 schemes and find statistically significant cuts of 5 to 21 percent (4 to 15 percent after correcting for publication bias), averaging 10.4 percent, "despite the low level of prices in most instances". Neither review reports, case by case, the size of the retail price increase or its carbon-price equivalent, and the meta-analysis lists the price elasticity of emissions as an evidence gap. This paper fills that gap for ten cases. Alongside carbon taxes and emissions trading, it includes fuel tax rises, a subsidy reform and a market shock, which raised fuel prices as much as carbon prices did or more: Germany's eco-tax, United States state gasoline taxes, Indonesia's subsidy reform and Germany's 2022 gas shock. It converts every price change to the same two yardsticks, percent of the retail price and dollars per tonne of carbon dioxide (CO_2), so the cases can be compared with each other and with model elasticities.

Section 3 sets out what counts as a natural experiment here and how prices are converted. Section 4 presents the ten cases. Section 5 draws out what they show together, Section 6 answers the strongest objections, Section 7 compares the evidence with CPAT, and Section 8 turns it into advice.

3 Method: what counts and how prices are compared

A case qualifies if a price change was large, dated and evaluated after the fact against a counterfactual. The paper uses "natural experiment" for a fuel price increase that a government or market imposed for reasons largely independent of the emissions trend being studied, and that researchers later evaluated with observed data. Three designs dominate. Synthetic control builds a weighted average of untreated countries or provinces that tracked the treated unit before the change, and reads the effect as the gap after it (Andersson 2019; Leroutier 2022). Difference-in-differences compares regulated with similar unregulated plants or regions before and after (Colmer et al. 2025). Panel and time-series methods

use the timing of many tax changes, or temperature-adjusted baselines, to separate the price effect from other influences (Davis and Kilian 2011; Ruhnau et al. 2023). Simulations of hypothetical policies are excluded. Two cases, Switzerland and Indonesia, rest partly on counterfactuals built from estimated elasticities applied to observed prices; the text says so.

Selection favored identification, then breadth. Twenty-one episodes were documented, the ten here and the eleven in Table 13, and several more were searched without finding an ex post estimate. The ten chosen have at least one peer-reviewed ex post estimate of the effect on emissions or fuel use, and together they cover road transport, buildings, industry and power, carbon taxes, fuel taxes, emissions trading, subsidy reform and a market shock, and both high-income and developing economies. Australia's 2012–2014 carbon price, Finland's and Norway's early carbon taxes, Britain's fuel duty escalator, the Regional Greenhouse Gas Initiative, France's carbon tax and Saudi Arabia's price reforms were left out of the main set because their evidence is thinner or contested. They are summarized in Table 13.

Four facts are reported for each case. The *sector and fuel* are those the measure covered. The *retail price increase* is the measure's per-unit amount, including any value added tax on it, as a percentage of the price that would have applied without it, assuming full pass-through to the final user. Where a source reports the measure's share of the tax-inclusive price instead, the paper reports that share and says so. For industrial users under emissions trading, the increase is the marginal carbon cost as a percentage of the pre-carbon fuel price. The *carbon price* is the statutory price per tonne of CO_2. For measures that are not carbon prices, the *carbon-price equivalent* is the per-unit price increase divided by the CO_2 emitted per unit of fuel. Dollar figures use the annual average exchange rate of the year shown. The *emission cut* is the evaluated study's own estimate, with its horizon and design. Appendix A lists the emission factors and exchange rates.

4 Ten natural experiments

Table 1 summarizes the ten cases. The sections that follow give each case's price path over time and its measured effect.

Table 1. The ten natural experiments at a glance: every case shows a cut in emissions or fuel use from the covered fuels. VAT = value added tax; ETS = Emissions Trading System. US$ at the annual average exchange rate of the year shown. Retail price increases assume full pass-through and are the author's calculations from the sources in each case section, except where stated. Sources: see Section 4.1 to Section 4.10.

Case	Sector and fuel	Carbon price or equivalent	Retail price increase	Ex post cut (design, horizon)
1. Sweden, 1991	Road transport; petrol and diesel	SEK 250/t (US$41) in 1991; SEK 910 (US$124) by 2004	Carbon tax with VAT: 21% of the petrol price in 2006 (+26% over the price without it)	Transport CO_2 −10.9% on average 1990–2005 with the 1990 fuel VAT; about −6.3% from the carbon tax alone (synthetic control, 15 years)
2. Sweden, 2001–2004	Buildings; heating oil	SEK 370 to 910/t (US$40 to 124)	Heating-oil tax up SEK 1.48/l before VAT; share of retail price not available	Residential CO_2 200–800 kg per person a year lower, roughly 11–46% (synthetic control, to 2010)

Case	Sector and fuel	Carbon price or equivalent	Retail price increase	Ex post cut (design, horizon)
3. Germany, 1999–2003	Road transport; petrol and diesel	Equivalent €65/t petrol, €57/t diesel by 2003 (US$74, 65)	Cumulative tax equal to 22% of the 1998 petrol price, 30% of diesel	Transport CO_2 −11.5% to −16% by 2005 (synthetic control, 6 years)
4. United States, 1966–2008	Road transport; gasoline	Typical rise of 5–10 cents/gallon = US$5.6–11.3/t	3–6%	Gasoline use −1.4% per 10 cents within a year (instrumental variables)
5. British Columbia, 2008	Transport, buildings; gasoline, diesel, natural gas	C$10/t (2008) to C$30 (2012) and C$80 (2024); US$9 to 30 to 58	Gasoline: 1.6% of pump price (2008), 4.8% (2012), 8.4% (2024)	Household gasoline −8% per 5 cents/litre; transport CO_2 −5% short run, −19% long run; total CO_2 not significant (panel, synthetic control)
6.Switzerland, 2008	Buildings, smaller firms; heating oil and gas	CHF 12/t (2008) to CHF 60 (2014), 84 (2016), 120 (2022); US$11 to 66, 85, 126	Heating oil: +3% (2008), +21–30% (2014–15), +40–65% (2016–21)	Heating-fuel CO_2 −4.3% to −9.6% in 2015 (model-based counterfactual); house owners' heating fuel −12% to −14% (survey)
7. EU ETS, 2005	Power and industry; coal, gas, oil	Phase II mean €13.7/t (US$19)	Marginal cost: gas +8–13%, coal +37–68% of fuel price (2008–2011)	Emissions at regulated plants about −10% 2005–2012, −15% in phase II (matched difference-in-differences)
8. Britain, 2013	Power; coal and gas	Total carbon price €10.6/t (2013) to €32/t (2015); US$14 to 36	Fuel cost of coal +39% to +141%; gas +7% to +30%	Power-sector CO_2 −6% (dispatch only) to −20–26% a year (all channels), 2013–2017
9. Indonesia, 2013–2015	Transport, electricity; gasoline, diesel, power	Gasoline equivalent US$88 (2013 step), US$72 (2014 step); US$143/t cumulative at 2014 exchange rates	Gasoline +44%, then +31% (+89% in total)	Electricity use −7% (about 13 Mt CO_2 a year); toll-road traffic −10% (panel, 2 years)
10. Germany, 2022	Buildings, industry; natural gas	Equivalent €150–900/t (US$160–950)	Household gas +130%, industrial gas +480% at peak	Gas use −23% against a temperature-adjusted baseline; national CO_2 only about −2% (regression, months)

4.1 Sweden, 1991: a carbon tax on motor fuels cut transport emissions by about 11 percent

Sweden taxed carbon in motor fuels from 1991 and raised the rate almost fourfold by 2004. The carbon tax started at SEK 250 per tonne of CO_2 on all major fossil fuels, as part of a reform that cut labor taxes; in March 1990 Sweden had also added 25 percent VAT to petrol and diesel for the first time (Hammar and Åkerfeldt 2011; Andersson 2017). The rate stayed at SEK 370 from 1996 to 2000, rose in steps to SEK 910 in 2004 and reached SEK 1,050 in 2009–2011. It was about SEK 1,330 in 2023, or US$119 at the Ministry of Finance's 2022 exchange rate (Government Offices of Sweden, Ministry of Finance 2023), and about SEK 1,450 (US$137) in 2024 on the author's calculation from the tax agency's per-unit rates. In petrol it added SEK 0.58 a litre in 1991, rising to SEK 2.11 in 2004–2005 before VAT (Table 2). The tax passed fully into pump prices: a regression of pump prices on taxes gives a coefficient of 0.97 on the carbon tax (95 percent confidence interval 0.80 to 1.15) (Andersson 2017).

By 2006 the carbon tax and the VAT on it made up a fifth of the petrol price. In April 2006 the carbon tax with VAT was SEK 2.53 of a pump price of SEK 12.22, or 21 percent, raising the price 26 percent above what it would have been without it. The share was the same in May 2024 (SEK 3.93 of 18.84). No source located for this paper gives the 1991 pump price, so the 1991 share is not reported. Two offsetting changes matter. Sweden cut energy taxes when the carbon tax began, and between 2000 and 2004 it cut the energy tax on petrol so far that the total tax on unleaded petrol rose only from SEK 4.47 to 4.79 a litre while the carbon tax more than doubled (Hammar and Åkerfeldt 2011).

Table 2. Sweden's carbon tax on motor fuels rose almost fourfold and cut transport emissions by about a tenth. Petrol at 2.323 kg CO_2 per litre; VAT 25%. The 2006 amount is levied on 95% of the volume because of the ethanol blend. The 2024 rate is derived from Skatteverket's per-unit rates. "Carbon tax alone" splits the synthetic-control gap using estimated demand elasticities. Sources: Hammar and Åkerfeldt (2011), Andersson (2017), Andersson (2019); shares are the author's calculation from Ekonomifakta (2006) and TT (2024) price reports in the research notes.

Year	Carbon tax, SEK/t (US$/t)	Carbon tax on petrol, SEK/l, with VAT	Share of pump price (increase over price without it)	Transport CO_2 against synthetic Sweden
1991	250 (41)	0.73	not available	Average 1990–2005: −10.9% with the fuel VAT; −6.3% from the carbon tax alone
2000	370 (40)	1.07	not available	−11.5% with VAT; −5.5% carbon tax alone
2004–05	910 (122–124)	2.64	not available	2005: −12.5% with VAT (−0.35 t per person, 3.2 Mt); −9.4% carbon tax alone
2006	920 (125)	2.53 (on 95% of volume)	20.7% (+26.0%)	Not evaluated
2024	about 1,450 (137)	3.93	20.8% (+26.3%)	Not evaluated

Against a synthetic Sweden built from other OECD countries, transport emissions fell about 11 percent. Andersson (2019) compares Swedish per-person CO_2 from transport with a weighted average of 14 OECD countries that tracked it closely from 1960 to 1989, mostly Denmark, Belgium and New Zealand. Emissions were 10.9 percent lower on average over 1990–2005 and 12.5 percent lower in 2005, a cumulative 40.5 million tonnes (Mt). Sweden's

gap is the largest of 15 placebo runs, the smallest p-value the design allows (1/15). The measured gap combines the 1990 VAT and the carbon tax. Splitting it with estimated demand elasticities attributes about 6.3 percent on average, and 9.4 percent in 2005, to the carbon tax alone. Those elasticities are the striking result: demand responded to the carbon tax with an elasticity of −1.57, three times its response to market price changes (−0.51).

The headline survives replication; the split between tax and price is less secure. An exact reproduction finds a median effect of −0.28 tonnes per person across 14 alternative specifications, against Andersson's −0.29 (Bonander et al. 2023). Dropping Denmark, itself a carbon-tax adopter in 1992, raises the combined effect to 12.9 percent and the carbon-tax share to 7.7 percent; a more efficient estimator halves both elasticity coefficients, though their ratio stays above two (Yu 2024). The same method finds only a 2.4 percent, statistically insignificant, effect for Norway, whose carbon tax exempted much of its economy (Yu 2024). The early 1990s recession is the main confounder; Andersson finds no rebound in emissions when Swedish output recovered.

4.2 Sweden, 2001–2004: tripling the tax on heating fuels cut household emissions

Between 2000 and 2004 Sweden raised its carbon tax from SEK 370 to SEK 910 a tonne without offsetting cuts for households. Households and services paid the full rate. Unlike motor fuels, heating fuels used by households got no matching cut in energy tax, so the whole increase reached them (Hammar and Åkerfeldt 2011). On heating oil, at 2.744 kg CO_2 a litre, the carbon tax rose from SEK 1.02 to SEK 2.50 a litre before VAT (Table 3), SEK 1.85 a litre more with VAT. In dollars the rate tripled, from US$40 to US$124 a tonne. No Swedish heating-oil retail price series was found for these years, so the paper does not report the increase as a share of the retail price.

Table 3. Sweden's 2001–2004 increase reached household heating fuels in full and cut residential emissions. Per-litre amounts are the author's calculation from the rates and the emission factor in Hammar and Åkerfeldt (2011). Effect: Runst and Thonipara (2020); 200 kg against countries with carbon taxes above €20 a tonne, 800 kg against countries without one.

Year	Carbon tax, SEK/t (US$/t)	Carbon tax on heating oil, SEK/l before VAT	Residential CO_2 against synthetic Sweden
1991	250 (41)	0.69 (energy tax cut 50%, total tax almost unchanged)	Low dose: pre-period for this experiment
2000	370 (40)	1.02	Pre-period
2001	530 (51)	1.45	Gap opens
2002	630 (65)	1.73	
2003	760 (94)	2.09	
2004	910 (124)	2.50	2005–2007: largest gap; 200–800 kg per person a year lower

Residential emissions fell by 200 to 800 kilograms per person a year relative to comparison countries. Runst and Thonipara (2020) apply synthetic control and difference-in-differences to residential CO_2 in 19 European countries over 1990–2016, controlling for heating degree days, income and fuel prices. The gap opens in 2001 and peaks in 2005–2007. It is 200 kg per person a year against countries that themselves taxed carbon at more than €20 a tonne and 800 kg against countries without a carbon tax. With average residential emissions of about 1.75 tonnes per person, that is roughly 11 to 46 percent, or about 2 to 7 Mt a year (the author's arithmetic, an order of magnitude only). Oil use fell mainly in 2000–2007, and annual heat-pump sales rose from 18,000–23,000 in the 1990s to about 60,000.

The design is weaker than for transport, and the authors call the estimates lower bounds. Sweden already taxed carbon before 2001, so there is no untaxed pre-period; the difference-in-differences shows a significant gap in 1997; and Norway dominates two of the three synthetic controls. The case is still the cleanest "dose" experiment in the set: the same households, a known tripling of the rate, and no offsetting tax cut. Sweden's fossil heating-fuel use has since fallen by more than 90 percent from 1990, helped by district heating and grants for switching (Government Offices of Sweden, Ministry of Finance 2023).

4.3 Germany, 1999–2003: the eco-tax on road fuels cut transport emissions by 11 to 16 percent

Germany raised its fuel tax by 3.07 cents a litre in each of five years, a cumulative carbon-price equivalent of about €65 a tonne. From April 1999 to 2003 the ecological tax reform added 6 pfennig (3.07 euro cents) a litre to petrol and diesel each year, 15.35 cents in all, or about 17.8 cents with 16 percent VAT (Basaglia et al. 2023). Each step raised pump prices by 3.4 to 6.1 percent of the previous year's average; the cumulative rise equaled 22 percent of the 1998 petrol price and 30 percent of the 1998 diesel price (ADAC, n.d.). In carbon terms the tax was worth €66 a tonne on petrol and €58 on diesel by 2003, about US$74 and US$65 (Basaglia et al. 2023). Crude oil moved pump prices at the same time: petrol rose 28 cents a litre between 1998 and 2003, of which the eco-tax explains about 18.

Table 4. Germany's eco-tax raised road-fuel prices by a fifth to a third over five years and cut transport emissions by more than a tenth. Petrol at 2.348 and diesel at 2.676 kg CO_2 per litre. Step shares and equivalents are the author's calculation from ADAC annual prices (ADAC, n.d.). Effects: Runst and Höhle (2022) (2005) and Basaglia et al. (2023) (2007; working paper).

Year	Cumulative eco-tax, cents/litre (with VAT)	Step as % of previous year's price: petrol / diesel	Carbon-price equivalent, €/t: petrol / diesel	Transport CO_2 against synthetic Germany
1999	3.07 (3.56)	4.4 / 6.1	13 / 11	
2000	6.14 (7.12)	4.1 / 5.6	26 / 23	
2001	9.21 (10.7)	3.5 / 4.4	39 / 34	
2002	12.28 (14.2)	3.5 / 4.3	52 / 46	
2003	15.35 (17.8)	3.4 / 4.3	65 / 57 (US$74 / 65)	
2005	Total = 21.9% / 30.4% of 1998 prices			−11.5% (−250 kg per person); −16% in alternative specifications; fuel use −9.6% to −14.7%
2007				−19% (−0.42 t per person; working paper)

Two independent synthetic-control studies find transport emissions about 10 to 16 percent below the counterfactual. Runst and Höhle (2022) build a synthetic Germany, mainly from France, the Netherlands and Switzerland, and find transport CO_2 0.2 to 0.35 tonnes per person a year lower; by 2005 the gap was 250 kg, 11.5 percent of 1999 transport emissions, and 16 percent in alternative specifications. Fuel use per person fell 9.6 to 14.7 percent by 2005, after a lag of three to four years, and the share of diesel cars rose. A working paper using a different donor pool and several estimators finds emissions 8.1 to 13.4 percent below the counterfactual on average over 1999–2009, 19 percent in 2007 and about 208 Mt in all; its generalized synthetic control gives −0.43 tonnes per person (95 percent confidence interval

−0.53 to −0.34) (Basaglia et al. 2023). The same paper estimates an elasticity of gasoline demand with respect to the eco-tax of −2.7, against −0.32 for the tax-exclusive price.

The main threats are fuel tourism and the shift to diesel. Drivers near borders may have bought fuel abroad, which country data count as abatement; Basaglia et al. (2023) exclude Austria and Luxembourg from the donor pool for that reason. Car makers' voluntary efficiency commitments and the move to diesel cars also lowered emissions, though the diesel shift is itself partly a response to the tax. The gaps narrow after 2007 as the financial crisis hit all countries.

4.4 United States, 1966–2008: state gasoline tax rises cut fuel use within a year

American states change their gasoline taxes often and by small amounts, which gives hundreds of small natural experiments. Between 1966 and 2008, state taxes rose in 488 state-years and fell in 44 (Li et al. 2014). Most changes were under 10 cents a gallon. At 8.887 kg CO_2 a gallon, 10 cents is a carbon-price equivalent of about US$11 a tonne; it was 3.1 percent of the average pump price in March 2008 ($3.21) and 5.7 percent at December 2008's $1.75 (Table 5). Taxes passed fully into prices: 113 percent of a state tax change reached the pump, with a standard error of 7 percent (Davis and Kilian 2011).

Table 5. In the United States a 10-cent state tax rise, worth about US$11 a tonne, cut gasoline use by about 1.4 percent within a year. Nominal averages from Li et al. (2014), Table 1. Effects: Davis and Kilian (2011) (10 cents) and Li et al. (2014) (5 cents). Carbon-price equivalents are the author's calculation.

Period	Average retail price, cents/gallon	State tax	Federal tax	Taxes as % of retail price
1986–1990	98.0	15.1	10.1	25.7
1991–1995	113.9	19.1	16.7	31.4
1996–2000	125.0	20.3	18.4	30.9
2001–2005	163.3	20.8	18.4	24.0
2006–2008	278.0	21.8	18.4	14.5
Typical change	*5–10 cents = 3–6% of price*			*= US$5.6–11.3/t; gasoline use −0.9% (5 cents) to −1.4% (10 cents) within a year*

A 10-cent tax rise cut gasoline use by about 1.4 percent within a year, and taxes moved demand more than prices did. Davis and Kilian (2011) instrument the pump price with 210 nominal state tax increases between 1989 and 2008 and estimate a price elasticity of −0.46 (standard error 0.23), which they regard as the most credible estimate and a plausible upper bound. A 10-cent tax would cut gasoline use by 1.43 percent (standard error 0.72), about 1.5 percent of vehicle CO_2 and 0.48 percent of total United States CO_2; cuts above 1.0 percent of the total can be ruled out with 95 percent confidence. Li et al. (2014) separate the tax from the rest of the price over 1966–2008 and find a tax elasticity of −0.29 against −0.11 for the tax-exclusive price. A 5-cent tax rise cut consumption by 0.86 percent, three times the 0.29 percent from an equal market price rise.

Part of the tax effect may be buying ahead of announced rises. Drivers fill up before tax increases and delay purchases before cuts. Allowing for this lowers the elasticity estimated from tax changes from −1.14 to −0.37, with a standard error of 0.24 (Coglianese et al. 2017). Even on that lower figure, a 10-cent tax cuts use by about 1.1 percent within a year. These

are one-year effects of small changes, so they bound the short-run response rather than the long-run one.

4.5 British Columbia, 2008–2025: a revenue-neutral carbon tax cut gasoline use and transport emissions

British Columbia taxed almost all fossil fuels from July 2008 and returned the revenue through tax cuts. The rate started at C$10 a tonne of CO_2 and rose C$5 each July to C$30 in 2012. It was frozen until April 2018, then rose to C$35, C$40 (2019–2021), C$45 (2021), C$50 (2022), C$65 (2023) and C$80 (2024), and was set to zero from 1 April 2025 (Government of British Columbia 2025). It covered roughly 70 to 75 percent of provincial greenhouse gas emissions (B. Murray and Rivers 2015; Pretis 2022). Until 2018 the revenue was returned through cuts in personal and corporate income tax and a low-income credit; in 2012/13 tax cuts worth C$1,375 million offset C$1,172 million of revenue (revised forecast).

Table 6. British Columbia's carbon tax reached 8 percent of the gasoline price before it was removed in 2025. Rates: Government of British Columbia (2025). Vancouver self-serve prices: Statistics Canada (2026). The increase includes the 5% GST on the tax. Shares and US$ are the author's calculation.

Effective date	Carbon price, C$/t (US$/t)	Gasoline, cents/ litre	Share of Vancouver pump price: gasoline / diesel	Increase over price without the tax, gasoline
1 July 2008	10 (9)	2.34	1.6% / 1.8%	1.7%
1 July 2010	20 (19)	4.45	3.8% / –	4.1%
1 July 2012	30 (30)	6.67	4.8% / 5.8%	5.3%
1 April 2019	40 (30)	8.89	5.3% / 7.4%	5.9%
1 April 2023	65 (48)	14.31	7.6% / 9.2%	8.6%
1 April 2024	80 (58)	17.61	8.4% / 10.9%	9.6%
1 April 2025	0	0	Pump price fell 17.2 cents/litre, against 18.5 predicted	

At C$30 a tonne the tax was about 5 percent of the pump price of gasoline and about 15 percent of a household gas bill. In July 2012 the tax of 6.67 cents a litre was 4.8 percent of the Vancouver pump price, raising it 5.3 percent above the price without the tax, and diesel's 7.67 cents was 5.8 percent (Table 6). On residential natural gas, C$1.49 per gigajoule was roughly 15 percent of a typical bill, because British Columbia's gas itself was cheap (the author's estimate from a 2018 sample bill; see the research notes). When the tax was removed in April 2025 the Vancouver pump price fell by 17.2 cents a litre, close to the 18.5 cents that full pass-through predicts, though crude prices also fell that month.

The tax cut gasoline use by more than equal price rises would have. Rivers and Schaufele (2015) find the decline in short-run gasoline demand significantly larger than an equivalent market price increase would cause, and estimate 2.4 Mt of CO_2 avoided from gasoline in the tax's first four years. Using household microdata, Lawley and Thivierge (2018) find that a 5-cent-a-litre tax (about C$22 a tonne) cut household gasoline use by 8 percent, with a conservative lower bound of 5 percent after allowing for cross-border buying and transit improvements. That is 2.9 times the response to an equal price change; households in Vancouver cut by about 12 percent, and rural households not at all. Diesel use fell 1.24 litres per person a month over 2008–2016, about 1.3 percent of 2008 diesel emissions a year (Bernard and Kichian 2019). Residential natural gas use per person fell about 7 percent against a synthetic control (Xiang and Lawley 2019).

Transport emissions fell; total emissions did not measurably fall. Using national inventory data for ten provinces over 1990–2016, Pretis (2022) finds transport CO_2 5 percent lower in the short run (standard error 1 percent) and 19 percent lower in the long run (standard error 3 percent); for total emissions the estimates are −1 percent (standard error 1) and −5 percent (standard error 4), not significant. Emissions from stationary fuel combustion did not fall. Pooling seven British Columbia studies, Döbbeling-Hildebrandt et al. (2024) put the effect at −5.4 percent (95 percent confidence interval −9.6 to −1.2) at an average price of about US$18. One synthetic-control study finds emissions and gasoline use rose relative to its comparison group (Arcila and Baker 2022), and another finds the extra response only in the tax's first years (Erutku and Hildebrand 2018). No ex post study yet covers the C$35–80 period or the 2025 removal.

4.6 Switzerland, 2008–2025: a rising levy on heating fuels cut their emissions by about 4 to 10 percent by 2015

Switzerland's CO_2 levy on heating fuels rose tenfold in fourteen years because interim targets were missed. The levy applies to heating oil and natural gas, not motor fuels. It started at CHF 12 a tonne in 2008 and rose automatically when emissions exceeded legal milestones: to CHF 36 in 2010, 60 in 2014, 84 in 2016, 96 in 2018 and 120 from 2022 (Federal Office for the Environment 2018; Ott and Weber 2022). Large firms in the Swiss trading system or with reduction commitments are exempt. About two-thirds of the revenue is returned to households and firms, and one-third funds building renovation and a technology fund. On heating oil, at 2.65 kg CO_2 a litre, the levy rose from 3.18 to 31.80 Swiss centimes a litre (Table 7).

Table 7. Switzerland's heating levy rose to a third of the price of heating oil, and measurable cuts appeared once it passed CHF 60 a tonne. Levy amounts: Swiss customs (BAZG) tables in the research notes. Shares: the author's calculation against annual heating-oil prices for purchases of 3,001–6,000 litres from Liechtenstein's statistics office, a proxy under the customs union; Francescutto and Mathys (2022) give 21% in 2015 before VAT. US$ at ECB annual rates. Effects: owners' heating fuel from Francescutto and Mathys (2022); 2015 emissions from Federal Office for the Environment (2018).

Years	Levy, CHF/t (US$/t)	Levy on heating oil, centimes/ litre	Share of heating-oil retail price, with VAT	Increase over price without the levy	Effect
2008–09	12 (11)	3.18	3–5%	+3–5%	No significant effect on owners' heating fuel
2010–13	36 (35–41)	9.55	10–12%	+11–14%	No significant effect on owners' heating fuel
2014–15	60 (62–66)	15.90	17–23%	+21–30%	Owners −12%; 2015 heating-fuel CO_2 −4.3% to −9.6% (0.8–1.8 Mt)
2016–17	84 (85)	22.26	31–34%	+44–52%	Owners −14%
2018–21	96 (97–105)	25.44	29–40%	+40–65%	Not evaluated
2022–25	120 (126–145)	31.80	25–36%	+33–56%	Not evaluated

By 2016 the levy had raised the price of heating oil by about half. Including VAT, the levy was 3 percent of the retail price of heating oil in 2008, 10 to 12 percent in 2010–2013, 17 to 23 percent in 2014–2015 and 29 to 40 percent in 2016–2021, when it raised the price 40 to 65 percent above the levy-free price. The range in each period reflects swings in oil prices, not in the levy. At CHF 120 the levy on natural gas is about CHF 24 per megawatt-hour.

The official evaluation attributes a 4 to 10 percent cut in heating-fuel emissions by 2015. The Federal Office for the Environment's evaluation, combining a time-series model with a general-equilibrium model on observed data, credits the levy with 0.8 to 1.8 Mt of CO_2 in 2015, 4.3 to 9.6 percent of the roughly 17 Mt of emissions it covered, and 4.1 to 8.6 Mt cumulatively over 2005–2015 (Federal Office for the Environment 2018). Net of the building programme and target agreements, the 2015 effect is about 1.3 Mt. About three-quarters came from households, mainly by switching from oil to gas and renewables. Because the counterfactual is modeled, this is the least design-based estimate in the set.

Survey data agree that households responded once the levy was high enough. Using the Swiss Household Budget Survey for 2006–2017, Francescutto and Mathys (2022) find no significant effect on house owners' heating-fuel demand at CHF 12 or 36, but cuts of 12 percent at CHF 60 and 14 percent at CHF 84 relative to 2006–2007; the levy moved demand almost twice as much per franc as the net oil price. A household panel finds no short-run response to the 2016 increase (Ott and Weber 2022). A firm-level working paper finds emissions 3 percent lower in 2010–2012 and up to 8 percent lower in 2013–2015 (Fauceglia et al. 2020).

4.7 European Union, 2005–2012: emissions trading cut emissions at regulated plants by about 10 percent at low prices

The EU Emissions Trading System put a price on carbon at power stations and heavy industry from 2005, mostly at 5 to 25 euros a tonne. Phase I (2005–2007) covered almost half of EU CO_2 emissions (Bayer and Aklin 2020). Allowance prices averaged about €21 in 2005 and €17 in 2006 before expiring Phase I permits fell to near zero in 2007. Phase II (2008–2012) averaged €13.7 (US$19), and prices then sat at €4.5–7.7 from 2013 to 2017 before rising to about €25 in 2019–2020 and €53–86 from 2021 (Table 8). Industrial plants received most allowances free, so the price raised the marginal cost of emitting, not the average energy bill.

Table 8. The EU trading system cut emissions at regulated plants by about a tenth in its first phases, at modest marginal cost increases for gas and oil. Annual means of ICAP daily secondary-market prices, the author's averaging. Fuel prices: Eurostat industrial gas (large users, excluding taxes), EU Weekly Oil Bulletin heavy fuel oil, World Bank South African export coal (an upper bound, as freight is excluded); the author's calculation. Effects: Dechezleprêtre et al. (2023), Colmer et al. (2025), Bayer and Aklin (2020).

Period	Allowance price, €/t (US$/t)	Marginal carbon cost as % of fuel price: gas / heavy fuel oil / coal	Ex post effect on regulated plants
Phase I, 2005–07	12.3 mean (15.2); 21 in 2005, 0.7 in 2007	– / 18–25% / 101–130% (2005–06)	−6%, not significant (four countries); −14% (French manufacturing)
Phase II, 2008–12	13.7 mean (19.0)	4–13% / 4–17% / 24–68%	−15% (four countries); −16.3% (French manufacturing); −11.5% in trading sectors, 2008–2016
2013–17	4.5–7.7	3–5% / 3–7% / 18–36%	No plant-level evaluation
2019–20	24.5–24.9	20–23% / 18–22% / 92–101%	No plant-level evaluation
2021–25	53–86 (62–92)	20–33% / 34–44% / 84–184%	No plant-level evaluation

Matched comparisons of regulated and unregulated plants find cuts of about 10 to 16 percent, mostly in Phase II. Dechezleprêtre et al. (2023) match regulated plants in France, the Netherlands, Norway and the United Kingdom with similar unregulated plants and find

emissions about 10 percent lower over 2005–2012 (sensitivity range −7 to −16 percent): −6 percent in Phase I, not significant, and −15 percent in Phase II. Regulated firms' profits and employment were unaffected. Colmer et al. (2025) use French administrative data on 4,201 manufacturing firms and find emissions 14 percent lower in Phase I and 16.3 percent lower in Phase II, with no detectable fall in economic activity and no evidence of outsourcing. At the sector level, a generalized synthetic control finds emissions in trading sectors 8.1 percent (95 percent confidence interval −13.2 to −1.7) to 11.5 percent (−16.9 to −5.4) below the counterfactual, about 1.2 billion tonnes over 2008–2016 or 3.8 percent of total EU emissions (Bayer and Aklin 2020). The meta-analysis puts the EU trading system's average effect at −7.3 percent (Döbbeling-Hildebrandt et al. 2024).

The cut was large for the price, which points to expectations rather than the spot price. Phase II prices raised the marginal cost of gas by 8 to 13 percent and of coal by 37 to 68 percent in 2008–2011, yet regulated plants cut emissions by about 15 percent. Bayer and Aklin (2020) argue that firms responded to the expected tightening of the cap, not to the current price, and that their estimates come on top of the effect of the 2008–2009 recession. No plant-level evaluation yet covers the much higher prices since 2021.

4.8 Britain, 2013–2017: a carbon price floor drove coal out of power generation

From April 2013 Britain taxed carbon in fuels for power generation on top of the EU allowance price. The tax, the Carbon Price Support, was £4.94 a tonne in 2013–14, £9.55 in 2014–15 and £18.08 in 2015–16, and has been frozen at £18 since 2016–17; in April 2026 the government announced its removal from April 2028 (Carbon Credits 2026). Added to the EU allowance price, generators faced a total carbon price of €10.6 a tonne in 2013, €18.4 in 2014, €32.0 in 2015 and €26.9 in 2016 (Abrell et al. 2022), about US$14 to 36. Because a coal plant emits about 2.4 times as much CO_2 per unit of electricity as a gas plant, the tax raised its costs 2.4 times as much (Table 9).

Table 9. Britain's carbon price floor raised coal plants' fuel costs by up to 141 percent, against 30 percent for gas, and cut power-sector emissions by a fifth or more. Total price and pre-carbon fuel prices from Abrell et al. (2022), Table 1 (working-paper version); cost increases are the author's calculation at 0.34 (coal) and 0.19 (gas) tCO_2 per MWh of heat. Coal shares: Department for Business, Energy and Industrial Strategy (2017) and Leroutier (2022). Effects: dispatch-only by year from Abrell et al. (2022) (working paper, Table 5); three-year effect from Gugler et al. (2023); all channels from Leroutier (2022).

Year (April–March)	Carbon Price Support, £/t	Total carbon price, €/t (US$/t)	Fuel cost increase per MWh of heat: coal / gas	Coal share of generation	Estimated cut in power-sector CO_2
2012	–	7.4 (EU allowance only)	–	39%	Baseline
2013	4.94	10.6 (14)	+39% / +7%	–	−1.7% (dispatch only)
2014	9.55	18.4 (24)	+73% / +17%	–	−4.2% (dispatch only)
2015	18.08	32.0 (36)	+141% / +30%	22%	−11.9% (dispatch only); −26% within three years, 2013–15
2016	18.00	26.9 (30)	+112% / +35%	9%	−10.7% (dispatch only)
2017–19	18.00	–	–	7% (2017), 2.1% (2019)	−20% to −26% a year over 2013–2017, all channels

Coal's share of generation fell from 39 percent in 2012 to 2 percent in 2019. The official statistics attribute the 2016 collapse, from 22 to 9 percent, to "the carbon price [making] coal generation more expensive than gas" (Department for Business, Energy and Industrial Strategy 2017). Three peer-reviewed studies measure the effect and differ mainly in what they count. Counting only the switch from coal to gas at plants that stayed open, a machine-learning counterfactual finds a cut of 6.2 percent over 2013–2016 at an average cost of €18 a tonne (Abrell et al. 2022). A regression discontinuity on hourly plant data finds a 26 percent cut (38.6 Mt) within three years (Gugler et al. 2023). A synthetic control built from other European countries, which also counts closures, finds emissions 20 to 26 percent lower each year over 2013–2017 (Leroutier 2022). Its working paper splits the effect roughly equally between plants that ran less, plants that closed or were not built, and older plants already scheduled to close under EU air-quality rules that closed sooner. It implies a cut of about 1.4 to 1.65 percent for each euro of the tax.

The British case shows how a modest price works when a substitute is standing by. Britain could switch quickly from coal to gas, and gas prices fell by almost half over 2013–2016 (Abrell et al. 2022); Gugler et al. (2021) conclude that a carbon price of about €30 a tonne was enough for large, cheap abatement where gas could replace coal. Some emissions moved abroad: Leroutier's working paper estimates about 6 Mt more in the Netherlands and 1 Mt in Ireland through electricity imports. None of the studies estimates the effect on retail electricity prices.

4.9 Indonesia, 2013–2015: cutting fuel and electricity subsidies cut electricity use by 7 percent and road traffic by 10 percent

Indonesia raised subsidized gasoline prices by 89 percent in two steps, a carbon-price equivalent of about US$143 a tonne. Before June 2013 subsidized gasoline sold for 4,500 rupiah a litre, about 47 US cents, below the cost of the crude oil in it (Burke et al. 2017). The government raised it to 6,500 rupiah in June 2013 and 8,500 in November 2014, and raised diesel from 4,500 to 5,500 and then 7,500 (Table 10). When world oil prices fell, gasoline prices were cut in early 2015 but stayed above their pre-reform level; in July 2017 gasoline was still 43 percent above it. Electricity tariffs rose quarterly from 2013, except for households with the smallest connections; average prices rose most for business in 2013 (16 percent), industry in 2014 (23 percent) and street lighting in 2015 (36 percent) (Burke and Kurniawati 2018).

Table 10. Indonesia's subsidy reform raised gasoline prices by up to 89 percent and cut electricity use and road traffic within two years. Prices: Burke et al. (2017). Equivalents are the author's calculation at 2.3 (gasoline) and 2.68 (diesel) kg CO_2 per litre and monthly exchange rates. Effects: Burke et al. (2017) (traffic) and Burke and Kurniawati (2018) (electricity).

Date	Gasoline, rupiah/litre (change)	Diesel, rupiah/litre (change)	Carbon-price equivalent, US$/t: gasoline / diesel	Measured effect
Before June 2013	4,500	4,500	–	
22 June 2013	6,500 (+44%)	5,500 (+22%)	88 / 38	
18 November 2014	8,500 (+31%)	7,500 (+36%)	72 / 61	Cumulative from 2013: 143 / 92
Early 2015	Cut to about 6,700	Fixed subsidy of 1,000/litre		Second half of 2015: toll-road traffic −10%; 2015: electricity

Date	Gasoline, rupiah/litre (change)	Diesel, rupiah/litre (change)	Carbon-price equivalent, US$/t: gasoline / diesel	Measured effect
				use −7% (16 TWh, about 13 Mt CO_2 a year)
July 2017	6,450 (+43% on 2013)		64 (lasting increase)	

Electricity use fell 7 percent and road traffic 10 percent below what would have happened without reform. Burke and Kurniawati (2018) estimate electricity price elasticities from a panel of six consumer groups in 16 regions over 1992–2015: about −0.15 to −0.2 in the same year and about −0.4 over four years. Applying them to the observed tariffs, they find electricity use in 2015 about 7 percent (16 TWh) below the no-reform path, avoiding about 13 Mt of CO_2 a year from the grid, with industry, households and business all contributing. Industry's oil use and total energy use were also lower in 2015 than in 2013, so the cut does not seem to have been offset by switching to other fuels. On 19 toll roads, mostly on Java, traffic in the second half of 2015 was about 10 percent below the no-reform path, with a fuel price elasticity of about −0.1 at once and −0.2 after a year (Burke et al. 2017).

The counterfactual rests on estimated elasticities, and the reform was partly reversed. Both studies identify the response from the timing of price changes, controlling for income, trends and road-specific factors, then apply it to the reform; neither has an untreated comparison group. Prices fell again in early 2016 with world oil prices, probably reversing part of the effect. The case matters because it is the only developing economy in the set, and it shows that consumers respond to large price rises even where incomes are low.

4.10 Germany, 2022: a gas price shock cut gas use by a quarter but national emissions by only about 2 percent

The gas crisis of 2021–2022, deepened by Russia's invasion of Ukraine, raised German gas prices by the equivalent of several hundred dollars a tonne of CO_2. Wholesale gas, at €15–20 per megawatt-hour before the pandemic, traded at €100–200 in 2022, with spikes to €227 and €339 (Ruhnau et al. 2023). Industrial purchase prices peaked in September 2022 at 580 percent of their pre-crisis level, and household prices in November 2022 were 130 percent above their 2019–2021 level. Averages over each half-year rose less because of long contracts: households in a typical consumption band paid 6.3 cents per kilowatt-hour on average in 2019–2021, 9.4 cents in the second half of 2022 and 12.3 cents in the first half of 2023 (Table 11). At 0.202 tonnes of CO_2 per megawatt-hour, these increases are worth about €150 to €900 a tonne. The government cut VAT on gas from 19 to 7 percent, and its gas price brake compensated households for 80 percent of past consumption while leaving the marginal price unchanged (Moll et al. 2023).

Table 11. Germany's 2022 gas shock, worth hundreds of dollars a tonne, cut gas use by about a quarter within months. Prices and effects: Ruhnau et al. (2023). Eurostat averages (households band D2 with all taxes; industry band I4 excluding VAT) and carbon-price equivalents are the author's calculation at 0.202 tCO_2 per MWh.

Period	Price measure	Increase over 2019–2021	Carbon-price equivalent, €/t (US$/t)	Gas use against temperature-adjusted baseline
September 2021	Wholesale rising	–	–	Industry −4%

Period	Price measure	Increase over 2019–2021	Carbon-price equivalent, €/t (US$/t)	Gas use against temperature-adjusted baseline
March 2022	Wholesale €100–200/MWh in 2022	About ten times	400–900 (420–950)	Small consumers −10%
September 2022	Industrial price at 580% of pre-crisis	+480%	about 750 (790)	Small consumers −28%
October 2022				Industry −27%
November 2022	Household price index +130%	+130%	about 405 (430)	Small consumers −21%
Second half of 2022	Eurostat averages: households +50%, industry +94%		147–154 (155–162)	All consumers −23%

Gas use fell 23 percent below a temperature-adjusted baseline in the second half of 2022. Ruhnau et al. (2023) regress monthly gas use on crisis-month indicators, seasonality, trend and a temperature-driven heating profile, separately for industry, small consumers and power. Industry began cutting in September 2021, as prices first rose, and was 27 percent below baseline by October 2022; small consumers, mostly on fixed-price contracts, cut 10 percent in March 2022 and 28 percent in September. Across all users the cut averaged 23 percent in the second half of 2022. The authors' rough implied elasticities are small: −0.04 for industry and −0.16 to −0.27 for small consumers. They cannot separate price from public appeals and fear of shortage.

The fall in national emissions was much smaller than the fall in gas use. Not adjusted for temperature, gas use from July 2022 to March 2023 was 157 TWh below its 2019–2021 average (Moll et al. 2023), which at 0.18–0.20 tonnes per megawatt-hour is about 29 to 32 Mt of CO_2 (the author's arithmetic). But power stations replaced gas with coal: by the environment agency's early estimate, energy-sector emissions rose about 10.7 Mt in 2022 and national emissions fell only about 15 Mt, or 1.9 percent (Umweltbundesamt 2023) [VERIFY: early estimate seen only in summary; check the final inventory]. Output in energy-intensive industry fell close to 20 percent, and some production, such as ammonia, moved abroad (Moll et al. 2023). A price on gas alone is not a carbon price: it can push power generation toward coal.

5 What the ten cases show together

Every case shows a cut in emissions or fuel use from the covered fuels. The well-identified estimates in Table 1 range from 1.4 percent within a year (United States) to 26 percent a year within five years (British power). Where a study tests significance, most effects are distinguishable from zero, though synthetic-control inference with one treated unit cannot do better than p = 1/15 or so. The only contrary estimate in the set is one synthetic-control study of British Columbia (Arcila and Baker 2022), against several studies of the same province that find cuts. Figure 1 plots each estimate against its price.

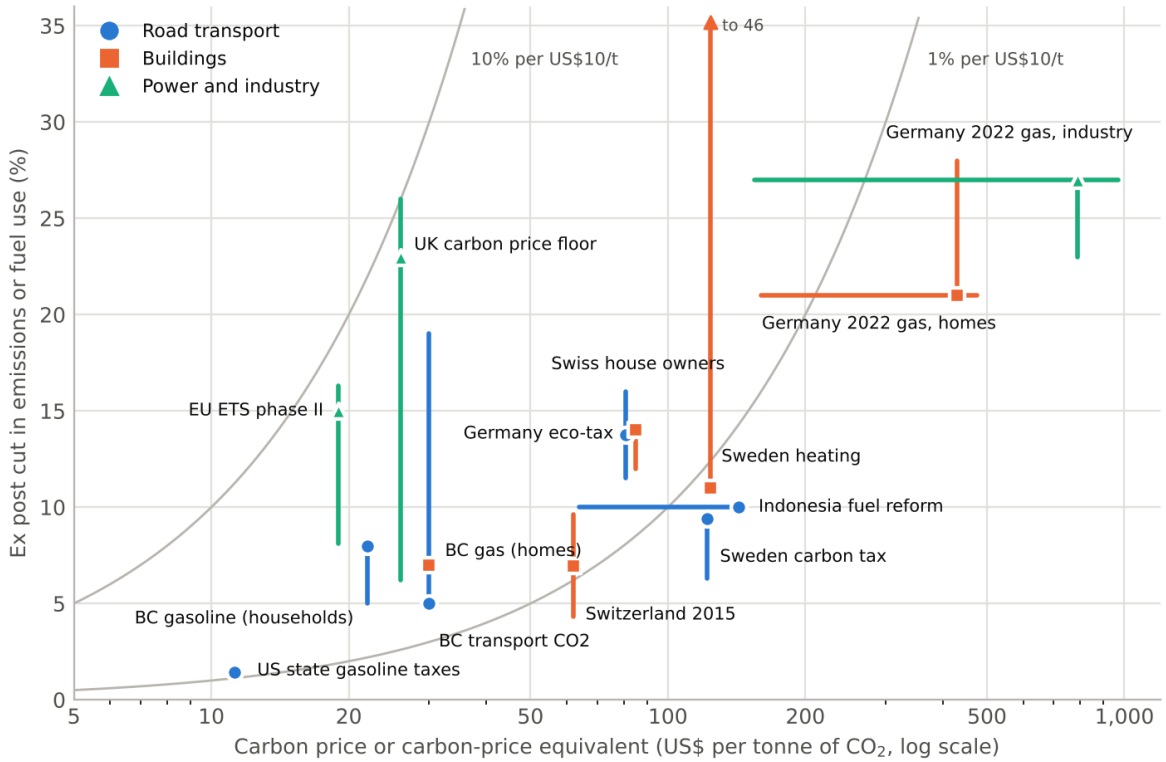


Figure 1. Ex post cuts against the carbon price or carbon-price equivalent that produced them. Each point is one case and sector; vertical lines span the range of published estimates or specifications, horizontal lines the range of price measures. Gray curves mark constant effects of 1 and 10 percent per US$10 a tonne. Horizons differ, from a year (United States) to fifteen years (Sweden). The Sweden heating range is the author's conversion of 200–800 kg per person into a share of residential emissions. Indonesia's electricity effect is not shown because no carbon-price equivalent by consumer group was computed. Source: author's calculation from the studies in Table 1, `2.Source/natural_experiments.py`.

Proposition 1. In road transport and buildings, a sustained carbon price cuts covered emissions by about 1 to 2 percent per US$10 a tonne within five to fifteen years. The condition is that the price reaches the user and is expected to last. Table 12 converts each case to this yardstick. Germany's eco-tax (1.4 to 2.0 percent per US$10), Switzerland (0.7 to 1.6), Sweden's transport tax (about 0.8, carbon tax alone) and British Columbia's tax on natural gas (2.3) cluster in this band; the United States' one-year response to small tax changes (1.0 to 1.3) does too. The yardstick is crude: a dollar is a bigger share of a cheap fuel, so it moves demand more where pre-tax prices are low, and it ignores differences in horizon. In elasticity terms, the transport cases imply about −0.4 to −0.7 and the heating cases about −0.15 to −0.45.

Table 12. Per dollar, cuts were about 1–2 percent per US$10 a tonne in transport and heating and several times larger in power. Cut per US$10 = cut divided by price, times 10. Implied elasticities divide the cut by the retail price increase in the case tables; "estimated" marks elasticities reported by the study. All are rough and the author's arithmetic except where marked. Source: `2.Source/natural_experiments.py`, `table_per10.csv`.

Case	Sector	Price, US$/t	Cut	Cut per US$10/t	Horizon	Implied price elasticity
United States	Gasoline	11	1.2–1.4%	1.0–1.3%	1 year	−0.37 to −0.46 (estimated)
British Columbia	Household gasoline	22	5–8%	2.3–3.6%	2–4 years	About −2, tax-specific

Case	Sector	Price, US$/t	Cut	Cut per US$10/t	Horizon	Implied price elasticity
British Columbia	Transport CO_2	30	5% (19% long run)	1.7% (6.3% long run)	Short and long run	About −1 short run
British Columbia	Residential gas	30	7%	2.3%	About 6 years	About −0.4
Germany	Transport CO_2	81	11.5–16%	1.4–2.0%	6 years	−0.4 to −0.7
Sweden	Transport CO_2, tax alone	122	9.4%	0.8%	14 years	About −0.4
Switzerland	Heating-fuel CO_2	62	4.3–9.6%	0.7–1.5%	8 years	−0.15 to −0.45
Switzerland	Owners' heating fuel	85	14%	1.6%	9 years	About −0.3
Sweden	Residential CO_2	124	11–46%	0.9–3.7%	1–6 years after 2004	n.a.
Indonesia	Toll-road traffic	64–143	10%	0.7–1.6%	2 years	−0.1 to −0.2 (estimated)
Indonesia	Electricity	n.a.	7%	n.a.	1–3 years	−0.15 to −0.4 (estimated)
EU ETS, phase II	Power and industry	19	8–16%	4–9%	1–5 years	n.a.
Britain	Power	26	6–26%	2.4–10%	1–5 years	n.a.
Germany, 2022	Household gas	160–475	21–28%	0.5–1.9%	Months	−0.16 to −0.27 (estimated)
Germany, 2022	Industrial gas	155–970	23–27%	0.2–1.7%	Months	−0.04 (estimated)

Proposition 2. Where a lower-carbon substitute is already installed, the cut per dollar is five to ten times larger. The condition is spare capacity in the substitute and a price wedge large enough to reverse the order in which plants run. In Britain, spare gas plants and falling gas prices let a total carbon price of US$14 to 36 move coal from the top of the merit order to the bottom; the cut was 2.4 percent per US$10 counting dispatch alone and up to 10 percent counting closures. EU trading cut 4 to 9 percent per US$10 at Phase II prices. In transport and heating, by contrast, the substitutes, more efficient cars or a heat pump, arrive only as equipment is replaced, so the response builds over a decade.

Proposition 3. Taxes move demand more than equal market price changes, at least for a time. The ratio is 2.9 in British Columbia's household data (Lawley and Thivierge 2018), about 3 in Sweden (Andersson 2019) and the United States (Li et al. 2014), about 8 in Germany's eco-tax time series (Basaglia et al. 2023), and about 2 in Switzerland (Francescutto and Mathys 2022). Explanations include salience, the expectation that taxes persist while market prices revert, and publicity. Part of the gap is an artifact: buying ahead of announced tax rises inflates tax-based estimates (Coglianese et al. 2017), and a more efficient estimator halves the Swedish coefficients (Yu 2024). The gap also fades: British Columbia's extra response appeared only in the tax's first years (Erutku and Hildebrand 2018).

Proposition 4. The cut per dollar is smallest for short, very large shocks and for prices too low to notice. Germany's 2022 gas shock and Indonesia's subsidy reform raised prices

by 89 to 480 percent and cut use by 10 to 28 percent, under 2 percent per US$10. Over months or a year or two, households and firms can turn down thermostats and drive less but cannot yet replace boilers, cars or furnaces. At the other end, Switzerland's levy had no measurable effect on owners' heating fuel at CHF 12–36, when it was 3 to 12 percent of the price, and a clear one at CHF 60–84 (Francescutto and Mathys 2022).

Proposition 5. Effects on total emissions are smaller than on covered fuels, because coverage is partial and design leaks. British Columbia cut transport emissions but not, measurably, the provincial total (Pretis 2022). Sweden offset its 2001–2004 motor-fuel tax rise with energy-tax cuts, and the transport gap barely widened (Andersson 2019). Germany's 2022 gas cut was largely undone by coal in power and by imports of gas-intensive goods (Moll et al. 2023; Umweltbundesamt 2023). Britain's cut was partly offset by electricity imports (Leroutier 2022). Norway, where the tax covered about 64 percent of CO_2 and demand in the taxed sectors was inelastic, cut emissions by only about 2 percent (Table 13).

5.1 Cases left out, and why

Eleven further episodes were examined and left out of the main set because their evidence is thinner, model-based or confounded. Table 13 lists them with their numbers. Most point the same way as the ten. Australia's carbon price (2012–2014) is the most informative omission: an unrefereed working paper credits it with a 3.2 to 5.6 percent annual cut in power-sector emissions, and emissions rose after it was repealed.

Table 13. Eleven further episodes mostly point the same way but rest on weaker evidence. Iran and Nigeria figures are from administrative data reported in the press (research notes).

Episode	Sector and price	Evidence	Why not in the main set
Finland, 1990 carbon tax	Transport; US$1.75/t (1990) to US$23 (2005)	Transport CO_2 16% lower in 1995, 25% in 2000, 30% in 2004 (Mideksa 2024)	Replication finds the effect driven by one donor country and about a third as large without it (Fernando 2026)
Norway, 1991 carbon tax	Most sectors; average US$21/t, US$51 on petrol (1999)	CO_2 2.3% lower in 1999 (Bruvoll and Larsen 2004); transport about 2.4%, not significant (Yu 2024)	Model-based counterfactual; wide exemptions
Australia, 2012–2014 carbon price	Power and large industry; A$23–24.15/t	Power-sector CO_2 3.2–5.6% a year lower, 11–17 Mt over two years; household electricity prices +10%, wholesale +59% (O'Gorman and Jotzo 2014); consumer electricity prices +15.3% in the quarter it began (Australian Bureau of Statistics 2012); pass-through to spot prices largely complete (Nazifi et al. 2021)	Emission estimate from one unrefereed working paper
Britain, fuel duty escalator, 1993–1999	Road transport	Transport CO_2 0.35 t per person a year lower; p about 0.07 (Bretschger and Grieg 2024)	One study; weak comparison group; duty rates not documented here
Regional Greenhouse Gas Initiative, 2009	Power, north-eastern United States; about US$2–4/t	Emissions would have been 24% higher without it (B. C. Murray and Maniloff 2015)	Price too low to isolate a price effect; revenue spent on efficiency

Episode	Sector and price	Evidence	Why not in the main set
France, 2014–2018 carbon tax	Fossil fuels outside the EU ETS (road fuels from 2015); €7/t (2014) to €44.6 (2018)	Manufacturing CO_2 about 5% lower over 2014–2018 (Dussaux 2020)	Working paper read only in summary; no ex post household study; oil price falls masked the signal
Saudi Arabia, 2016 and 2018	Gasoline, residential electricity; gasoline equivalent US$35–132/t	2018 gasoline 2.0–2.8 billion litres lower (4.6–6.4 Mt CO_2); residential electricity 139 to 130 TWh (Aldubyan and Gasim 2021); 164 Mt over 2016–2018 (Gasim et al. 2023)	Counterfactual from an estimated demand model
Iran, 2019 gasoline price rise	Gasoline; price +50% within quota, +200% above	Sales reportedly −22% in three weeks	Administrative data only; rationing introduced at the same time
Nigeria, 2023 subsidy removal	Petrol; subsidy removed May 2023	Depot loadings −30% to −35%	Loadings, not use; reduced smuggling
Germany, 2021 national emissions trading	Heating and transport fuels; €25/t (2021) to €55 (2025)	None ex post	The official evaluation calls an ex post estimate infeasible (Zerzawy et al. 2024)
Ireland, 2010 carbon tax	Heating and transport fuels; €15–20/t	None ex post found	No counterfactual study; deep recession

6 The strongest objections

Objection: each case has one treated unit, so the effects could be chance. Synthetic-control studies of a single country cannot produce conventional confidence intervals, and their placebo p-values bottom out at about 0.07 (Andersson 2019; Leroutier 2022). The answer is replication across cases and methods. Ten cases in different sectors, countries and decades, analyzed with synthetic control, matched difference-in-differences, instrumental variables and regression discontinuity, all point the same way, which chance alone would rarely produce even if each estimate alone is marginal.

Objection: published estimates are biased toward large effects. They are. Döbbeling-Hildebrandt et al. (2024) find that correcting for publication bias lowers the range of significant scheme-level effects from 5–21 percent to 4–15 percent, and paper 5.4 shows that correction halves the average published long-run gasoline elasticity (Stretton 2026a). The ranges here should be read as upper-middle estimates. The direction is unaffected, and the cases most exposed to the bias, single-country synthetic controls, have been reproduced independently (Bonander et al. 2023; Yu 2024).

Objection: something else happened at the same time. Recessions coincided with Sweden's tax (1991–1993), the EU system's Phase II (2008–2009) and British Columbia's tax (2008–2009). Oil prices swung in all the transport cases, and other policies ran alongside the Swiss levy and Britain's floor. The better studies address each: Andersson finds no

rebound when Swedish output recovered; Bayer and Aklin (2020) estimate effects on top of the recession's; Pretis (2022) controls for provincial output; the Swiss evaluation nets out the building programme (Federal Office for the Environment 2018); and Leroutier (2022) subtracts biomass conversions, renewables support and imports. What remains is imprecise, not absent.

Objection: some counterfactuals are models, not experiments. Switzerland's official estimate and Indonesia's estimates apply estimated elasticities to observed prices. That is a weaker design. The paper keeps them because each is backed by a peer-reviewed micro study with a design-based result: survey evidence for Swiss owners (Francescutto and Mathys 2022) and a panel identified from the timing of price changes in Indonesia (Burke and Kurniawati 2018; Burke et al. 2017).

7 What the cases imply for models such as CPAT

The ex post evidence supports CPAT's long-run response for road fuels and suggests its response for home heating is too high. CPAT's default long-run price elasticity is −0.64 for gasoline in transport and −0.70 for natural gas in homes in low- and middle-income countries (Stretton 2026a). The transport cases imply about −0.4 to −0.7 over five to fifteen years, so CPAT sits inside the range. At a pump price of US$1.20 a litre and 2.3 kg of CO_2 a litre, a US$10 carbon price adds 1.9 percent, which at −0.64 cuts use by 1.2 percent, within the 0.8 to 2.0 percent per US$10 of the German, Swedish and United States cases. The heating cases imply −0.15 to −0.45 after eight to nine years in Switzerland and about −0.4 for natural gas in British Columbia, below CPAT's −0.70. Heating equipment lasts decades, so the full long-run response may be larger than these horizons show; but the evidence gives no support for a higher value.

The timing of the response matters as much as its size. Paper 5.4 finds that CPAT applies the full long-run response in the first year (Stretton 2026a). The natural experiments show responses that build over years: German fuel use fell only after three to four years, Swiss households responded only once the levy had risen and stayed up, and British Columbia's long-run transport effect is four times its short-run effect. A model that front-loads the response will overstate early cuts and understate early revenue.

Coal-to-gas switching in power needs its own treatment. The British and EU cases show that a modest price can cut power emissions by a fifth when gas capacity is available. A model with only own-price demand elasticities will miss that, and a model that lets switching happen regardless of spare capacity will overstate it elsewhere. Each case in Section 4 can serve as a back-cast test, the procedure paper 5.3 recommends (Stretton 2026b): give the model the pre-policy data and the observed price path, and compare its predicted cut with the measured one.

8 Policy implications

Plan on about 1 to 2 percent fewer emissions per US$10 a tonne in transport and buildings, building up over a decade. A sustained carbon price of US$50 a tonne on road fuels and heating should cut emissions from those fuels by roughly 5 to 10 percent within ten years. That is enough to matter and not enough on its own to reach net zero. Revenue erodes slowly, which helps the budget.

Expect much larger, faster cuts in power where cleaner capacity already exists. In a system with idle gas or renewable capacity and expensive coal, a price of US$20 to 40 a

tonne can cut power-sector emissions by a fifth within five years, as in Britain. Where no substitute exists, the same price mostly raises tariffs.

Do not undo the price with the other hand. Sweden's offsetting energy-tax cuts on petrol in 2001–2004, Germany's switch to coal in power in 2022 and Norway's exemptions all diluted the effect. The price should cover the fuels that can be substituted against each other: a price on gas without one on coal can raise emissions.

Make the path credible and visible. Responses were larger to taxes than to market prices, larger where the rise was expected to last, and absent where the price was too small to notice. A published, rising schedule, like Switzerland's automatic increases, does more than an unannounced change of the same size. Subsidy reform counts too: Indonesia's price rises cut electricity use and traffic within two years.

The conditions under which these numbers fail. They come from high- and upper-middle-income economies with mature fuel markets, plus one developing economy. In countries with weak pass-through, large informal fuel markets or heavy smuggling, measured cuts may overstate real ones, as the Nigerian and Iranian figures in Table 13 show.

9 Conclusion

Carbon prices have cut emissions wherever they have been properly measured, by amounts that a ministry can plan around. Ten natural experiments, from Sweden in 1991 to Germany in 2022, show cuts of about 1 to 2 percent per US$10 a tonne in transport and heating over five to fifteen years, and several times more in power where coal could give way to gas. The main limitation is that most cases are single countries with one treated unit, so each estimate is imprecise and the yardstick per dollar is rough. The next step is to back-cast these cases in CPAT and in other models used for policy advice. That would show, fuel by fuel, whether the models' responses match what happened, and would extend the evidence to the much higher prices of the EU trading system since 2021, British Columbia's C$80 tax and its 2025 removal, which no one has yet evaluated.

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Appendix A: Conversions

Emission factors. Petrol: 2.323 kg CO_2 per litre (Sweden, Swedish Ministry of Finance), 2.348 kg per litre or 8.887 kg per US gallon (Germany and United States, US EPA), 2.22 kg per litre (British Columbia, implied by its own rates, which exempt the ethanol blend), 2.3 kg per litre (Indonesia). Diesel: 2.676 kg per litre (Germany, Umweltbundesamt), 2.56 kg per litre (British Columbia, implied by its rates), 2.68 kg per litre (Indonesia). Heating oil: 2.744 kg per litre (Sweden), 2.65 kg per litre (Switzerland, Swiss customs). Natural gas: 0.202 tonnes per megawatt-hour on a net calorific basis (0.182 on a gross basis); British Columbia 49.7 kg per gigajoule. Coal: 0.34 tonnes per megawatt-hour of heat. Power plants: coal about 0.9 and gas about 0.37 tonnes per megawatt-hour of electricity at the efficiencies in Abrell et al. (2022) (38 and 51 percent).

Exchange rates. Annual averages from the Federal Reserve's H.10 release (FRED series AEXSDUS, AEXUSEU, AEXCAUS, AEXUSUK, AEXSZUS), except: Swiss and EU ETS conversions at European Central Bank annual rates or ICAP's daily dollar values; Indonesian conversions at monthly OECD rates; Sweden's 2023 figure at the Ministry of Finance's rate of 3 October 2022.

Retail price increase. Per-unit amount, plus VAT where the final user pays it, divided by the tax-inclusive retail price minus that amount, assuming full pass-through. A share of the price is that amount divided by the full tax-inclusive price.

Cut per US$10 a tonne. The study's estimated percentage cut divided by the carbon price or equivalent in US$ a tonne, times ten. It is a rough semi-elasticity; it ignores differences in horizon, coverage and pre-tax prices.

Appendix B: Evidence register

Table 14. Evidence register for the ten cases. Research notes with page references: `5.Notes/research/`.

Case	Study	Design and data	Status	What was read
Sweden transport	Andersson (2019)	Synthetic control, 25 OECD countries, 1960–2005	Peer-reviewed	Abstract, online appendix, 2017 working paper; numbers checked against two replications
Sweden transport	Bonander et al. (2023); Yu (2024)	Reproduction and replication	Discussion paper; peer-reviewed	Full text (working-paper versions)
Sweden heating	Runst and Thonipara (2020)	Synthetic control and difference-in-differences, 19 countries, 1990–2016	Peer-reviewed	Abstract; full working paper
Germany eco-tax	Runst and Höhle (2022)	Synthetic control, 23–25 countries	Peer-reviewed	Abstract; full working paper
Germany eco-tax	Basaglia et al. (2023)	Synthetic control, generalized synthetic control, time series	Working paper	Full text

Case	Study	Design and data	Status	What was read
United States	Davis and Kilian (2011); Li et al. (2014); Coglianese et al. (2017)	State panels, instrumental variables, 1966–2008	Peer-reviewed	Abstracts; full working papers
British Columbia	Rivers and Schaufele (2015); Lawley and Thivierge (2018); Bernard and Kichian (2019); Xiang and Lawley (2019)	Province and household panels, cointegration, synthetic control	Peer-reviewed	Abstracts; working papers where available
British Columbia	Pretis (2022)	Difference-in-differences and synthetic control, 10 provinces, 1990–2016	Peer-reviewed	Full text
Switzerland	Federal Office for the Environment (2018)	Time-series and general-equilibrium models on observed data	Official evaluation	Full text of fact sheet
Switzerland	Francescutto and Mathys (2022); Ott and Weber (2022); Fauceglia et al. (2020)	Household survey; household panel; firm panel	Peer-reviewed; peer-reviewed; working paper	Full text; working paper; abstract and introduction
EU ETS	Dechezleprêtre et al. (2023); Colmer et al. (2025); Bayer and Aklin (2020)	Matched difference-in-differences; generalized synthetic control	Peer-reviewed	Full texts (Colmer et al.: 2023 discussion paper)
Britain	Leroutier (2022); Abrell et al. (2022); Gugler et al. (2023)	Synthetic control; machine-learning counterfactual; regression discontinuity in time	Peer-reviewed	Published abstracts; full working papers (Leroutier, Abrell et al.)
Indonesia	Burke and Kurniawati (2018); Burke et al. (2017)	Panel elasticities applied to observed prices	Peer-reviewed	Full working papers
Germany gas	Ruhnau et al. (2023)	Regression on temperature-adjusted baseline, monthly	Peer-reviewed	Full accepted manuscript