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De-fueling externalities: How tax salience and fuel substitution mediate climate and health benefits

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De-fueling externalities: How tax salience and fuel substitution mediate climate and health benefits

By Pier Basaglia, Sophie M. Behr, Moritz A. Drupp*

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Abstract

This paper is the first to investigate the effectiveness of fuel taxation to jointly deliver climate and health benefits in a quasi-experimental setting. Using the synthetic control method, we compare carbon and air pollutant emissions of the actual and synthetic German transport sector following the 1999-2003 German eco tax reform. We demonstrate sizable average reductions in CO₂ (12%), PM_{2.5} (10%) and NO_X (6%) emissions between 1999 and 2009 across a range of specifications. Using official cost estimates, we find that the eco-tax saved more than 40 billion euros of external damages. More than half of the reductions in external damages are health benefits, highlighting the importance of accounting for co-pollution impacts of carbon pricing. Our fuel and emission specific tax elasticity estimates suggest much stronger demand responses to eco tax increases than to market price movements, primarily due to increases in tax salience, which we measure using textual analysis of newspapers. We further show that gasoline-to-diesel substitution substantially mediates the trade-off between climate and health benefits. Our results highlight the key roles of tax salience and fuel-substitution in mediating the effectiveness of fuel taxes to reduce climate and health externalities.

Keywords: Environmental policy, carbon tax, eco tax, tax elasticity, tax salience, fuel consumption, fuel substitution, externalities, climate, pollution, health

JEL codes: Q51, Q58, Q41, H23

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1 Introduction

Fuel taxation is an important policy instrument to reduce negative externalities of fossil fuelled transportation (Parry et al., 2007; Sterner, 2007), which has seen renewed interest amidst increasing concerns about climate change, air pollution, and energy security (e.g., Shaw et al., 2014; Grigolon et al., 2018; Parry et al., 2021; Gars et al., 2022). Understanding how changes to fuel taxation affect behavioral responses in fuel consumption is essential to effectively leverage this tool for public policy. Most previous assessments rely on the assumption that demand responses to fuel tax changes are equivalent to those of market-driven price variations and generally estimate limited impacts of higher tax rates on carbon emissions (e.g., Green, 2021). In contrast, recent contributions highlight the existence of considerable tax salience effects (e.g., Chetty et al., 2009), which could imply that more modest fuel taxes may achieve politically desired fuel reductions (e.g., Li et al., 2014; Rivers and Schaufele, 2015; Andersson, 2019). Additionally, carbon abatement represents only part of the economic benefits that can justify fuel taxation, as reducing fossil fuel consumption can also yield substantial benefits for population health and productivity due to reduced air pollution (World Health Organization, 2012; Shaw et al., 2014; Parry et al., 2015, 2021). Accounting for and communicating such health co-benefits may be important for gathering public support for fuel or carbon pricing policies.

We investigate the effectiveness of fuel taxation to reduce carbon and air pollutant emissions with a quasi-experimental assessment of the German Ecological Tax Reform. The reform increased fuel taxes in Europe’s largest transport sector in yearly steps from 1999 to 2003 to 15.35 cents per liter on gasoline and diesel, and kept it constant thereafter in nominal terms (Appendix A provides detailed background). In 2003, implicit carbon costs due to the German eco-tax were the second highest globally, with an effective price per tCO₂ of €58 for diesel and €66 for gasoline, close to the carbon tax level in Sweden (World Bank, 2020), which was largely levied on transport fuel (Andersson, 2019).

The focus of our analysis is threefold. First, we estimate the causal impact of the eco tax on per capita emissions of CO₂, PM_{2.5}, and NO_x from the German transport sector to capture both its climate *and* health benefits. Using the synthetic control method (SCM)

(Abadie and Gardeazabal, 2003; Abadie et al., 2010, 2015), we build a counterfactual synthetic Germany with a weighted combination of control countries and compare emission paths of the actual and synthetic German transport sector. Our strategy draws on a growing literature relying on the SCM to perform policy evaluations (e.g., Lindo and Packham, 2017; Cunningham and Shah, 2018), particularly for environmental regulations (e.g., Andersson, 2019; Maamoun, 2019; Isaksen, 2020; Bayer and Aklin, 2020; Mideksa, 2021; Leroutier, 2022). Our SCM results imply that, between 1999 and 2009, the eco tax led to average reductions of around 12% in CO₂, 10% in PM_{2.5}, and 6% in NO_X emissions in the transportation sector and to an average reduction in external damages of 43 billion euros. Our findings are qualitatively robust to a host of placebo and sensitivity tests, including in-time placebos, the use of alternative donor pools, sets of predictors, and emission data sources, different pre-treatment time frames, the use of a generalized SCM with interactive fixed effects models (Xu, 2017), the exclusion of one donor pool country at a time, and a set of permutation tests where we sequentially apply the SCM to every country in the potential donor pool. While modeling studies consistently indicate that decreasing reliance on fossil fuels could foster considerable positive health impacts (e.g., Shaw et al., 2014; Markandya et al., 2018; Vandyck et al., 2020; Choma et al., 2021; Reis et al., 2022), this paper is the first observational study to quantify and compare the climate *and* health benefits of fuel or carbon pricing in a quasi-experimental framework.

Second, we estimate the price and tax elasticities of demand for both gasoline and diesel to disentangle behavioral responses, complementing the literature that focused largely on gasoline (c.f. Zimmer and Koch, 2017). Our preferred specifications yield a tax-exclusive price elasticity of demand for gasoline (diesel) of -0.32 (-0.26) and an eco-tax elasticity of demand of -2.7 (-1.1). Fuel-specific eco tax elasticities are 4 to 8.5 times higher than the tax-exclusive price elasticity (a ratio referred to as *tax saliency ratio*), indicating that changes in environmentally motivated taxation are much more potent than equivalent market-driven price changes. These results are in line with Li et al. (2014), Rivers and Schaufele (2015), and Andersson (2019), who also find stronger demand responses due to gasoline taxes. Our fuel-specific tax saliency ratios underscore potentially large biases in

policy evaluations that rely on consumer responses to market-driven fuel price changes as a proxy for the response to a comparable change in a fuel tax. Our simulations based on fuel-specific tax elasticities further indicate that around three thirds of the reduction in carbon emissions is attributable to contractions in gasoline consumption, partly driven by substitution towards diesel. Conversely, almost all decreases in $PM_{2.5}$ and more than half of decreases in NO_x emissions are driven by lowered diesel consumption due to the eco tax. These findings highlight important trade-offs that can arise between climate and local air pollution targets. This is particularly relevant in the context of price instruments set on the carbon content of fuels that could foster gasoline-to-diesel substitution. Such fuel substitution is—with the exception of [Linn \(2019\)](#)—not accounted for in existing policy evaluations. We complement [Linn \(2019\)](#) by relaxing the assumption that consumers respond similarly to fuel taxes as to other sources of variation of fuel prices. We find that accounting for tax salience effects illuminates a much more sizable trade-off between climate and health benefits due to reduced air pollution.

Finally, we develop an empirical framework to quantify the role of salience changes in the media in driving the estimated effects of the eco tax. We construct a newspaper-based index to capture the evolution of the eco tax salience based on textual analysis of German newspaper articles. We then leverage annual variations in our salience index to empirically isolate the additional effect on fuel consumption reduction, for a given tax rate, which is attributable to greater media salience. We find that greater tax salience is associated with lower consumption of both gasoline and diesel and that these effects increase with the eco tax rate. Specifically, for the average eco-tax rate, when salience exhibits an increase of one standard deviation in our index relative to the mean, the reduction of gasoline (diesel) consumption induced by the additional salience alone amounts to 4.2% (1.14%). These empirical results provide first direct empirical evidence for the hypothesis that consumers react more strongly to fuel taxes the more salient they are. It follows that complementary measures to make policy instruments more salient to consumers, such as disclosure or information campaigns, may have considerable potential to foster climate and health benefits—alongside energy security benefits due to reduced reliance on fossil-

fuel imports—through a greater demand response at a given tax rate and thus enhance the cost-effectiveness of price instruments to internalize externalities.

We contribute to several literatures. First, we link to studies exploring effects of gasoline and energy prices on fuel demand and carbon emissions (e.g., [Dahl and Sterner, 1991](#); [Levin et al., 2017](#); [Linn, 2019](#); [Marin and Vona, 2021](#); [Parry et al., 2021](#)). These studies typically rely on fuel and energy prices as proxies for environmental and carbon pricing schemes and use changes in prices over time to estimate impacts on fuel demand. Yet, fuel prices are prone to endogeneity concerns, hampering the identification of causal effects and likely biasing the estimation of price elasticities downwards ([Kilian, 2008, 2009](#); [Davis and Kilian, 2011](#); [Coglianese et al., 2017](#)). We focus on fuel-specific demand adjustments made in response to changes in tax rates. This allows recovering causal estimates of the effectiveness of fuel taxation. Our approach can also capture substitution between modes of transport and fuels, departing from previous studies that rely on changes in gasoline consumption as a proxy for aggregate reductions in emissions (c.f. [Davis and Kilian, 2011](#); [Rivers and Schaufele, 2015](#)). Accounting for gasoline-to-diesel substitution is crucial in the European context with its relatively high diesel share and allows us to quantify trade-offs between climate and health benefits induced by fuel substitution.

Second, we speak to several strands of the literature on the effectiveness of carbon pricing schemes. Existing evidence has indicated that the aggregate reductions in carbon emissions attributable to carbon pricing tend to be limited ([Haites, 2018](#); [Green, 2021](#)), although some recent analyses suggest sizable reductions (e.g., [Andersson, 2019](#); [Bayer and Aklin, 2020](#); [Mideksa, 2021](#); [Colmer et al., 2022](#); [Dechezleprêtre et al., 2023](#)). Isolating the effectiveness of carbon pricing tends to be challenging, as carbon taxes in Europe have often been implemented as a replacement for and not in addition to existing energy taxes; and they are often accompanied by numerous tax cuts or exemptions and compensation schemes to mitigate concerns about leakage, creating substantial differences in tax rates across sectors ([Basaglia et al., 2023](#); [Gerster and Lamp, 2023](#)), which may undermine the reliability of the estimated effects. Mindful of these concerns, our analysis is restricted to fuel taxes in the transport sector, for it has been fully covered by increases in the eco tax.

Third, in terms of empirical scope and methodology, our study relates to [Andersson \(2019\)](#) and [Mideksa \(2021\)](#), who investigate the Swedish and Finnish carbon taxes using the SCM and provide evidence on the impacts of carbon pricing primarily through fuel taxation. A contemporaneous paper by [Runst and Höhle \(2022\)](#) also evaluated the impact of the German eco tax on CO₂ emissions using the SCM, with similar results to ours on CO₂ reductions. We go beyond these studies in several dimensions. We enhance the climate benefit assessment by disentangling effects by fuel type and investigating behavioral responses. Moreover, we provide insights on the key role of salience in mediating the effectiveness of fuel taxation. Another key difference is that these studies exclusively focus on carbon abatement and thereby consider only a smaller part of benefits from fuel taxation. By contrast, our analysis highlights the importance of accounting for health benefits due to improved air quality, examining reductions in the two key transport-related air pollutants PM_{2.5} and NO_x, which amount to 53% percent of overall non-market benefits, and illuminates the trade-offs between climate and health benefits linked to fuel substitution.

Finally, we contribute to a growing literature on the role of salience for environmental policy ([Davis and Kilian, 2011](#); [Li et al., 2014](#); [Rivers and Schaufele, 2015](#); [Coglianese et al., 2017](#); [Huse and Koptuyug, 2022](#)). Similarly to [Li et al. \(2014\)](#), we rely on textual analysis of newspaper data to explicitly investigate tax salience. [Li et al. \(2014\)](#) show that a tax change is associated with a greater increase in media coverage relative to a comparable change in the tax-exclusive price of fuel. Our analysis goes beyond by explicitly quantifying the extent to which fuel consumption responses to tax changes are mediated by salience spikes. Our fuel-specific eco-tax elasticities suggest that fuel and carbon taxation is considerably more effective than previously estimated ([Steiner and Cludius, 2010](#)), and as assumed in a simulation study by [Edenhofer et al. \(2019\)](#) to inform the government on the introduction of the 2021 carbon tax levied also on transport fuel. That targeted emission reductions may be achievable at lower-than-suggested tax levels is good news for climate policy, as the implemented price path falls short of what has been suggested by academics (e.g., [Edenhofer et al., 2019](#); [Drupp et al., 2023](#)).

2 Methodology

We aim at estimating causal effects of fuel taxes on per capita emissions of carbon dioxide and local air pollutants using the synthetic control method (SCM). We further investigate how fuel-specific tax effectiveness is mediated by salience and fuel substitution using log-linear semi-elasticity models. First, we estimate what effect the eco tax reform had on CO₂ and local air pollution emissions within the transport sector by comparing Germany with a synthetically constructed counterfactual “synthetic Germany”. Second, we estimate price and tax elasticities of gasoline and diesel consumption and use these to perform counterfactual simulations.

2.1 The Synthetic Control Method

For our first strategy, we draw on a growing empirical literature relying on the SCM to perform policy evaluations, as discussed in the introduction. Below, we explain the SCM following [Abadie and Gardeazabal \(2003\)](#) and [Abadie et al. \(2010\)](#) and explain how we leverage the SCM approach in our empirical analysis.

The synthetic control estimator. Suppose there are $J + 1$ countries in the sample. Each country is indexed by j where $j = 1$ denotes the *treated* country (i.e., the country affected by the policy intervention), which in our setting is Germany, while $j = 2, \dots, J + 1$ are countries unaffected by the intervention, which are referred to as the *donor pool*, and can be used to construct a control group. There are T time periods, divided into pre-treatment and post-treatment (i.e., after the Ecological Tax Reform in 1999) with T_0 indicating the period prior to the policy shock ($t = t_0, t_{-1}, \dots, T_0$). Denoting the intervention as I , the SCM considers that the observed outcome, y_{jt} , is the effect from the treatment, $\alpha_{jt}I_{jt}$, and the counterfactual outcome, y_{jt}^J :

$$y_{jt} = \alpha_{jt}I_{jt} + y_{jt}^J \tag{1}$$

The underlying idea of the SCM is to construct a vector of weights over J donor countries such that the weighted combination of donor countries closely mimics the outcome of the treated country in the pre-treatment period, T_0 . This weighted combination of donor units is called the synthetic control (i.e., synthetic Germany). In this setting, we define X_1 as the $k \times 1$ vector comprising of the characteristics k of Germany (i.e., the treated unit) over the pre-intervention period. Analogously, the $k \times J$ vector, which contains the same pre-treatment characteristics for the donor pool, is defined as X_0 . The synthetic control algorithm identifies non-negative donor weights \mathbf{W} , such that $\sum_{w_2}^{w_{J+1}} = 1$, to minimize the divergence between pre-treatment characteristics \mathbf{X}_1 and \mathbf{X}_0 of the treated country and the untreated donors. More formally, the vector \mathbf{W}^* is chosen to minimize the mean square prediction error (MSPE) over k pre-treatment characteristics:

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

where \mathbf{V} is a matrix of non-negative components measuring the relative importance of each predictor, v_m . Given optimal weights w_j^* for each $j = 2, \dots, J + 1$ donor country, the synthetic control at any time t is the weighted combination of the outcome variable (e.g., CO₂ emissions in the transport sector) in the donor countries, $\sum_{j=2}^{J+1} w_j^* y_{jt}$. The treatment effect α_{1t} is then the difference between emissions in the treated country y_{1t} and emissions in the synthetic counterfactual in the post-treatment period, $t > T_0$:

$$\hat{\alpha}_{1t} = y_{1t} - \sum_{j=2}^{J+1} w_j^* y_{jt} \quad (3)$$

The average treatment effect¹ in the post-treatment period $t = t_1, \dots, T$ is therefore expressed as follows:

$$\hat{\beta}_{1t} = \frac{1}{T} \sum_{t=t_1}^T (y_{1t} - \sum_{j=2}^{J+1} w_j^* y_{jt}) \quad (4)$$

Choice of predictors. There are various different methods for choosing the relative importance of each predictor (v_m), such as manually assigning a weight to a predictor -

¹Following the original notation by [Abadie and Gardeazabal \(2003\)](#), the counterfactual per capita emissions from transport, \mathbf{Y}_1^* , are given by $\mathbf{Y}_1^* = \mathbf{Y}_0 \mathbf{W}^*$ while the treatment effect is equal to $\mathbf{Y}_0 - \mathbf{Y}_1^*$.

i.e., based on empirical findings in the literature (Abadie and Gardeazabal, 2003; Abadie et al., 2010). The standard approach in the literature, which is also followed here, is to select the matrix \mathbf{V} along with the weights \mathbf{W} so that the difference between Germany’s emissions and synthetic Germany’s emissions in the pre-treatment is minimized.²

Despite being a primarily data-driven approach, the literature has pointed out that there is a degree of discretion in the specification of the SCM, which might lead to “cherry picking” – i.e. choosing certain combinations of predictors that influence the result. Specifically, Ferman et al. (2020) consider the choice of the pre-treatment outcome lags in the SCM literature and show how different choices affect the weights of all predictors (v_m) and the weights of the donor countries (w_j) and, consequentially, the result.³ To our knowledge, there is no consensus or guidance about how to best include pre-treatment outcome lags.⁴ Given this lack of consensus in the literature on how to choose the best specification, we report results for a range of specifications drawing from previous SCM evaluations in the existing applied literature. We refer to the specification used by Andersson (2019) as the *Baseline* model.⁵ Table 1 provides a detailed summary on the set of specifications we consider.

Statistical inference. An inherent limitation of the SCM is that it does not allow to employ standard (large-sample) inferential methods to evaluate the statistical significance of the results. The primary reasons behind this limitation are the number of observations in the donor pool and the number of periods covered by the sample, which are usually limited in comparative country-level case studies like ours. As Abadie et al. (2010, 2015) and Abadie (2021) suggested, however, placebo experiments based on permutation techniques can be implemented to make inferences. Drawing on their approach, we implement cross-sectional placebo tests by sequentially applying the synthetic control algorithm to

²This is done using the *synth* package in STATA developed by Abadie et al. (2010).

³Typical choices on the number of pre-treatment outcome lags involve (i) including all pre-treatment years, (ii) only including the mean of all pre-treatment years, or (iii) including a set of specific years.

⁴As a case in point, Kaul et al. (2015) point out that including the entire pre-treatment time frame of the outcome variable as a predictor causes all other covariates to be obsolete, while Ferman et al. (2020) advise to use all pre-treatment periods as it is less arbitrary, unless the researcher considers it important that other covariates receive a weight as well.

⁵Powerful predictors of post-intervention values of the outcome variable, aside from lagged values of the outcome, also decrease the potential for over-fitting, especially when T_0 is small (Abadie, 2021).

Table 1: Overview of the specification choices for the SCM

Specification	Lagged outcome variable	Covariates	Literature
Baseline	Lagged CO ₂ or PM _{2.5} in 1998 (t_0)	Yes	Montalvo, 2011; Kaul et al., 2015; Andersson, 2019; Leroutier, 2022
Lags (Mean)	Pre-treatment mean of CO ₂ or PM _{2.5}	Yes	Abadie and Gardeazabal, 2003; Kleven et al., 2013; DeAngelo and Hansen, 2014; Ferman et al., 2020
Lags (All)	Lagged pre-treatment CO ₂ or PM _{2.5}	Yes	Billmeier and Nannicini, 2013; Bohn et al., 2014; Dustmann et al., 2017; Ferman et al., 2020; Isaksen, 2020
Lags (Selected)	Lagged CO ₂ in 1971, 1980, 1991, 1998 Lagged PM _{2.5} in 1991, 1995, 1998	Yes Yes	Cavallo et al., 2013; Smith, 2015; Eren and Ozbeklik, 2016; Cunningham and Shah, 2018; Mideksa, 2021
Reunification	Lagged CO ₂ in 1990 and 1998 Lagged PM _{2.5} 1991 and 1998	Yes Yes	<i>Specific to the German case:</i> c.f. Abadie et al. (2015)
Tax anticipation	Lagged CO ₂ or PM _{2.5} in 1999 (t_1)	Yes	Abbring and Van den Berg, 2003; Coglianese et al., 2017
No Covariates	Lagged pre-treatment CO ₂ or PM _{2.5}	No	Hinrichs, 2012; Gobillon and Magnac, 2016; Lindo and Packham, 2017; Ferman et al., 2020

Notes: The Table above summarizes the different specifications of the SCM considered in our empirical strategy. *Specification* denotes the name by which a given specification of the SCM will be referred to henceforth. *Lagged outcome variable* specifies the number and the years of the pre-treatment outcome lags included in each specification. *Covariates* indicates whether the specification additionally include our set of predictors, namely (i) GDP per capita, (ii) gasoline consumption, (iii) diesel consumption, (iv) the share of urban population, and (v) the number of vehicles per 1000 people. All specifications for PM_{2.5} include the Environmental Policy Stringency Index by the OECD as an additional predictor (c.f. Section 3).

every country in the donor pool and compare the estimated placebo effects with the baseline results for Germany, after accounting for the quality of the pre-treatment match, which we do by scaling the effects by the relevant pre-treatment RMSPE. This is meant to assess the robustness of our baseline results by examining whether potential comparison countries show treatment effects larger than the baseline estimates. A p-value is then computed as the proportion of control units that have an estimated effect at least as large as that of the treated unit. More specifically, suppose that the estimated effect for a particular post-treatment period is $\hat{\alpha}_{1t}$ and that the distribution of corresponding in-place placebo is $\hat{\alpha}_{1t}^{PL} = \{\hat{\alpha}_{jt} : j \neq 1\}$. The two-sided p-value is then given by

$$p = Pr(|\hat{\alpha}_{1t}^{PL}| \geq |\hat{\alpha}_{1t}|) = \frac{\sum_{j \neq 1} 1(|\hat{\alpha}_{1t}^{PL}| \geq |\hat{\alpha}_{1t}|)}{J} \quad (5)$$

and the one-sided p-values are

$$p = Pr(\hat{\alpha}_{1t}^{PL} \geq \hat{\alpha}_{1t}) \quad (6)$$

$$p = Pr(\hat{\alpha}_{1t}^{PL} \leq \hat{\alpha}_{1t}) \quad (7)$$

Following [Firpo and Possebom \(2018\)](#), [Li \(2020\)](#) and [Abadie and L'hour \(2021\)](#), we implement a one-sided test as statistical power tends to be a concern in comparative country-level case studies ([Abadie, 2021](#)). One-sided inference allows us to construct p-values based on placebo effects, $\hat{\alpha}_{1t}^{PL}$, that yield reductions in emissions in the post-intervention period, as only negative effects of fuel taxes on emissions are of interest in our setting for the rank statistics of the unit-level treatment effects. We additionally report two-sided p-values to further support the general validity of our findings. To evaluate how the significance of the effects of fuel taxation unfolded following the Ecological Tax Reform, we apply the permutation-based inference procedure described above for each year of the post-intervention period. This approach allows us to analyze the timing of the impact of the eco tax, whose significance may vary across time periods.

2.2 Semi-elasticity models

Our analysis continues by estimating fuel-specific price and tax elasticities, using two different specifications that extend [Andersson \(2019\)](#) to consider both gasoline and diesel. First, we calculate real price elasticities and compare them to typical fuel demand elasticities (c.f. Equation 8: *Real price elasticities*). Second, in line with [Li et al. \(2014\)](#), we split the real price into its three main elements: the eco tax, other existing fuel taxes (henceforth the energy tax), and the remaining tax-exclusive component, here called the raw price (c.f. Equation 9: *Eco-tax elasticities*). The estimated elasticities from Equation 9 are then used to simulate the predicted pathways of CO₂ and air pollution emissions under different taxation regimes. The resulting models are given as:

$$\log(y_t) = \beta_0 + \varphi_1 p_t^{real} + \beta_2 D_t^{eco} + \lambda' \mathbf{X}_t + \epsilon_t \quad (8)$$

$$\log(y_t) = \beta_0 + \varphi_2 p_t^{excl} + \varphi_3 p_t^{eco} + \varphi_4 p_t^{energy} + \beta_2 D_t^{eco} + \lambda' \mathbf{X}_t + \epsilon_t \quad (9)$$

These are static log-linear models with t indicating the time variable in years. The outcome variable y_t refers to logarithmic fuel consumption per capita for either gasoline

or diesel in liters terms.⁶ p_t^{real} is the retail price in real terms, including the VAT. p_t^{excl} refers to the retail price excluding the energy and eco tax but including the VAT, in real terms.⁷ p_t^{eco} and p_t^{energy} refer to the eco and energy tax, respectively, including VAT and are included in the models as separate terms (c.f. Equation 9). The reason these variables are split is to firstly estimate and secondly predict fuel consumption without the eco tax and both tax rates. D_t^{eco} is a dummy variable that is equal to one after the implementation of the eco tax in 1999 and zero otherwise. \mathbf{X}_t is a vector of control variables that includes GDP per capita, the unemployment rate, and a time trend.⁸ The error terms are denoted by ϵ_t . We estimate the model using an OLS regression. As autocorrelation is detected,⁹ we use the Newey-West-estimator, which is robust against autocorrelation and heteroskedasticity.¹⁰

A standard concern with estimating fuel elasticities is an endogeneity problem, with fuel demand affecting supply (and thus the price) and not only the other way around (c.f. [Hughes et al., 2008](#); [Kilian, 2008, 2009](#); [Coglianese et al., 2017](#)). Endogeneity is arguably a lesser source of concern in a single European country setting, as crude oil prices are set in a global market and changes in demand in a single country are thus expected to have a relatively marginal impact on overall demand. One possibility to address this issue and to validate our estimates is to additionally adopt an instrumental variable (IV) approach. In line with [Li et al. \(2014\)](#) and [Andersson \(2019\)](#), we complement our OLS regressions with an IV approach and use the (brent) crude oil price as an instrument to validate the demand elasticity of the real price of gasoline and diesel, i.e. Equation 8.

⁶Prior to taking the logarithm, we convert fuel consumption from kilograms of oil equivalent to kilograms as a first step and to liters as a second step. For gasoline, that means dividing it by 1.051 to convert it to kg and multiply by 1.33 to obtain liters. Similarly, diesel is divided by 1.01 and subsequently multiplied with 1.19 ([Eurostat, 2018](#); [der deutschen Bioethanolgesellschaft, nd](#)).

⁷The prices are not in logarithmic form as the eco tax equals zero for a long time period, which leads to missing variables. Moreover, it leads to collinearity with other covariates. Thus, we would not be able to use the automatic lag-selection or all control variables, which is why we decided against using the log.

⁸Basic models estimating fuel elasticities include fuel prices and income (e.g., [Dahl and Sterner, 1991](#)).

⁹Autocorrelation is detected with using the Breusch-Godfrey test (Stata command “estat bgodfrey”). Results indicate that for both, gasoline and diesel, the null hypothesis of no serial correlation is rejected.

¹⁰Standard errors are calculated using the number of lags, which are chosen automatically using the *auto* option in Stata following [Newey and West \(1994\)](#).

3 Data

Our analysis is structured in two parts. In each step, we combine several data sources. First, we use the SCM to evaluate the effect of the eco tax on CO₂, PM_{2.5} and NO_x emissions, building on a panel dataset that consists of OECD countries. Second, we estimate price elasticities relying on a time-series dataset constructed specifically for Germany. We then examine the mechanism of tax salience in detail, relying on textual analysis of German newspapers. Appendix B provides a detailed overview of all variable sources.

Panel Dataset for the Synthetic Control Method for CO₂. To analyse the effect of the ecological taxation reform on CO₂ emissions of the transport sector with the SCM, we construct an annual panel dataset beginning in 1971 and consisting of OECD countries. Our main sample for the CO₂ analysis thus includes 28 pre-treatment and 11 post-treatment years. The outcome variable is per capita CO₂ emissions from the transportation sector, measured in metric tons. This variable is constructed by multiplying total CO₂ emissions from fuel combustion with the percentage share of total fuel combustion for transportation. Total CO₂ emissions from fuel combustion is taken from the International Energy Agency (IEA). The share of transport emissions is published by the World Bank, which again draws on original IEA data.¹¹ Population data to calculate the emissions per capita is also taken from the World Bank. The data for the gross domestic product (GDP) refers to expenditure-side real GDP at current purchasing power parities (in million 2011 US dollars) drawn from the Penn World Table. The data for the share of urban population, diesel and gasoline consumption per capita in kilograms of oil equivalent, and the total emissions for all OECD countries combined all stem from the World Bank. The number of vehicles for each country was provided by Dargay et al. (2007).

We limit our dataset to countries that are part of the OECD, as these share more structural similarities with Germany in terms of their economic situation, emissions, and

¹¹The share of CO₂ emissions from transport relates to IPCC source/sink category 1A3 (IPCC, 2019), and is composed of emissions from domestic aviation, domestic navigation, road, rail and pipeline transport. This category includes emissions from fuel combustion of all transport activity for all sectors except marine bunkers and international aviation (World Bank, 2023), which refer, among others, to private cars, public transportation, and transportation of goods. It does not, however, include fuel combustion related to industrial processes within the transportation sector such as emissions from car manufacturing.

form of government, which is desirable for the SCM (Abadie, 2021). However, to build a suitable synthetic control for Germany, we additionally exclude a number of OECD countries for reasons which are detailed below. First, data for the Baltic countries, Slovakia, Czech Republic, and Slovenia is very sparse (especially prior to 1989), which is why we cannot consistently use them for the SCM starting from 1971. Second, we exclude countries that have implemented an explicit CO₂ price in the transport sector. This concerns Finland, Sweden, Norway, and the Netherlands (Kossoy et al., 2015). Although Denmark also implemented a carbon tax around the same time as the above-named countries, the Danish carbon tax did not include the traffic sector, which is why Denmark remains in the sample (Andersson, 2019). Similarly, Poland also implemented a carbon tax, but remains in the sample as the cost for a ton of carbon dioxide is less than one dollar and thus negligible (Kossoy et al., 2015). Since a number of countries implemented carbon taxes in the transport sector in 2009 or shortly thereafter, our main analysis focuses on the time frame from 1971 to 2009.¹² Third, we exclude countries that implemented fuel taxes in the transport sector that are not labeled as carbon taxes—similar to the eco tax in Germany. This includes Italy, the United Kingdom (OECD, 2001), and Spain (Bosch, 2001). Fourth, we exclude Japan due to its successful top runner program implemented in the year 1998 that set requirements for the fuel efficiency of vehicles (Osamu, 2012).¹³ Fifth, we exclude Ireland due to its exceptional economic growth in the 1990s. Finally, we exclude Austria and Luxembourg as there is likely non-negligible fuel tourism at the borders.¹⁴ These restrictions, mostly due to carbon and environmental taxation, leave us with a main sample of 20 countries for the time frame from 1971 to 2009.

¹²We end the time frame of our empirical analysis in 2009. This underlying rationale is threefold. First, many countries in the sample implemented some form of carbon taxes or made significant changes to fuel taxation from 2009 onwards. Second, this mitigates concerns of capturing differential economic recovery trends in the aftermath of the global financial crisis. Third, we choose 2009 as the end date because since 2010 Germany has regularly auctioned emission allowances on the European Energy Exchange (EEX), moving away from free allocation within the European Union Emission Trading Scheme (EU ETS).

¹³The expected energy savings amounted to 23% for gasoline vehicles and 15% for diesel in 2005 (Nordqvist, 2007). While this was not a hard incentive like a tax, the program was seen as quite successful. Moreover, taxes on fossil fuels were increased in 2003 (Onoda and Schlegelmilch, 2015), which, overall, means that Japan is deemed unsuitable for inclusion in the SCM donor pool.

¹⁴Luxembourg's fuel sales are 5 to 8 times higher per capita than those of the neighboring countries (Dings, 2004). Austria, too, has very low taxes with a tax minimum in 2005 and a downward trend from 1997 onwards. This is a contrast to tax increases in Germany and Italy in 1999. As a result, more fuel tourism has likely taken place and emission data is not reliable (Dings, 2004).

Panel Dataset for the Synthetic Control Method for $\text{PM}_{2.5}$. The empirical estimation of the effect on $\text{PM}_{2.5}$ largely draws on the same data sources described above. In line with the [World Health Organization \(2016\)](#), we focus our empirical analysis on co-benefits on $\text{PM}_{2.5}$ concentration and use it as an indicator of general population exposure to air pollution. Officially reported data for $\text{PM}_{2.5}$ emissions within the transportation sector is taken from the European Monitoring and Evaluation Programme (EMEP) and is constructed by aggregating yearly $\text{PM}_{2.5}$ emissions for different categories within the transport sector.¹⁵ One key difference with the sample for carbon emissions is that officially reported data on $\text{PM}_{2.5}$ is only available for European countries and begins in 1990.¹⁶ It follows that this part of the analysis draws on a donor pool that comprises European OECD countries only. Our main sample for the $\text{PM}_{2.5}$ analysis begins in 1991, the first year following the German reunification, and includes 8 pre-treatment and 11 post-treatment years.¹⁷ To control for any European emission standards that were introduced or adjusted throughout the time frame of our analysis, we rely on the Environmental Policy Stringency Index (EPS) provided by the OECD. More specifically, we include the index on non-market stringency to control for the emissions thresholds of vehicle fumes. One key difference with our panel dataset for the analysis on carbon emissions is that the shorter pre-treatment period allows us to retrieve consistent data on the number of passenger cars per thousand people from Eurostat that additionally include Slovakia, Czech Republic, and Slovenia. Applying the same set of restrictions described above to enhance the comparability of Germany and our donor pool, our sample for the $\text{PM}_{2.5}$ analysis consists of 13 countries, namely Belgium, Switzerland, the Czech Republic, Denmark, Estonia, France, Greece, Hungary, Iceland, Portugal, Poland, the Slovak Republic, and Slovenia.

¹⁵We include the following categories to obtain total annual $\text{PM}_{2.5}$ emissions in the transport sector: *Road paving with asphalt*, *Road transport: Automobile road abrasion*, *Road transport: Automobile tyre & brake wear*, *Road transport: Gasoline evaporation*, *Road transport: Mopeds & motorcycles*, *Road transport: Heavy duty vehicles & buses*, *Road transport: Light duty vehicles*, *Road transport: Passenger cars*.

¹⁶We rely on officially reported data on emissions for our main estimations, however, to mitigate concerns related to the shorter pre-treatment period and the restricted donor pool, we later test the robustness of our results on local air pollution by relying on additional emission datasets that comprise a larger set of countries and go further back in time (c.f. Section 4.1).

¹⁷Relying on our longer panel dataset for the SCM for CO_2 , we show that results are robust to the use of both pre-treatment time frames (c.f. Appendix C).

Time-Series Dataset Germany for Price Elasticities. To disentangle the different taxation changes and estimate the elasticity of the eco tax, we additionally constructed an annual time-series dataset for Germany, spanning from 1971 to 2009. A peculiarity of Germany is its division until the year 1990. As there was no market economy in the German Democratic Republic (GDR), there were no market prices and no taxes in the same sense as in the Federal Republic of Germany (FRG). For our analysis, this implies that all prices that will be discussed in the paper relate only to the FRG for the time prior to 1991, while data from 1991 onward reflects the entirety of Germany.¹⁸

The data for the gasoline and diesel prices comes from the [Mineralwirtschaftsverband \(2020\)](#) and reflects the yearly consumer prices for both fuels including VAT. The price indices that are used to convert all nominal prices to real prices are taken from [Destatis \(2023\)](#). Energy and eco tax rates are taken from the [Bundesministerium der Finanzen \(2014\)](#) and the strategic reserve is given by the [Erdölbevorratungsverband \(2023\)](#).

As the VAT is not only imposed on the tax-free price p but also on the eco and energy taxes, τ^{eco} and τ^{energy} , respectively, and the strategic reserve, τ^{sr} , in the same way as on the price, the retail price p^r can be defined as follows:

$$p^r = (p + \tau^{eco} + \tau^{energy} + \tau^{sr}) * (1 + VAT) \quad (10)$$

To account for this, the VAT is already included in each retail price element.¹⁹ All prices given in Deutsche Mark are converted to Euro at the rate of $1\text{€} = 1.95583\text{ DM}$ given by the German Statistical Office. Furthermore, inflation is accounted for by converting all

¹⁸Specifically, while the fuel consumption variable relates to Germany as a whole, prices and taxes do not. Within the GDR, the fuel price for gasoline and diesel was set by the five-year-plans and was not affected by market movements. Even throughout the oil price crisis in 1979/1980, the gas station prices remained the same ([Joint Economic Committee & Congress of the United States, 1989](#)). Moreover, from 1980 onwards, energy consumption of companies was centrally planned as well. This led to some energy consumption cutbacks in the short run but not in the medium run ([Joint Economic Committee & Congress of the United States, 1989](#)). Thus, it seems likely that energy consumption and prices stayed fairly constant in the GDR. However, as there may be valid concerns with using the entire time frame of the data, the price elasticities are also estimated for the time frame from 1991-2009. Appendix D.2 and Appendix D.3 show the results for the restricted time window starting in 1991 after German reunification. The estimated price elasticities for both time frames yield very similar results.

¹⁹If the eco tax was raised by 10 cents, the fuel price would increase by 11.90 cents with a VAT rate of 19%. Thus, the eco and energy tax rates include the VAT. In our calculations, the price increase is attributed to a change in the eco tax rate.

nominal prices and absolute tax rates into real 1995 prices and taxes using the consumer price index given by the German Statistical Office. We chose 1995 as a convenient base year that is close to the implementation of the eco tax. Whenever a certain tax rate changed within a year, we weighted the different rates according to the date at which the change took place and used the resulting average tax rates. The (brent) crude oil price used for the IV regressions comes from the IEA. It is converted from dollars per barrel to euros per liter with the help of the euro/dollar exchange rate from [Eurostat \(2020\)](#).

Saliency: Newspaper data. Our empirical analysis further examines the role of salience in driving consumers’ responses to the eco tax reform. To this end, we rely on newspaper data as a proxy of tax salience within the media. We extract information from the Factiva database, which stores all articles published by major newspapers worldwide, and rely on this data to develop a newspaper-based index to capture the evolution of salience of the eco tax based on textual analysis of German newspaper articles. We focus our text-based analysis on *Der Spiegel*, *Die Welt*, *Die Zeit*, and *Focus*.²⁰

Our salience index is constructed using the number of articles published in leading German national newspapers after 1991 that discuss the effects of the eco tax on fuel prices scaled by newspaper-specific publishing trends specific to the topic of environmental taxation.^{21,22} To obtain newspaper article counts, we rely on a set of text-based search strategies that identify around 5,700 unique articles. After scaling the raw counts, we standardize each newspaper’s series, average across all papers, and normalize the resulting index to 100 over the over the period. We follow the same standardization and normalization procedure proposed by [Baker et al. \(2016\)](#) to leverage newspaper data in an empirical setting. A detailed description of our search strategies and the steps undertaken to construct the salience index can be found in Section [E.2](#).

²⁰We restrict our analysis to daily and weekly newspapers with the largest readership groups and circulation of copies which could be retrieved from Factiva. This was primarily for two reasons: firstly, focusing on a single dataset allows to retrieve consistent and comparable frequency counts across newspapers; secondly, limiting the search to leading newspapers ensures that our measure of salience is based on outlets that reach a wide public while avoiding including newspapers that only exceptionally report on the topic, which could introduce structural one-off volatility peaks over time.

²¹There was no unified press prior to Reunification in Germany.

²²This is to ensure that spikes in our index are not driven by newspaper-specific trends.

4 Results from the Synthetic Control Method

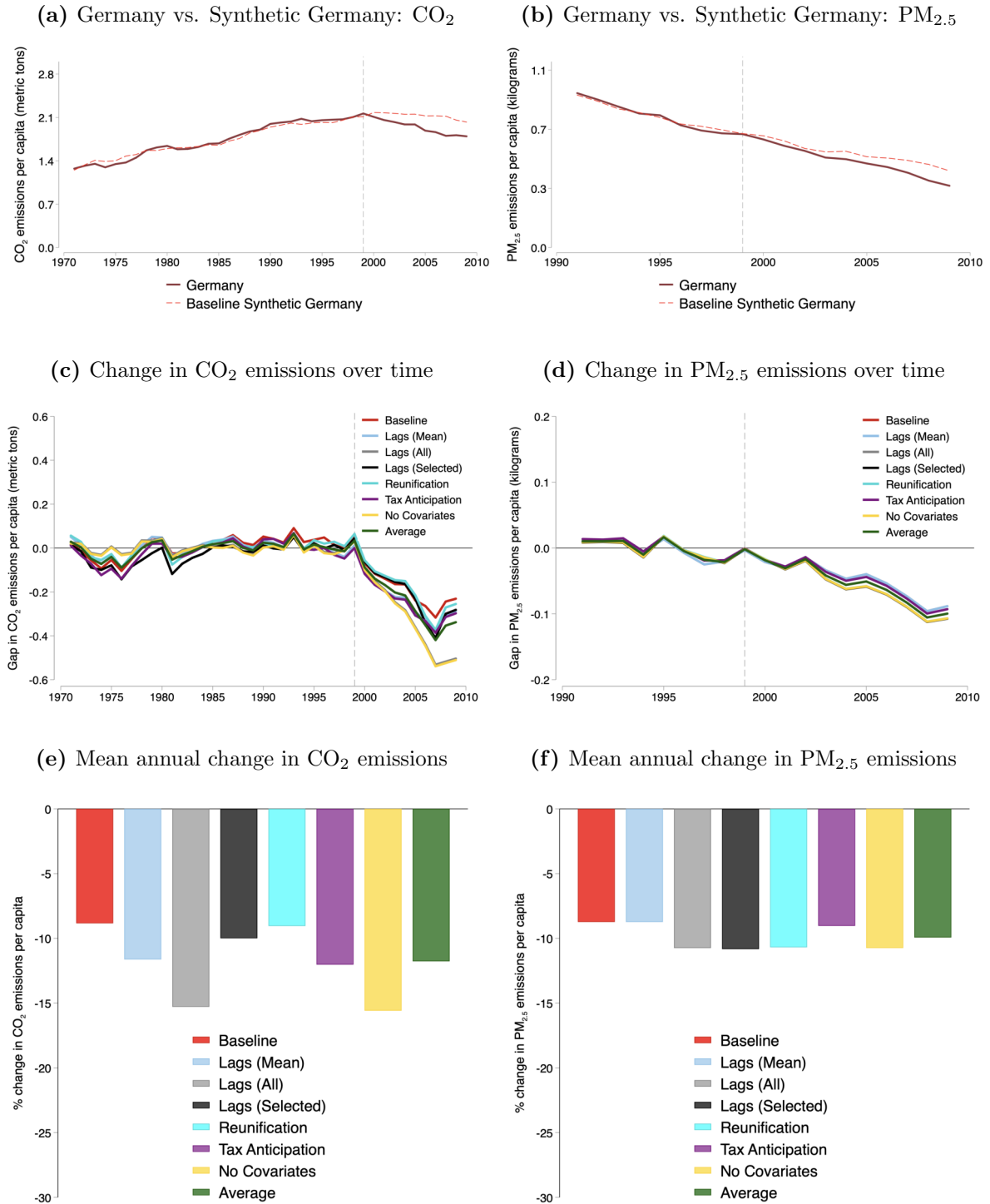
In this section, we present and discuss the implemented SCMs described in Section 2.2 to estimate the impact of the eco tax on CO₂ and local air pollution emissions within the transport sector. Figure 1 graphically summarizes our key findings, while additional supporting evidence can be found in Appendix C.

Emissions relative to a synthetic counterfactual development. Panels (a) and (b) in Figure 1 plot the path of CO₂ and PM_{2.5} emissions in Germany (solid line) and synthetic Germany (dashed line) for the baseline specification (c.f. Table 1) throughout the time period under investigation. The overlap between the solid and dashed line before 1999 captures the quality of the pretreatment fit achieved by the SCM algorithm; the same graphical comparison after 1999 plots the dynamic treatment effects for the ten years that followed. Both panels visibly reveal a sizable effect on both CO₂ and PM_{2.5} emissions in the transport sector following the Eco Tax Reform in 1999.

As discussed in Section 2.1, the validity of SCM effects is contingent upon synthetic Germany's ability to accurately replicate emissions from the German transportation sector prior to the introduction of the eco tax. Specifically, if synthetic Germany can accurately reproduce emissions during the pre-treatment period, it would lend credibility to the main identifying assumption that the synthetic control reflects the path of emissions that would have occurred in the absence of the eco tax from 1999 to 2009. Panels (a) and (b) show that prior to the treatment, CO₂ and PM_{2.5} emissions from transportation in Germany and its synthetic counterpart exhibit a high degree of similarity, with an average absolute difference of less than 0.04 metric tons of CO₂ and 0.01 kilograms of PM_{2.5}. Tables C.1 and C.12 report country-specific weights and the values of key predictors for Germany prior to 1999 with those for synthetic Germany and an average across the selection of countries in the donor pool (c.f. Section 3). Overall, for the set of predictors considered, synthetic Germany exhibits a more refined fit compared with the donor pool average.

Panels (c) and (d) report the estimated gap in metric tons of CO₂ and kilograms of PM_{2.5} emissions from our baseline model (red line) and show how these estimations vary

Figure 1: Synthetic Control Method results for CO₂ and PM_{2.5} emissions

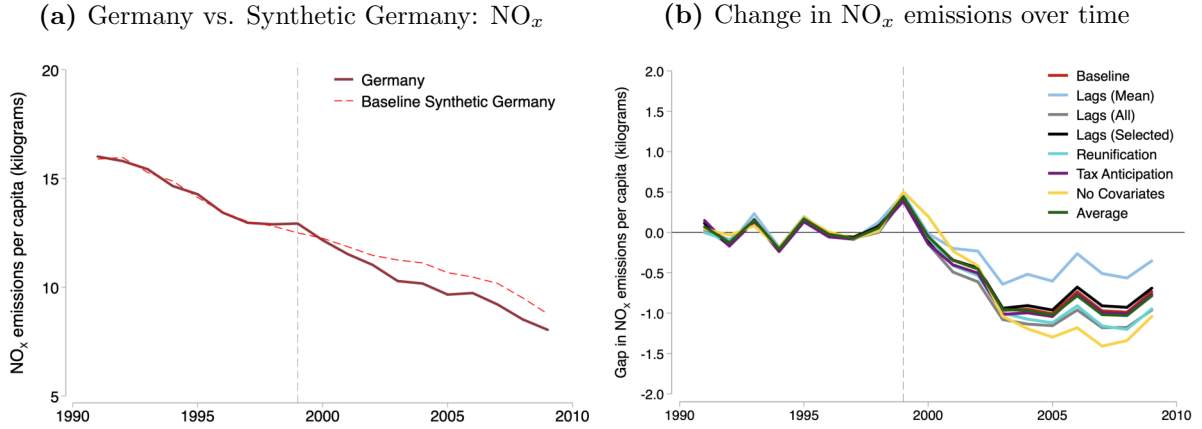


Notes: The figure plots the estimated reductions in CO₂ and PM_{2.5} emissions relative to a (synthetic) counterfactual development. Panels (a), (c), and (e) refer to reductions in CO₂ emissions per capita expressed either in metric tons or percentage terms (as indicated on the respective y-axis). Panels (b), (d), and (f) refer to reductions in PM_{2.5} emissions per capita expressed either in kilograms or percentage terms (as indicated on the respective y-axis). Panels (a) and (b) plot the absolute paths of CO₂ and PM_{2.5} emissions, respectively, in Germany and Synthetic Germany for our *Baseline* specification (see Table 1). Panels (c) and (d) report gaps in CO₂ and PM_{2.5} emissions over time relative to synthetic Germanies, estimated by each of our seven different specifications and their average. More details on the choice of the predictors used to construct different Synthetic Germanies can be found in Table 1. Panels (e) and (f) plot the mean percentage reductions in CO₂ and PM_{2.5} emissions per capita across the 10 post-treatment years for each specification.

with the six alternative specifications of the SCM (other colored lines), where *Average* refers to the simple average of the estimated change in emission gaps across all seven specifications of the SCM (green line). All our different specifications point to a sizable effect of the German eco tax reform on both CO₂ and PM_{2.5} emissions in the transport sector following the Eco Tax Reform in 1999. Panel (c) shows that the distance between Germany and synthetic Germany is steadily growing between 1999 and 2007.²³ In 2007, in the baseline specification, this distance was -0.32 metric tons of CO₂ per capita, equivalent to a 15 percent reduction of emissions. Between 1999 and 2009, annual emission reduction amounted to 0.17 metric tons of CO₂ per capita on average, which sums up to 156,284,018 tons of CO₂ for the entire post-treatment period. Panel (d) presents the change in the emission gap over time for PM_{2.5}. According to the baseline specification, 0.045 kilograms of per capita PM_{2.5} less were emitted on average each year in comparison to a setting had the eco tax not been implemented, which amounts to cumulative PM_{2.5} savings of around 41,090 tons from 1999 to 2009. The largest difference between Germany's and synthetic Germany's emissions occurred in 2008 with a difference of almost 0.10 per capita kilograms, equivalent to a 20 percent reduction of emissions, or, put differently, to an overall nationwide gap of around 7,870 tons of PM_{2.5}. Panels (e) and (f) provide mean annual changes in emissions in percentage terms to put into perspective the distribution of the effect magnitudes from different specifications (c.f. Table 1). CO₂ per capita emissions of the transportation sector decrease, on average, between 8.8% and 15.6% between 1999 and 2009, conditional on the specification used, while PM_{2.5} per capita emission reductions range between a 8.7% and a 11.2%. Our finding that emission reductions due to the eco tax are sizable is thus qualitatively robust across a range of specifications that have been explored in the SCM literature.

²³There are several possible explanations for the convergence in emissions between Germany and synthetic Germany after 2007. One reason could simply be that synthetic Germany does not describe the counterfactual situation as well due to the implemented EU ETS, which may have indirectly affected Germany and some of the donor countries even though the EU ETS did not include the road sector. Another potential driver is the global financial crisis in 2007 which evolved into an economic crisis across the EU in 2008. It is possible that the crisis affected Germany differently than donor countries, again meaning that synthetic Germany does not describe the counterfactual from 2007 to 2009 as accurately as for previous years in the sample. Setting aside these caveats, another potential explanation is decreasing fuel taxes in real terms. As the last increase of the eco tax took place in 2003, the real fuel tax on gasoline and diesel has been decreasing ever since then due to inflation.

Figure 2: Synthetic Control Method results for NO_x emissions



Notes: The figure above plots the estimated reductions in NO_x emissions relative to a (synthetic) counterfactual development expressed in kilograms per capita. Panel (a) plots the path of NO_x emissions in the actual and synthetic German transport sector for our *Baseline* specification (see Table 1). Panel (b) reports gaps in NO_x emissions over time relative to synthetic Germanies, estimated by each of our seven different specifications and their average. More details on the choice of the predictors used to construct different Synthetic Germanies can be found in Table 1.

Impact of the eco tax on emissions of nitrogen oxides. We complement our analysis by additionally reporting results on the effects of the eco tax on emissions of another key pollutant in the transport sector: nitrogen oxides (NO_X).²⁴ Figure 2 provides a graphical summary of the key findings for NO_X from our set of SCM specifications.²⁵

Panel (a) compares the German transport sector (solid line) with the baseline synthetic counterfactual development (dashed line) showing that the eco tax decreased per capita NO_X emissions. Following an increase in NO_X emissions in the first treatment year, the distance between Germany and synthetic Germany grows steadily between 2000 and 2003, along with the gradual eco tax rate increases, before flattening out once the annual tax adjustments were discontinued.²⁶ Panel (b) reports the estimated gap in kilograms of NO_x emissions from our baseline model (red line) and displays how our estimations change with the six alternative specifications of the SCM (other colored lines). Taking again the baseline as a reference, annual emission reduction amounted to 0.62 kilogram

²⁴Road transport represents the largest contributor to NO_X emissions in the EU (EEA, 2021). Taken together, $\text{PM}_{2.5}$ and NO_X are the two main sources of air pollution from road transport in the EU (Pastorello and Melios, 2016), which is why we restrict our analysis to these two pollutants.

²⁵Our SCM specifications for NO_X rely on the same set of predictors discussed in Table 1. We include $\text{PM}_{2.5}$ emissions as a general proxy for air pollution as an additional covariate to further account for the impact of unilateral policies affecting emission levels.

²⁶This is likely the result of gasoline-to-diesel substitution as shown in the simulation results for diesel presented in Panel (b) of Figure 4. Diesel has much higher emission rates of nitrogen dioxides compared to gasoline, which can explain the increase in per capita NO_X emissions in 1999.

of NO_x per capita on average (approximately 6% less), which cumulatively amount to 559,751 tons of NO_x less relative to a counterfactual without the eco tax. To test the robustness of the estimated effects on NO_x , we further leverage an alternative dataset on NO_x transport-related emissions maintained by the OECD which provides data for a larger pool of donor countries (i.e., including non-European OECD members). Relying on our baseline specification, the SCM with the larger donor pool yields an almost identical average yearly emission reduction of 0.60 kilogram of NO_x per capita (c.f. Figure C.2). Appendix C provides additional results for NO_x emissions with alternative donor pools.

4.1 Additional sensitivity and placebo tests

Our findings are robust to a host of standard sensitivity and placebo tests, including in-time placebos, the use of alternative donor pools and emission data sources, different pre-treatment time frames, the use of a generalized SCM (Xu, 2017), the exclusion of one donor pool country at a time, and a set of permutation tests where we sequentially apply the SCM algorithm to every country in the pool of potential donors.

In-time tests. For the in-time placebos, the year of treatment is shifted to a selection of years prior to the actual ecological tax reform. Any sizable and enduring placebo effect would cast doubt on the validity of the results from Figure 1 and 2. Figure C.7 shows that the synthetic control closely resembles the actual emission trajectories in Germany prior to 1999 and that no significant divergence is detected.

Alternative donor pools. To investigate the sensitivity of our results to the composition of the donor pool, we perform the following tests: (i) implementing the SCM without any sample restriction, (ii) “leave-one-out” tests, following Abadie et al. (2015), where we iteratively eliminate each one of the donor countries from the unrestricted sample, and (iii) “leave-one-out” tests from the estimation sample by sequentially excluding the control countries that got a weight larger than 0.001 (0.1 percent). The results are summarized in Figures C.1 and C.8 and show that none of the possible alternative donor pool compositions yield a non-negative gap in the post-intervention period.

Alternative emission data sources. Our results for local air pollution are subject to at least two potential caveats: (i) a shorter pre-intervention training period and (ii) potential inconsistencies in officially-reported pollution data over time and across countries.²⁷ Synthetic control weights computed with short pre-treatment periods (T_0) and outcome variables that include substantial random noise may increase the potential for bias in the SCM estimator (Ferman and Pinto, 2021). To address these concerns, we additionally rely on the EDGAR v6.1 database, which allows us to track emissions from the transport sector for a longer time frame spanning from 1971 to 2009 also for air pollutants (Crippa et al., 2019). Another crucial advantage of the EDGAR data is that emissions are computed relying on a consistent technology based emission factor approach and harmonized sector definitions, which ensures direct cross-country comparisons.²⁸

Figures C.10 and C.11 summarize the baseline SCM results using EDGAR data both from 1971 and 1991 onwards.²⁹ These additional analyses corroborate our finding that the eco tax delivered health co-benefits, but the magnitude is somewhat larger than our previous results in Figures 1 and 2. Using EDGAR data, we now estimate an annual average per capita reduction of 0.12 kilogram of PM_{2.5} and 1.3 kilogram of NO_x emissions throughout the post-intervention period.³⁰ We interpret these estimates as an upper bound of the emission reductions in air pollutants induced by the eco tax.

Generalized SCM with interactive fixed effects models. Drawing on Gobillon and Magnac (2016) and Xu (2017), we additionally rely on a generalized SCM based on a linear interactive fixed effects model (henceforth GSCM). This allows us to account for unobserved time-varying confounders specific to each country, such as structural factors,

²⁷Although official EU inventories (i.e., EMEP data) are subject to harmonizing EU-wide guidelines and verification procedures (Ntziachristos and Samaras, 2019), methodologies to calculate officially reported emissions can change over time (and countries) and thus potentially introduce random noise. Another potential issue is cross-country comparability related to the scope of sector definitions and the application of different definition of the emission sources, which may hinder the extent to which direct comparisons are possible and increase measurement error (Janssens-Maenhout et al., 2012; Solazzo et al., 2021).

²⁸The EDGAR database compiles GHG and air pollutant emissions for all countries in the world and all anthropogenic activities with the exception of Land Use, Change and Forestry (LULUCF) relying on a consistent methodology. More details on the EDGAR database can be found in Appendix C.4.

²⁹Note that official EMEP inventories and the EDGAR databases are highly related, with a Pearson correlation coefficient of 0.99 for CO₂ emissions, 0.95 for PM_{2.5} emissions and 0.96 for NO_x emissions.

³⁰As an additional robustness exercise, we also compute the effects on CO₂ emissions relying on EDGAR v7.0 data and show that both estimations yield comparable magnitudes (c.f. Figure C.10).

which may not be fully picked up by a selection of covariates.³¹ In our setting, this is particularly relevant as the 2007/2008 financial crisis had a different impact on Germany relative to other European economies in the donor pool. These unobserved heterogeneous shocks, which cannot be properly accounted for by either unit or time fixed effects alone, are modeled through interactive fixed effects. Our complementary GSCM results (see Figure C.9) are qualitatively robust with our results in Figure 1 and 2 and provide an alternative upper-bound estimate of the reductions in air pollution attributable to the eco tax.³² Additional details on our GSCM specification can be found in Appendix C.3.

Inference from permutation tests. As discussed in Section 2.1, we rely on permutation tests to gauge the significance of the estimated treatment effects. Figure 3 plots the estimated p-values in each post-intervention year computed as the proportion of effects from control units that have a post-treatment RMSPE at least as great as the treated unit in each post-intervention time period, after scaling it by the relevant pre-treatment RMSPE. The underlying assumption is that a p-value below conventional significance levels is indicative of a plausibly true casual effect of the treatment. We report yearly permutations for both (i) the unrestricted sample and (ii) the estimation sample.³³ We additionally report p-values for our *Tax Anticipation* specification (c.f. Table 1) to account for how anticipatory behavior in the construction of our synthetic counterfactual may affect our results (c.f. Coglianesse et al., 2017). Overall, the distribution of the estimated p-values is centered well below a 10% significance threshold level, and often at or below a 5% threshold, throughout the post-intervention period, particularly after the last eco tax rate increase in 2003.

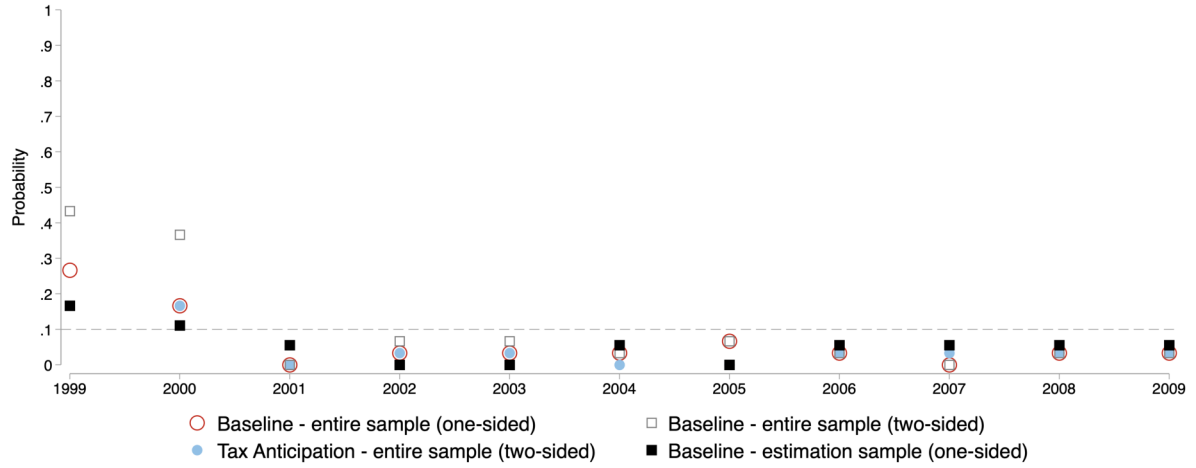
³¹Note that relying on a linear interactive fixed effects model rather than a selection of covariates has the additional advantage of retaining a greater number of countries in the donor pool by relaxing the inclusion restrictions linked to data availability (c.f. Section 3).

³²Our baseline results are also robust to the use of a “bias-corrected” SCM adjusted for discrepancies in predictor variable values between a treated country and its donor pool, proposed by Abadie and L’hour (2021) and Ben-Michael et al. (2021). Results are available upon request.

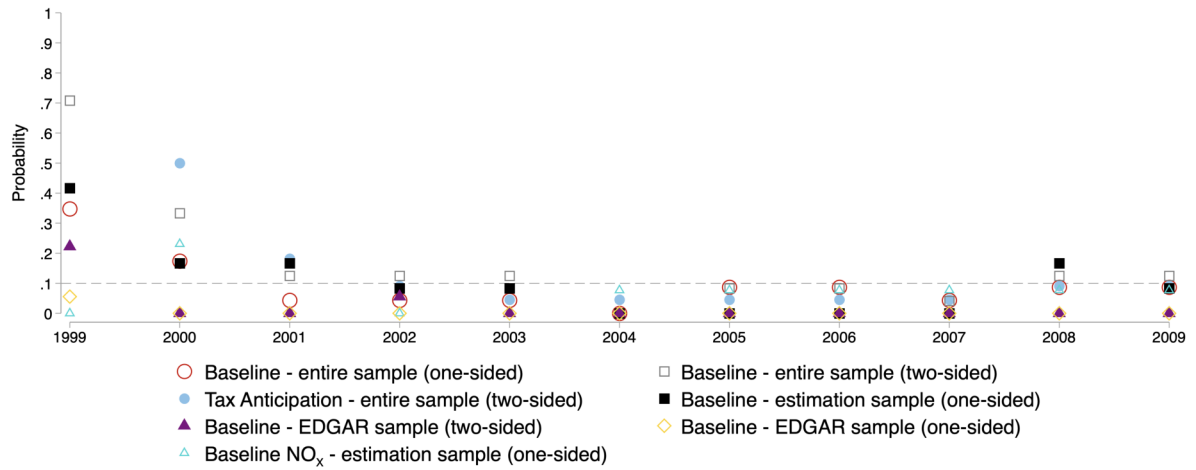
³³Note that relying on the unrestricted sample allows us to retain greater statistical power, which tends to be a concern in country-level comparative studies (Abadie, 2021). Leveraging the higher power, we conduct both two-sided and one-sided inference to further corroborate the significance of our results. Furthermore, by relying on the unrestricted sample, we can additionally show that the significance of our results is not driven by the exclusion of selected donor countries.

Figure 3: Inference for the Synthetic Control Method

(a) Annual significance levels of the results for carbon emissions



(b) Annual significance levels of the results for local air pollution



Notes: The figure plots the estimated p-values following [Abadie \(2021\)](#) computed from the proportion of effects from control units that have a post-treatment RMSPE at least as great as the treated unit in each post-intervention time period, after scaling it by the relevant pre-treatment RMSPE.

5 Results on Fuel and Tax Elasticities

This section leverages the semi-elasticity models described in Section 2.2 to disentangle effects of the eco tax, the energy tax, and VAT in order to compare behavioral responses from changes to the eco tax rate and equivalent fuel real price changes.

Tax pass-through. Before computing fuel-specific price and tax elasticities, we check if the tax increases get effectively passed through to the retail price of fuel to ensure that changes in taxation are noticeable to consumers (c.f. [Andersson, 2019](#)). We use first-differencing to regress the crude oil price i and the combined nominal energy and eco tax $\tau^{eco,energy}$ on the retail fuel price p^* of gasoline and diesel, respectively:

$$\Delta p_t^* = \alpha_0 + \alpha_1 \Delta \sigma_t + \alpha_2 \Delta \tau_t^{eco,energy} + \epsilon_t \quad (11)$$

The Newey-West estimator relies on the automatic bandwidth selection procedure following [Newey and West \(1994\)](#). The p-values of a linear Wald test shows that for both regressions, the tax coefficient α_2 is not significantly different from unity.³⁴ For gasoline, α_2 equals 0.94 (with a 95% confidence interval of [0.75; 1.13]). The result is comparable for diesel, where the coefficient is 0.86 [0.54; 1.17]. We repeat the estimation with the tax rates being formally separated into energy and eco tax in the model:

$$\Delta p_t^* = \alpha_0 + \alpha_1 \Delta \sigma_t + \alpha_3 \Delta \tau_t^{energy,VAT} + \alpha_4 \Delta \tau_t^{eco,VAT} + \epsilon_t \quad (12)$$

Again, we are not able to reject the hypothesis that there is full pass-through.³⁵ This indicates that fuel taxes have been noticeable for consumers and that we can interpret our estimates of fuel-specific tax elasticities as price elasticities of demand.

³⁴The p-value of the linear Wald test for $\Delta \alpha_2 = 1$ are equal to 0.49 for gasoline and 0.35 for diesel.

³⁵For gasoline, α_3 equals 0.92 [0.75; 1.09] and α_4 1.02 [0.83; 1.20]. While the eco tax coefficient for diesel is similar at 0.96 [0.49; 1.43], the one for the energy tax is slightly lower at 0.64 [0.05; 1.22]. The p-values of the linear Wald tests for $\Delta \alpha_3 = 1$ are 0.34 for gasoline and 0.21 for diesel, and 0.84 and 0.86 for $\Delta \alpha_4 = 1$, respectively. These results imply that we cannot reject the null hypothesis that there is full pass-through, which is in line with a growing body of evidence showing that fuel taxes and carbon costs are passed through onto consumer prices (c.f. [Marion and Muehlegger, 2011](#); [Li et al., 2014](#); [Fabra and Reguant, 2014](#); [Andersson, 2019](#); [Neuhoff and Ritz, 2019](#); [Ganapati et al., 2020](#)).

5.1 Real price elasticities for gasoline and diesel

Tables 2a and 2b report estimates from the *Real price elasticities* specification (c.f. Section 2.2) for gasoline and diesel consumption, respectively. Additional robustness results based on a shorter time frame (1991–2009) are presented in Tables D.2 and D.4. Using our estimate from column (3) in Table 2a, we derive a real price elasticity of gasoline of -0.54.³⁶ The IV regression, shown in column (4) of Table 2a, yields a very similar price elasticity of demand of -0.50, indicating that endogeneity of gasoline prices is likely not a major source of concern in this setting. To test the relevance condition of our instrument, we use an F-test for that single instrument. For the price of gasoline, the F-statistic is 69.47 suggesting that the relevance condition is fulfilled and that brent crude oil price can be considered a suitable instrument for gasoline prices. Our elasticity estimate falls into the range of price elasticities of demand for gasoline in the literature.³⁷

Table 2b displays results for diesel consumption from the real price elasticity specification (c.f. Section 2.2). The real price elasticity of demand for diesel shown in column (3) of Table 2b is somewhat lower than the one for gasoline at -0.34. The IV regression in column (4) yields an estimate of -0.28, which deviates slightly more than the IV and OLS regressions for gasoline, but is still sufficiently close to corroborate the magnitude of the real price elasticity for diesel.

³⁶In order to calculate the elasticities from our log-level model estimates, the coefficient for each tax is multiplied with the average mean of the sample of the real fuel price. This is because the elasticity of demand is given by $\epsilon = \frac{dY}{dX} * \frac{X}{Y}$ and our model is expressed in log-level terms: $\log(Y) = a + bX$. This implies that $\frac{dY}{dX} = be^a e^{bX}$. Plugging this into the elasticity, we obtain $\epsilon = \frac{be^a e^{bX}}{e^a e^{bX}} * X = bX$. The real mean price of gasoline over the given time period is 89.8 cents, for diesel 76.4 cents.

³⁷Goodwin et al. (2004) show in an extensive literature review that, when using a static model, estimated elasticities range from -0.11 to -1.12, with a mean of -0.43. Labandeira et al. (2017) recently published a meta-analysis of price elasticities and find average short- and long-term elasticities for gasoline are -0.195 and -0.526. Using panel estimation methods, Frondel and Vance (2014) estimate German fuel elasticity for gasoline and diesel and find a range of -0.51 to -0.41.

Table 2: Real price elasticities for transport fuels

(a) Gasoline consumption					(b) Diesel consumption				
	(1)	(2)	(3)	(4)		(1)	(2)	(3)	(4)
	OLS	OLS	OLS	IV: Brent Crude		OLS	OLS	OLS	IV: Brent Crude
Real price of Gasoline	-0.00698 (0.00419)	-0.00675* (0.00395)	-0.00603** (0.00279)	-0.00553* (0.00305)	Real price of Diesel	-0.00482*** (0.00119)	-0.00473*** (0.00140)	-0.00440*** (0.00103)	-0.00361*** (0.000856)
Dummy Eco Tax	-0.221 (0.146)	-0.186 (0.121)	-0.154 (0.130)	-0.161 (0.129)	Dummy Eco Tax	-0.00672 (0.0424)	-0.0272 (0.0571)	-0.0205 (0.0564)	-0.0415 (0.0561)
Trend	0.0117*** (0.00401)	0.0240** (0.00897)	0.00158 (0.0139)	0.00127 (0.0125)	Trend	0.0326*** (0.00134)	0.0273*** (0.00309)	0.0189*** (0.00587)	0.0176*** (0.00546)
GDP per capita		-0.0000211 (0.0000125)	0.000000174 (0.0000116)	0.000000318 (0.0000102)	GDP per capita		0.00000938** (0.00000412)	0.0000177*** (0.00000522)	0.0000199*** (0.00000420)
Unemployment rate			0.0292 (0.0178)	0.0298* (0.0165)	Unemployment rate			0.0107* (0.00560)	0.0126** (0.00615)
Instrument F-statistic	69.47				Instrument F-statistic	168.86			
Observations	38	38	38	38	Observations	39	39	39	39

Notes: The dependent variable is the log of fuel consumption in liters per capita, which refers to total fuel consumption or either gasoline or diesel consumption (as indicated by the column heading). Columns (4) use the brent crude oil price as an instrumental variable for the real fuel price. Prices are in 1995€. Results for gasoline consumption refer to 1972-2009 due to missing price data prior to 1972. Unemployment is measured as percentage of total labor force. Newey-West standard errors in parentheses are heteroskedasticity and autocorrelation robust. Standard errors are calculated relying on the automatic bandwidth selection procedure following [Newey and West \(1994\)](#). * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

5.2 Tax elasticities for gasoline and diesel

Table 3a displays results for gasoline consumption from the eco-tax elasticity specification (c.f. Section 2.2). The OLS results in column (3) in Table 3a indicate that the price elasticity of demand for the price excluding the energy and the eco tax (but including the VAT) is -0.32. The energy tax elasticity of demand, instead, amounts to -0.22. Both elasticities are computed relying on coefficients that exhibit a considerably lower statistical significance. This contrasts the eco tax elasticity of demand, which is estimated at -2.7 and is thus around 8.5 times larger than the tax-exclusive price elasticity. This indicates that an increase in the price of gasoline due to the eco tax would result in a stronger behavioral response than a comparable market-driven price increase.

There may be two different underlying reasons that would reconcile our findings and explain the estimated stronger behavioral response to the eco tax (c.f. [Li et al., 2014](#)). The first one is *persistence*, meaning that consumers rely on these tax changes to build expectations for the future price of gasoline. A tax increase may thus be perceived as more enduring than market-driven price fluctuations, which, in turn, would stimulate a stronger consumer response. The second is *salience*, meaning that consumers are more aware of the price change due to media coverage. [Rivers and Schaufele \(2015\)](#) also find that

Table 3: Eco tax elasticities for transport fuels

(a) Gasoline consumption				(b) Diesel consumption			
	(1)	(2)	(3)		(1)	(2)	(3)
Gasoline price (only VAT)	-0.00360 (0.00312)	-0.00358* (0.00197)	-0.00357* (0.00197)	Diesel price (only VAT)	-0.00324*** (0.000816)	-0.00339*** (0.00104)	-0.00346*** (0.00104)
Energy Tax on Gasoline	-0.00625** (0.00259)	-0.00160 (0.00495)	-0.00242 (0.00503)	Energy Tax on Diesel	-0.00132 (0.00291)	-0.00538 (0.00339)	-0.00729** (0.00284)
Eco Tax on Gasoline	-0.0342*** (0.00794)	-0.0325*** (0.00707)	-0.0306*** (0.00774)	Eco Tax on Diesel	-0.0170*** (0.00196)	-0.0163*** (0.00212)	-0.0143*** (0.00361)
Dummy Eco Tax	0.0718** (0.0334)	0.119** (0.0517)	0.104** (0.0409)	Dummy Eco Tax	0.101*** (0.0190)	0.0890*** (0.0214)	0.0794*** (0.0172)
Trend	0.0145*** (0.00452)	0.0327*** (0.0137)	0.0240 (0.0219)	Trend	0.0353*** (0.00175)	0.0266*** (0.00587)	0.0187** (0.00752)
GDP per capita		-0.0000345 (0.0000295)	-0.0000245 (0.0000320)	GDP per capita		0.0000120 (0.00000963)	0.0000201*** (0.00000724)
Unemployment rate			0.00902 (0.0243)	Unemployment rate			0.00651 (0.00811)
p-value Raw price = Eco tax	0.006	0.002	0.008	p-value Raw price = Eco tax	0.000	0.000	0.023
Observations	38	38	38	Observations	39	39	39

Notes: The dependent variable is the log of fuel consumption in liters per capita, which refers to total fuel consumption or either gasoline or diesel consumption (as indicated by the column heading). Prices are in 1995€. Results for gasoline consumption refer to 1972-2009 due to missing price data prior to 1972. Unemployment is measured as percentage of total labor force. Newey-West standard errors in parentheses are heteroskedasticity and autocorrelation robust. Standard errors are calculated relying on the automatic bandwidth selection procedure following [Newey and West \(1994\)](#). * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

environmental tax shifts result in a stronger demand response than market price shifts. Drawing on these findings, we hypothesize that intensified media salience may explain a considerable share of the estimated consumer response, given the prominent public debate about the eco tax reform that occurred before and throughout its implementation. In Section 5.4, we will formally quantify the role of greater media salience, by leveraging newspaper data, in driving behavioral responses to changes in the eco tax.

As in the case of gasoline, the eco tax elasticity of diesel demand is significantly higher than that for the real price. Table 3b displays the results for the different tax rates for diesel, i.e. eco-tax elasticity specification. Using column (3) in Table 3b, the resulting elasticity for the real price, excluding the energy and eco tax, is -0.26. The energy tax elasticity of demand is -0.56, which is slightly higher than the price elasticity. The eco tax elasticity of demand is again the highest level at -1.1, thus being about 4 times larger than the tax-exclusive price elasticity. It follows that, as in the case of gasoline, an increase in the eco tax predicts a stronger response in demand than that of a market-driven price

change.³⁸ As discussed above, the reasons could involve *persistence* and/or *salience* of the eco tax reform as well as their combination, as media salience could potentially also affect expectations on the persistence of the tax policy. It is noticeable that the gasoline demand is generally more elastic than that of diesel. One possible explanation could be that most trucks use diesel and that the elasticity for the transportation of goods is lower than the private elasticity. Another reason could be that company cars typically use diesel, which would mean that a share of the price is paid for by the company. Thus, the price incentive is not expected to be as strong as when the full price is paid for by private consumers.

5.3 Emissions under different taxation scenarios

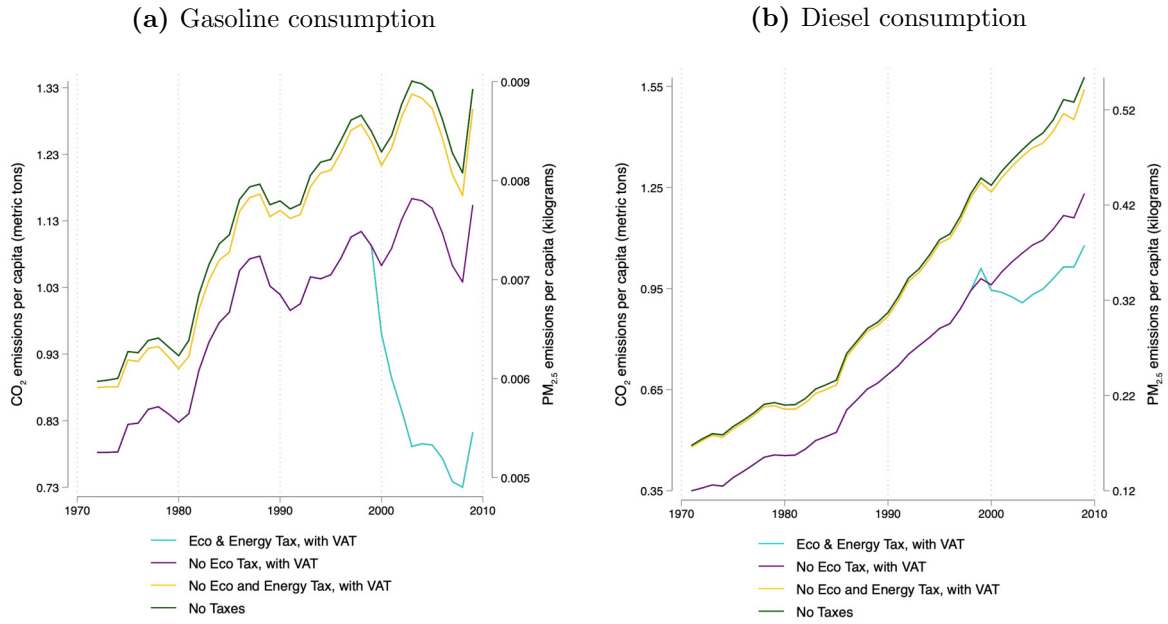
In this next step of the analysis, we rely on the estimated fuel-specific price and tax elasticities from columns (3) in Tables 3a and 3b to compute the resulting CO₂ and PM_{2.5} (and NO_x) emissions for different taxation scenarios, namely a scenario where no VAT and no taxes are introduced, a scenario where either VAT or VAT and the energy tax is added to the price of fuels, and, finally, a scenario where both the eco and the energy tax are implemented along with the VAT.³⁹ We refer to this as the *Simulation Approach*.

Predicted emissions in the Simulation Approach. Panels (a) and (b) in Figure 4 graphically summarize the estimated evolution of CO₂ (left-hand side primary y-axis) and PM_{2.5} (right-hand side secondary y-axis) emissions by fuel in the German transport sector under different tax regimes. The light blue line represents projected emissions accounting for all existing tax measures, including the eco tax, energy tax, and VAT. The purple

³⁸We additionally amend our semi-elasticity models by including a lead to test whether consumers increased their purchases of transport fuel in anticipation of tax increases, which could potentially bias estimated price and eco tax coefficients (Coglianese et al., 2017). We do not find evidence of a potential anticipatory effect, and the estimated real price and eco tax elasticities are very similar to the main result reported in Tables 2a - 3b (see Figure D.5). One explanation is that anticipatory behavior is a lesser source of concern when dealing with yearly data as compared to relying on monthly variation.

³⁹The combustion of one liter gasoline (diesel) emits 2.235kg (2.66kg) of CO₂ (US EPA, 2005). With the help of this factor, the predicted log gasoline (diesel) consumption values can first be turned into liters and then CO₂ emissions. To estimate PM_{2.5} emissions from fuel consumption, we rely on estimates from the European Environment Agency (EEA) on average emission factors for gasoline (diesel) vehicles in Germany (Ntziachristos and Samaras, 2019) of 0.02 grams (1.12 grams) of PM_{2.5} per kg of gasoline (diesel). Although EEA only reports emission factors for PM without specifying the size range, it clarifies that PM mass emissions in vehicle exhaust mainly fall in the PM_{2.5} category. The predicted log gasoline (diesel) consumption values are first be turned into kilograms and subsequently into PM_{2.5} emissions.

Figure 4: Estimated emissions by fuel under different taxation scenarios



Notes: The figures above plot predicted emissions from the eco-tax specification of our log-level semi-elasticity models (c.f. Section 2.2) under different taxation scenarios. We rely the estimated fuel-specific price and tax elasticities computed from our estimates from column (3) in Tables 3a and 3b. Panel (a) refers to predicted emissions from gasoline consumption, while Panel (b) covers diesel consumption. In each panel the left-hand side primary y-axis refers to per capita CO₂ in metric tons, while the right-hand side secondary y-axis refers to per capita PM_{2.5} in kilograms. The top green line displays predicted emissions when the eco and energy tax elasticities are set to zero, and VAT is deducted from the fuel price. For the yellow line, the eco and energy tax elasticities are set to zero but VAT is included. The purple line shows how predicted emissions change when the eco tax is set to zero, but we include the energy tax and VAT. The light blue line provides predicted emissions using the full model with differentiated tax and price elasticities. The corresponding simulations for NO_x emissions can be found in Appendix D.6.

line plots the estimated evolution of emissions in the absence of the eco tax, while the yellow line depicts the expected path of emissions with neither the eco tax nor the energy tax, thereby solely incorporating VAT. The green line shows predicted emissions without any tax policies. The gap between the light blue and purple line highlights the estimated emission gap solely attributable to the eco tax, while the other lines can be interpreted as alternative counterfactuals to juxtapose the evolution of different behavioral responses.

Panel (a) in Figure 4 points out that between the years 1999 and 2009, the decrease in emissions of CO₂ (PM_{2.5}) from gasoline induced by the eco tax was around 0.27 tons (0.002 kilograms) per capita on average per year. Similarly, Panel (b) provides the estimated emission reductions from diesel consumption. Given that the eco tax demand elasticity for diesel is lower than that of gasoline, the projected emission reductions tend to be less marked. From 1999 to 2009, the mean decline in annual emissions of CO₂ (PM_{2.5}) from diesel induced by the eco tax was around 0.11 tons (0.04 kilograms) per capita.

Panels (a) and (b) in Figure 5 contrast the estimated share of aggregate reductions in emissions attributable to contractions in either gasoline or diesel use for CO₂ and PM_{2.5}, additionally including reductions in NO_x emissions. On average across our time frame, contractions in gasoline (diesel) use were responsible for around 72% (28%) of overall reductions in CO₂ emissions. Conversely, reduced diesel use is responsible for almost the entirety (95%) of the reduction of PM_{2.5} emissions. In other words, on average, reductions in diesel consumption have contributed around 21 (0.4) times more to the decline in PM_{2.5} (CO₂) emissions relative to gasoline.

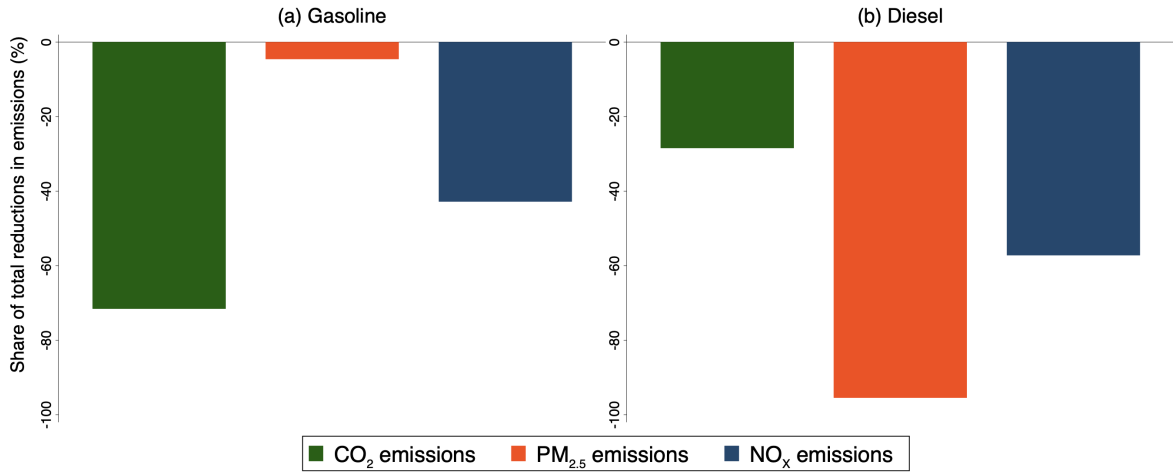
Fuel substitution and abatement trade-offs. Diesel fuel vehicles contribute considerably more to emissions of fine particulates, such as PM_{2.5}, than gasoline vehicles.⁴⁰ However, diesel vehicles have lower CO₂ emissions rates per traveled kilometer compared to gasoline vehicles, by approximately 20% for otherwise virtually identical vehicles (Linn, 2019).⁴¹ It follows that policy measures that foster a switch from gasoline vehicles to diesel vehicles (e.g., taxes based on the carbon content of fuels), could, in turn, lead to a decrease in CO₂ emissions but also an increase in particulate matter emissions. Previous research on fuel and carbon taxation has not explicitly considered this trade-off in policy evaluations, with the exception of Linn (2019). Tables D.5 and D.6 in the Appendix provide empirical evidence of gasoline-to-diesel substitution in our setting. This indicates that part of the observed contraction in CO₂ linked to reduced gasoline consumption came at the expense of greater PM_{2.5} emissions due to fuel substitution. Precisely, we estimate that, for the average eco tax rate of 13.05 cents, the share of diesel consumption is predicted to increase by approximately 4% more than it would have had in the absence of the eco tax throughout the post-treatment period.⁴² Our back-of-the-envelope calculations suggest that the gasoline-to-diesel substitution due to the eco tax translated, on average, into an annual increase in per capita PM_{2.5} emissions due to increased diesel consumption of around 0.03 kilograms from 1999 to 2009, or a cumulative increase of 25 thousand tons.

⁴⁰Relying on emission factors provided by the EEA for Germany, the average PM_{2.5} emission factor for diesel vehicles is around 56 times larger than that for gasoline (Ntziachristos and Samaras, 2019).

⁴¹This is because diesel engines are typically much more fuel-efficient than gas engines.

⁴²To contextualize the magnitude of this result, from 1998 to 2009 the share of diesel use in total fuel consumption increased from around 42% to 56% (c.f. Figure D.4).

Figure 5: Share of total emission reductions by fuel due to the eco tax



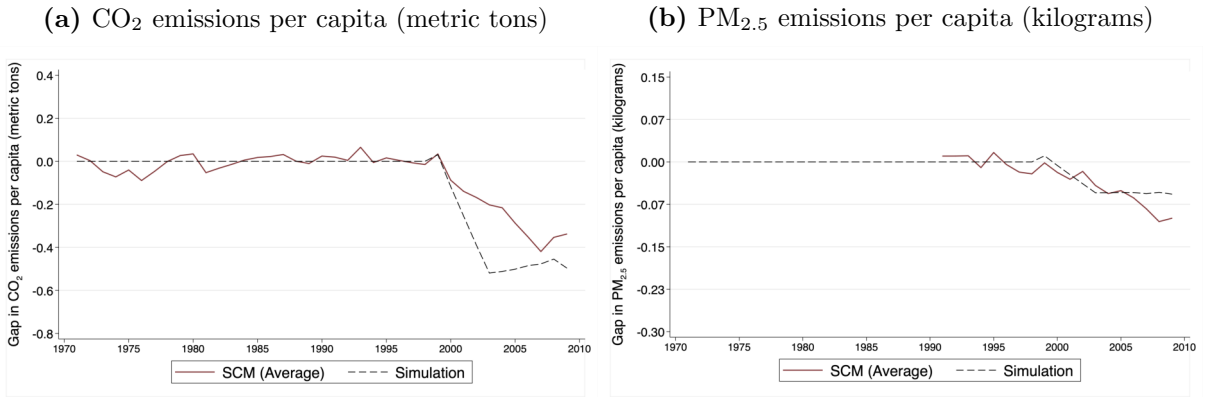
Notes: The figures above plot the share of total predicted emissions reductions by fuel type from our log-level semi-elasticity models (c.f. Section 2.2). Specifically, Panel (a) refers to the share of predicted per capita emissions reductions attributed to reduced gasoline consumption, while Panel (b) refers to predicted per capita emissions reductions (in relative percentage terms) due to decreased diesel consumption. The share of total emission reductions for each fuel type is computed from the estimated post-treatment gap in emissions from gasoline (diesel) consumption due to the eco tax, which refers to the distance between the bottom light blue line and the purple line in Figure 4.

Comparing the SCM and the Simulation Approach. Finally, we directly compare the SCM and the Simulation Approach. Figure 6 displays the estimated gaps in per capita emissions estimated by each method. The black solid line represents the average gap detected in our SCM specifications and the gray dashed line the predicted reductions from the eco tax reform considering the combined emission abatement from gasoline and diesel based on our log-level semi-elasticity models. The two approaches yield annual average reductions in per capita CO₂ emission ranging between 0.23 (SCM) and 0.38 (Simulation) metric tons per year. For PM_{2.5}, the estimated contraction in per capita emissions ranges from 0.04 (Simulation) and 0.048 (SCM) kilograms per year.⁴³

The emission paths derived from the two strategies capture different effects and can be interpreted as follows. The SCM provides a plausibly causal estimate of the actual emission reductions attributable to the introduction of the eco tax in 1999 and the subsequent changes in the VAT and the eco and energy tax rates between 1999 and 2009. In contrast, the simulation exercise does not account for substitution between modes of

⁴³Note that the SCM and simulation results for PM_{2.5} emissions are not directly comparable. A key difference is that the simulation approach does not structurally account for non-exhaust emissions coming from road paving with asphalt, road abrasion, automobile tyre and brake wear, and fuel evaporation which we can explicitly account for in the SCM. This is because emissions from fuel consumption are computed by multiplying fuel use by EEA fuel-specific emission factors that, by structure, do not account for non-exhaust emissions (Ntziachristos and Samaras, 2019).

Figure 6: Gap in per capita emissions: SCM vs Simulation Approach



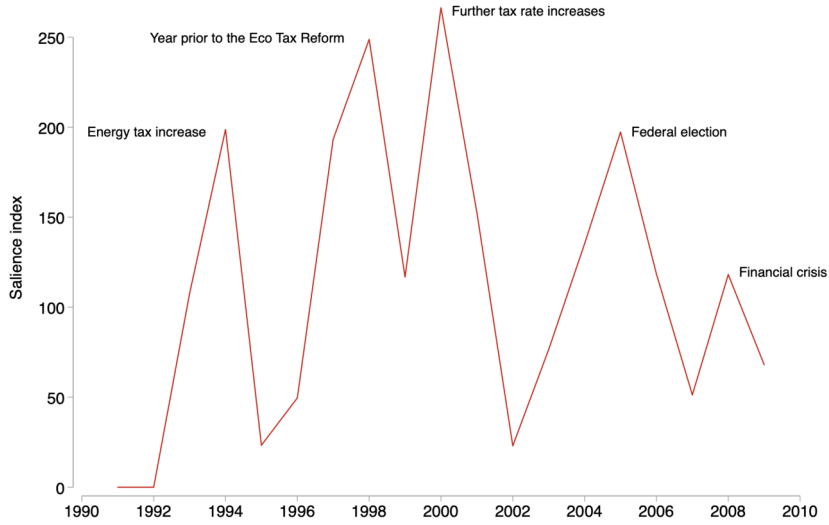
Notes: The figures above plot the estimated average gap in per capita emissions from our synthetic control experiment (c.f. Section 2.1) and the simulation approach based on our log-level semi-elasticity models (c.f. Section 2.2). Nationwide reductions in emissions in the simulation approach have been computed by accounting for predicted emission reductions from both gasoline and diesel. The black (solid) line in Panel (b) begins in 1991 due to data availability limitations in the construction of our SCM to estimate PM_{2.5} emission reductions (see Section 3 for more details). The corresponding comparison graph for our NO_x results can be found in Appendix D.7.

transport (i.e., private or public transportation), which is one key difference that can explain the divergence in the estimated carbon reductions following the first treatment years. After 2003, when the real eco tax rate started declining with inflation, the two estimates tend to converge. The predicted decrease in carbon emissions in the simulation approach after 2007 reflects the increase in the VAT in that year (c.f. Section A).

5.4 Tax salience

Our empirical analysis continues by quantifying the role of eco tax salience in the media in driving the estimated effects of the eco tax. We draw on a growing number of economic studies leveraging newspaper data as source of variation in the salience of events (e.g., Li et al., 2014; Baker et al., 2016; Caprettini and Voth, 2020; Basaglia et al., 2021; Ager et al., 2022; Beach and Hanlon, 2022), and construct a newspaper-based index to capture the evolution of salience of the eco tax based on textual analysis of German newspaper articles (see Section 3). The underlying rationale of our approach is that as more print media coverage is devoted to the repercussions of the eco tax in terms of fuel prices, the policy becomes more salient for the public. For each year, our main indicator measures the number of articles that discuss the effects of the eco tax on fuel prices relative to newspaper-specific publishing trends specific to the topic of environmental taxation.

Figure 7: Evolution of the salience index over time



Notes: Based on yearly series from 1991 to 2009. Authors' own calculations based on newspaper articles from Factiva (c.f. Section 3). A detailed description of the steps undertaken to construct the newspaper index can be found in Appendix E.

Figure 7 plots the evolution of our salience index over time. In the following we leverage annual variations in the newspaper-based salience index to empirically investigate how variations in media salience affect fuel-specific consumption responses. More specifically, we amend our static log-linear semi-elasticity models (c.f. Section 2.2) by interacting our eco tax salience newspaper index with the annual real rate of the eco tax. This allows to empirically isolate how salience affects fuel consumption in accordance with the evolution of the eco tax. Our identification strategy captures the additional effect on fuel consumption reduction (at a given fuel tax rate) attributable to greater eco tax media salience. Our regressions focus on salience in the previous year, as print media coverage tends to peak prior to actual or proposed changes to the eco tax rate (c.f. Li et al., 2014).

Column (2) in Table 4 reports our preferred coefficients of the amended elasticity model. The significant interaction term indicates that greater tax salience is associated with lower consumption of both gasoline and diesel and that these effects increase with the eco tax rate. Furthermore, the eco tax elasticities tend to converge to the real price elasticities after explicitly accounting for salience, suggesting that much of the divergence in the behavioral response for the increase in the eco tax—relative to market-driven price

Table 4: Effects of salience on fuel consumption

(a) Gasoline consumption				(b) Diesel consumption			
	(1)	(2)	(3)		(1)	(2)	(3)
Gasoline price, only VAT	-0.00264 (0.00237)	-0.00278 (0.00174)	-0.000503 (0.00130)	Diesel price, only VAT	-0.00305*** (0.000753)	-0.00325*** (0.00103)	-0.00197*** (0.000656)
Energy Tax	-0.00611** (0.00237)	-0.00340 (0.00489)	-0.00716 (0.00427)	Energy Tax	-0.00102 (0.00284)	-0.00722** (0.00269)	-0.00774** (0.00328)
Eco Tax	-0.00556 (0.00495)	-0.00694 (0.00591)	0.00955 (0.0105)	Eco Tax	-0.0117*** (0.00135)	-0.00802*** (0.00179)	0.000453 (0.00304)
Eco Tax x Salience Index	-0.00540*** (0.00133)	-0.00449** (0.00193)	-0.00195** (0.000753)	Eco Tax x Salience Index	-0.00102** (0.000491)	-0.00122* (0.000706)	0.000372 (0.000349)
L.Eco Tax x Salience Index			-0.000475 (0.00197)	L.Eco Tax x Salience Index			-0.00166** (0.000709)
L2.Eco Tax x Salience Index			-0.00612*** (0.00207)	L2.Eco Tax x Salience Index			-0.00184* (0.000946)
Controls	×	✓	✓	Controls	×	✓	✓
N	38	38	37	N	39	39	37

Notes: The dependent variable is the log of fuel consumption in liters per capita, which refers to total fuel consumption or either gasoline or diesel consumption (as indicated by the column heading). Prices are in 1995€. Results for gasoline consumption refer to 1972-2009 due to missing price data prior to 1972. Our set of controls include: GDP per capita, the unemployment rate, a time trend and a binary variable that is equal to one after the implementation of the eco tax in 1999 and zero otherwise. Unemployment is measured as percentage of total labor force. Newey-West standard errors in parentheses are heteroskedasticity and autocorrelation robust. Salience index is our original newspaper-based index expressed in logarithmic terms (c.f. Section E.2). Standard errors are calculated relying on the automatic bandwidth selection procedure following Newey and West (1994).

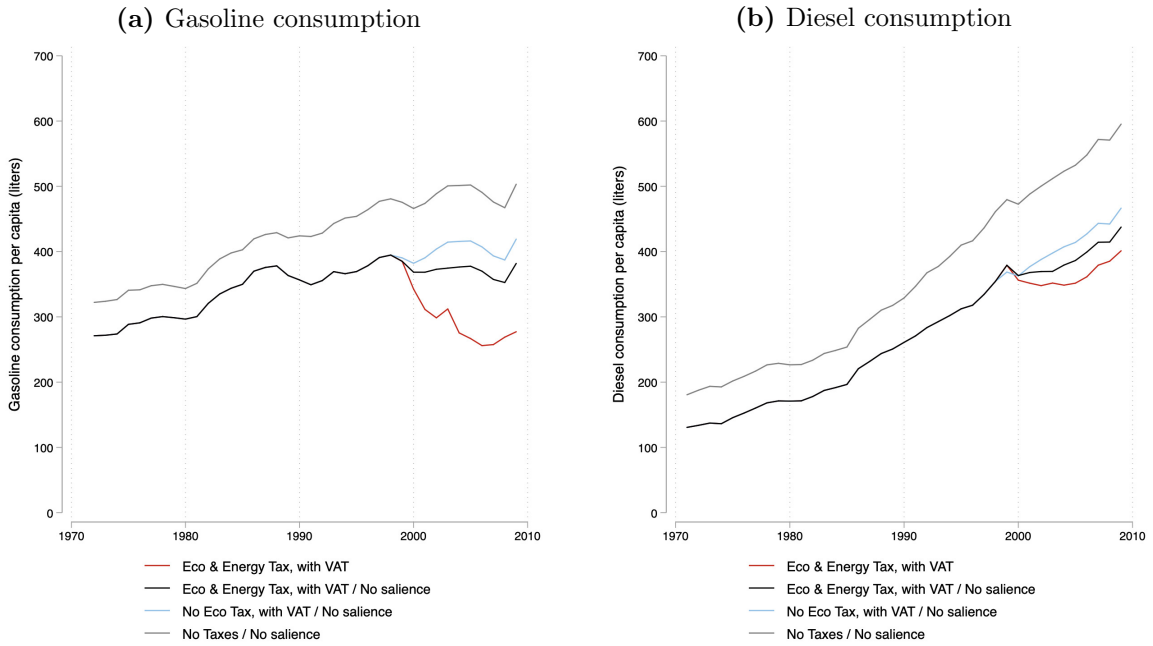
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

changes—can be explained by tax salience in our model.⁴⁴ To put our coefficients to perspective, let’s consider the average eco tax rate for gasoline (diesel) in real terms of 13.05 cents per liter. Our estimates from column (2) suggest that when our salience index exhibits an increase of a standard deviation relative to the mean, the additional reduction of gasoline (diesel) consumption induced by salience amounts to 4.2% (1.14%).⁴⁵ Leveraging our results from column (2), Figure 8 plots predicted gasoline and diesel consumption in the German transport sector under different taxation regimes and compares their evolution with and in the absence of salience. We show that salience is responsible for around 71% (55%) of the contraction in gasoline (diesel) consumption in our simulation.

⁴⁴Specifically, relying on the estimates from column (2) in Table 4, we compute a salience-exclusive gasoline eco tax elasticity of 0.62 and a diesel eco tax elasticity 0.61, which are now only 1.1 and 1.8 times higher in magnitude than the real price elasticities computed from our estimates from column (3) in Table 2a and 2b.

⁴⁵Our salience index exhibits a mean value of 112.9 with a standard deviation of around 81. A standard deviation increase thus represents a 72% increase relative to the mean. Both fuel consumption and the salience index are expressed in log terms in our model. Thus, denoting the coefficient of the interaction term as φ_6 , we can interpret the estimated coefficients, $\hat{\varphi}_6$, as follows: For the average eco tax rate of 13.05 cents, a standard deviation increase (or 72% increase relative to the mean) in our salience index will lead to an additional percentage reduction in fuel consumption which amounts to $13.05 \times [(1.01^{\hat{\varphi}_6} - 1) \times 100] \times 0.72$.

Figure 8: Estimated fuel consumption under different taxation and salience scenarios



Notes: The figures above plot predicted fuel consumption from our amended log-level semi-elasticity models (c.f. Section 2.2 and 5.4) under different taxation scenarios. We rely on the estimated fuel-specific price and tax elasticities computed from our estimates from column (2) in Table 4a and 4b. Specifically, Panel (a) refers to predicted per capita gasoline consumption (in liters), while Panel (b) is based on predicted per capita diesel consumption (in liters). The top gray line displays predicted emissions in the absence of taxes, which means both the eco and energy tax elasticities are set to zero, and the VAT is deducted from the fuel price. For the light blue line, the eco tax elasticity is set to zero but the VAT-inclusive energy tax is now included. The black line shows how predicted emissions change when we include both the eco and energy taxes with the VAT but we set salience (as proxied by our newspaper-based index) equal to zero. The bottom red line provides predicted emissions using the full model described in Section 5.4 with the differentiated tax and price elasticities which additionally includes the salience interactive term.

Finally, regressions in column (3) of Table 4 further investigate lagged responses to salience by including lags of the interaction term. More precisely, we want to test whether the detected larger demand response induced by salience endures beyond the exposure period. The coefficient of our lagged interactions reveal that the greater behavioral response induced due to salience lasts for multiple years after a spike in our index for both gasoline and diesel demand. These results provide suggestive evidence that a differential effect of fuel taxes vis-a-vis tax-exclusive prices could persist even in the long-run. Overall, these results corroborate the hypothesis that consumers react more strongly—relative to market prices—to environmental taxes that are salient.

6 Non-market benefits of the eco tax

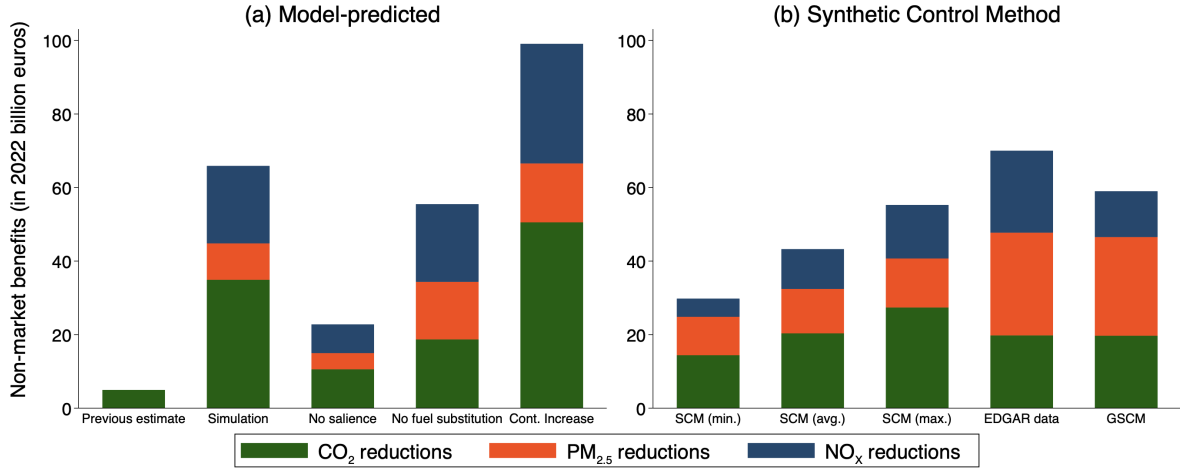
While previous reports suggested that environmental improvements due to the German eco tax have been limited (Steiner and Cludius, 2010; Kemfert et al., 2019), we document substantial reductions in both carbon and local air pollutant emissions. To quantify climate and health benefits of the eco tax, we apply official cost estimates for CO₂, PM_{2.5} and NO_x emissions from the first comprehensive guidelines by the German Environmental Protection Agency (Umweltbundesamt, 2012). We, first, apply these to a prior evaluation of carbon emission reductions by Steiner and Cludius (2010) and subsequently illustrate results for our own estimates, both relying on simulation approaches and SCM results.

The Umweltbundesamt (2012) recommended to value the social costs per ton of CO₂ emitted in 2010 by 80 euros (valued in 2010 euros).⁴⁶ The Umweltbundesamt (2012) further provides dis-aggregated cost estimates for PM_{2.5} in the transport sector, distinguishing social costs of PM_{2.5} released within cities (364,100 euros per ton) and released outside of cities (122,800 euros per ton), recognizing that within city emissions contribute more directly to human health costs. Umweltbundesamt (2012) also provides a breakdown of the relative share of PM_{2.5} within and outside of cities for different modes of transport, with passenger cars split between 37% within city and 63% outside of city emissions. For calculating external costs of PM_{2.5} emissions, we first take an average of the eight categories, which amounts to a within city PM_{2.5} share of 38%, close to that for passenger cars, and second use a weighted average of within and outside of city damages. For external costs of NO_x, the Umweltbundesamt (2012) does not distinguish across locations, and uses a cost estimate of 15,400 euros per ton. Finally, we transform cost estimates from a base year 2010 to a base year 2022 using official inflation statistics.

Steiner and Cludius (2010) estimate a price elasticity of fuel demand of -0.18 based on household survey data and attribute -0.1 to the tax elasticity component. They use this estimate to quantify reductions of CO₂ emissions due to the eco tax, which they report as amounting to 120 kg CO₂ per household per year. Multiplying with the yearly number

⁴⁶The Umweltbundesamt (2012) did not provide guidance on how cost estimates may increase over time, such as along income, thus we use these cost estimates for the whole time frame from 1999 to 2009.

Figure 9: Non-market benefits of the eco tax



Notes: The figure above plots the estimated non-market benefits based on our estimates from (a) the Simulation Approach and (b) the Synthetic Control Method on CO₂, PM_{2.5}, and NO_x reductions and compares their magnitudes with the implied benefit estimates from [Steiner and Cludius \(2010\)](#). Aggregate benefits are computed relying on pollutant-specific official cost estimates provided by the [Umweltbundesamt \(2012\)](#) and expressed in 2022 euros.

of households in Germany over the time span from 1999 to 2009, this sums up to 50.73 million tons of CO₂ emissions. Evaluating these emission reductions with the estimate of the social cost per ton of CO₂ in 2022 euros yields a climate benefit due to the eco tax of 4.9 billion euros (see first bar of Panel (a) in Figure 9).

We first contrast this previous estimate with results from our Simulation approach that also builds on elasticity estimates. Simulating emission reductions of CO₂ related to the “no eco tax” counterfactual yields an estimate of 344 million tons of CO₂ emissions, and an aggregate climate benefit due to the eco tax of around 35 billion euros, which is 7 times as large as the previous estimate. In addition, our Simulation approach suggests reductions of PM_{2.5} and NO_x emissions of 36,368 tons and 1.08 million tons, respectively.⁴⁷ Using the [Umweltbundesamt \(2012\)](#) cost estimates, this translates into local health benefits of 31 billion euros. In sum, the Simulation Approach suggests that the eco tax has reduced external damages by 66 billion euros (second bar of Panel (a) in Figure 9), 13 times as much as the previous estimate by [Steiner and Cludius \(2010\)](#) suggested.

While this is not a causal estimate of the emission reductions due to the eco tax, the Simulation Approach allows us to consider alternative scenarios. First, we consider

⁴⁷To estimate NO_x emissions from fuel consumption, we rely on estimates from the European Environment Agency on average emission factors for gasoline (diesel) vehicles in Germany ([Ntziachristos and Samaras, 2019](#)) of 5.61 (20.1) grams of NO_x per kg of gasoline (diesel).

a scenario in which the eco tax had not been salient. We find that external damage reduction due to the eco tax might have been smaller by around two-thirds, at 22.7 billion euros, in absence of a salient price increase due to the eco tax. Second, we consider a scenario in which there would not have been fuel substitution from gasoline to diesel, which faced a lower (effective) tax burden.⁴⁸ We find that external damage reductions would have amounted to a reduced total of 55.5 billion euros. More interestingly, the composition of benefits would have been very different: While not switching to diesel would have substantially reduced carbon benefits (34.9 versus 18.7 billion euros), benefits to due reducing PM_{2.5} would have been considerably higher (30.9 versus 36.7 billion euros). Third, we consider a scenario in which the (planned) yearly increase in the eco tax had not been stopped in 2003 but continued until 2009. We estimate that this would have led to reductions in external damages of almost 100 billion euros.

We now move from model-predicted Simulation approach estimates to plausibly causal estimates of reductions in external damages using our SCM approaches. The first three bars in Panel (b) of Figure 9 show the results of our standard SCM for specifications yielding minimal, average and maximal emission reductions. The average across all seven SCM specifications suggests climate and health benefits due to the eco tax of 43 billion euros, almost 9 times as much as the estimate by [Steiner and Cludius \(2010\)](#) suggested.

Complementary to our SCM based on official emissions data, we illustrate results in the baseline specification using EDGAR emissions data and find that the reduction in external damages would be substantially larger, at around 70 billion euros. The difference stems from greater health benefits, which are likely a result of the the enhanced cross-country harmonization in the Edgar data that limits the potential for bias of the SCM estimator (c.f. Section 4.1). We consider this an upper-bound estimate of the non-market benefits

⁴⁸We compute the *No fuel substitution scenario* by holding annual traveled kilometers per capita fixed. As gasoline vehicles are less fuel efficient per kilometer vis-a-vis comparable diesel vehicles, this assumption implies that the the foregone increase in diesel consumption due to fuel substitution translates into a 1.2 times increase in gasoline consumption to account for the lower fuel efficiency ([Linn, 2019](#)). Foregone gasoline-to-diesel substitution is computed relying on column (3) in Table D.6. We then subtract the estimated foregone substitution towards diesel from predicted diesel consumption from column (3) in Table 3a and 3b. Different scenario assumptions on greater gasoline-fueled vehicles efficiency or, more generally, that would result in reduced annual traveled kilometers per capita would yield higher aggregate non-market benefits, primarily through a greater overall reduction in carbon emissions.

of the eco tax.⁴⁹ Finally, we compute climate and health benefits using the generalized SCM and find slightly higher non-market benefits than in the maximum specification of the standard SCM. It is particularly noteworthy that both the SCM using EDGAR data and the GSCM provide very similar estimates of carbon benefits as the average standard SCM, but that the EDGAR data suggest larger benefits due to NO_x reduction and both suggest considerably larger benefits due to reducing $\text{PM}_{2.5}$.⁵⁰

Overall, our results suggest that the eco tax was orders of magnitude more effective in reducing external damages and delivering both climate and local health benefits than previously suggested. Crucially, evaluations of fuel or carbon taxes that focused solely on climate benefits (e.g., [Andersson, 2019](#); [Mideksa, 2021](#); [Runst and Höhle, 2022](#)) will miss a substantial share of non-market benefits. For the case of the German eco tax, we find that neglecting health benefits due to reduced air pollution would miss 53% of the reductions in external damages. Furthermore, a non-salient price increase may have delivered only around a third of the reductions in external damages. Assuming non-wasteful use of the revenue, society got back between 1.4 and 1.7 cents in return for every 1 cent increase in the eco tax. This implies that the deadweight loss or inefficiency in revenue recycling can be substantial and the policy would still be welfare-enhancing on aggregate. Our finding on the substantial reduction in local health damages is also crucial for an evaluation of distributional effects. While the direct consumer cost incidence of fuel taxation tends to burden lower-income households disproportionately (e.g., [Nikodinoska and Schröder, 2016](#); [Sternier, 2012](#)), poorer households may also benefit disproportionately from the reductions in air pollution (e.g., [Banzhaf et al., 2019](#); [Colmer et al., 2020](#); [Drupp et al., 2021](#)).

⁴⁹Note that officially reported emissions, the EDGAR database and the emission factors used in the Simulation approach are based on laboratory emission rates which tend to significantly underestimate actual on-road nitrogen dioxides and particulate matter emissions ([Carslaw et al., 2011](#); [Franco et al., 2013](#)), also partly due to the recent *Dieseltgate* scandal ([Grange et al., 2020](#)). It follows that our estimated impacts on on-road emissions of local air pollutants may represent lower-bound estimates.

⁵⁰The smaller cumulative reduction in NO_x emissions when comparing results with the GSCM and the EDGAR database can be explained by the larger detected increase in nitrogen oxides in the first treatment year plausibly induced by gasoline-to-diesel substitution captured by the GSCM specification based on an interactive fixed effects model.

7 Conclusion

This paper provides the first comprehensive quasi-experimental assessment of the effectiveness of fuel taxes to jointly reduce carbon and air pollutant emissions. We study the 1999–2003 Ecological Tax Reform in Germany, which levied the then second highest effective carbon price on fuel worldwide in the largest European transport sector. Previous assessments painted the German eco tax as an environmental policy “flop” (Kemfert et al., 2019), however without carrying out a causal policy analysis. While modelling studies suggest that decreasing reliance on fossil fuels could foster sizeable health benefits (Shaw et al., 2014; Markandya et al., 2018; Vandyck et al., 2020), no empirical policy evaluation to date has jointly evaluated climate and health benefits in a causal framework.

Using the synthetic control method, we compare carbon and air pollutant emissions of the actual and synthetic German transport sector between 1999 and 2009. We find that fuel taxes are much more effective in internalizing external damages than previously considered. Using official cost estimates for carbon and local pollutant emissions, we show that the German eco tax has saved more than 40 billion euros of external damages between 1999 and 2009. Our finding of substantial reductions in external damages is qualitatively very robust across a host of specifications that have been used in the literature, a battery of sensitivity and placebo checks as well as using the generalized synthetic control method, which yields more sizable estimates. We thus show that the eco tax was considerably more effective in delivering CO₂ emission reductions than previous estimates suggested that relied on simple elasticity simulations based on household survey data (Steiner and Cludius, 2010). On average, we find that the eco tax has reduced CO₂ emissions by around 12% per year between 1999 and 2009, which is comparable to what Andersson (2019) has documented for an explicit carbon price in Sweden.

We complement our synthetic control analysis with analyses of fuel-specific tax elasticities, of the role of tax salience based on newspaper data, and by simulation approaches using tax retail fuel price and tax elasticities that highlight the role of fuel-substitution from gasoline to diesel and of tax salience in mediating the effectiveness of how fuel taxes can foster climate and health benefits. Drawing on these additional analyses, we make

three main contributions beyond the general finding that the fuel taxation part of the German eco tax reform was a very successful environmental policy.

First, we show that the much higher demand response to the eco tax is primarily due to increased tax salience, which we measure explicitly based on newspaper data. We thereby extend prior work on the role of salience (Li et al., 2014; Rivers and Schaufele, 2015) by providing the first direct empirical evidence for the hypothesis that consumers react more strongly to fuel taxes the more salient they are.

Second, we show that solely focusing on carbon abatement, as almost all prior analyses have done (e.g., Andersson, 2019; Pretis, 2022; Leroutier, 2022), misses a substantial amount of the comprehensive effectiveness of a fuel tax to reduce externalities. In the case of the German eco tax, around half of the benefits, 53% on average across our synthetic control specifications, accrue to health benefits from reduced air pollutants.

Third, our simulation approach using predicted emissions from fuel specific elasticities underscores the important role of interfuel substitution from gasoline to diesel for the effectiveness of the eco tax and the trade-off between attaining climate and local pollution or health targets. We estimate that without fuel substitution, the overall effectiveness of the eco tax to yield reductions in external damages would have been slightly reduced, but with a considerable change in the composition: Our simulations suggest that without the shift from gasoline to diesel, carbon abatement benefits would have been around 54% lower as compared to our base simulation, while particulate matter reductions would have been 58% larger. Relatedly, our simulations indicate that around three-quarters of the reduction in carbon emissions is attributable to contractions in gasoline consumption, partly driven by fuel substitution towards diesel. Conversely, almost all of the decrease in PM_{2.5} emissions is driven by lowered diesel consumption due to the eco tax.

Overall, our results highlight the key roles of co-pollution, fuel substitution and tax salience for the overall effectiveness of fuel taxes to reduce external damages. Our findings carry important policy implications in three respects. First, a sole focus on carbon abatement of fuel taxes and carbon prices will miss a sizable portion of co-benefits by not considering reductions in air pollutant emissions (e.g., Ekins, 1996; Wagner and De Preux,

2016; Parry et al., 2021). Capturing and communicating such health co-benefits, which positively and more immediately affect the populations that bear the consumer costs of these pricing instruments, may be crucial to gather support for unilateral fuel and climate policies (e.g., Longo et al., 2012; Löschel et al., 2021).

Second, it is important for evaluations of fuel and carbon pricing to consider the trade-offs that can arise between climate and air pollution targets (e.g., Ambec and Coria, 2013; Linn, 2019; Parry et al., 2021). We show that this is particularly relevant in the context price instruments set on the carbon content of fuels that can foster gasoline-to-diesel substitution. While this is less important in the USA due to a large share of gasoline-fuelled cars, it is key when evaluating pricing schemes in Europe (Zimmer and Koch, 2017; Linn, 2019). We show that relaxing the assumption that consumers respond similarly to fuel taxes as to other sources of fuel price variation (Linn, 2019) suggests that policy makers have to navigate a much larger trade-off between climate and health benefits.

Finally, our results underscore the crucial roles of salience in fostering the effectiveness of fuel taxation and carbon pricing (Li et al., 2014; Rivers and Schaufele, 2015). Our empirical findings provide the first direct evidence that consumers react more strongly to fuel taxes when these are more salient. Thus, complementary measures such as disclosure or information campaigns may have considerable potential to foster environmental, climate and energy security benefits through a greater demand response at a given tax rate, and hence enhance the cost-effectiveness of price instruments to internalize externalities.

In closing, we note that the important role of salience is a double-edged sword for fossil fuel and climate policy design. On the one hand, this is good news for policies aimed at reducing external damages or attaining specific mitigation targets, as fuel or carbon taxes may yield larger demand responses than is routinely considered in policy analysis using price elasticities estimated solely on market-price movements (e.g., Edenhofer et al., 2019). On the other hand, tax salience may not only lead to stronger demand reductions but also impede more stringent future policies due to stronger public resistance, such as in the case of the French “Yellow vests” (Douenne and Fabre, 2022). Although there were plans to continuously increase the stringency of the eco tax, the yearly increase was discontinued

in 2003. Our simulation suggests that non-market benefits between 1999 and 2009 would have been around a third higher had the eco tax increase been continued until 2009. Additionally, the important role of tax salience that we document can have implications for instrument choice. Due to inherently fluctuating prices, price salience may likely be less pronounced in the case of emissions trading schemes. As such, increased fuel prices may induce a lower demand response. Investigating the role of salience for demand responses when policy relies on emission trading schemes is especially important given that the European Union has recently decided to introduce a second emissions trading scheme that encompasses the transport sector and that may subsequently replace the current approach in many countries to levy taxes on fuels. Such a shift to emission trading schemes may require more targeted communication and information campaigns to yield comparable demand responses as fuel or carbon taxes.

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Online supporting material

De-fueling externalities: How tax salience and fuel substitution mediate climate and health benefits

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Appendix A Background on the Ecological Tax

Taxing oils and fuels has a long history in Germany; the first mineral oil tax was established in 1939 for gasoil, fuel oil, other mineral oils such as gasoline and petroleum, coal oil as well as their mixtures ([Bundesministerium der Finanzen, 2014](#)). Until the first change of the mineral oil tax law in 1951, the tax amounted to 2.29 cents for a litre of gasoline and 1.68 cents for a litre of diesel (nominal price converted to euros).

The idea of an ecological fiscal reform in Germany was already proposed in the 1980s by [Binswanger \(1992\)](#), who suggested an ecological tax to internalise the externalities from the transport sector by implementing a tax at a low level and raise it until emissions have decreased to an environmentally sustainable level ([Knigge and Görlach, 2005](#)). The idea gained popularity throughout the 1990s until the ecological fiscal reform came into effect in 1999 ([Bundesgesetzblatt I, S.378, 1999](#)). The law was then continued for multiple phases and updated in 2002, where some tax rates were increased and special rules implemented ([Bundesgesetzblatt I, S. 2432., 1999](#); [Bundesgesetzblatt I, S. 4602, 2002](#)). Since then, it has not been changed, implying that taxes on transport fuels have remained the same since 2003 up until the introduction of an explicitly labeled CO₂-price in January 2021.

Figure [A.1](#) shows the nominal mineral oil tax from 1939 to 2009 for gasoline and diesel. For real values and other tax rates, please refer to Appendix [A.2](#) and Appendix [A.3](#). Over time, this law was changed frequently until its name was eventually changed to energy taxation law in 2006 [Bundesministerium der Finanzen \(2014\)](#). This is why we refer to the mineral oil tax as “energy tax” henceforth.

The eco tax reform starting in 1999 was comprised of several areas that are responsible for a large part of CO₂ emissions. Energy taxes were increased for fuels, gas, electricity, and heating oil ([Steiner and Cludius, 2010](#)). Yet, the biggest component was the taxation of fuel. In each year between 1999 and 2003, the fuel tax on gasoline and diesel was increased by 3.07 cents (6 Pfennig) per litre. This led to a total tax increase of 15.35 cents per litre for each fuel and is hereafter referred to as the eco tax. Due to economic and social concerns regarding the eco tax, a lot of exemptions, and special regulations were put in place, such as for manufacturing, industry and agriculture ([Knigge and Görlach,](#)

2005). As these exemptions are fairly extensive, the eco tax only affected the price of fuels and the use of electricity for less energy-intensive industries (Bach, 2009). For this reason, we focus our analysis on the German transport sector only instead of total economy-wide emissions.

As mentioned in the main text, the German eco tax is not a direct carbon tax, as the price is not paid by ton of CO₂ emitted, however, it can be interpreted as one. As of 2020, the total energy tax per litre of gasoline is 65.45 cents (Bundesministerium der Finanzen, 2014). The combustion of one litre of gasoline emits 2.325 kg of CO₂ (US EPA, 2005). If this is taken as a base, the energy tax on gasoline indirectly amounts to 281.51€ per ton of CO₂. The numbers are slightly different for diesel with 2.660 kg of CO₂ emitted as a result of the combustion of one litre and an energy tax of 47.04 cents per litre (US EPA, 2005; Bundesministerium der Finanzen, 2014). Still, this amounts to a price of 176.84€ per ton of CO₂. Prior to the eco tax reform, the energy tax resulted in an indirect carbon tax of 215.53€ per ton of CO₂ for gasoline and 119.17€ for diesel. This means, that the eco tax increased the effective carbon price by 57.67€ (\$65.17) for diesel and 65.98€ (\$74.56) for gasoline between 1999 and 2003. Thereby the eco tax effectively represented the second highest tax on CO₂ in the world at that time.⁵¹

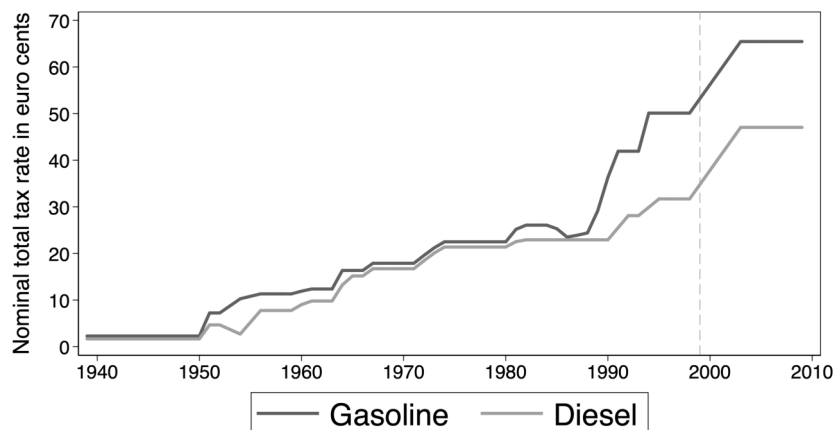


Figure A.1: Nominal taxes of gasoline and diesel from 1939 to 2009 as reported by the Bundesministerium der Finanzen (2014). Note that whenever a Tax changed throughout a year, the average tax is calculated and shown here. Numbers are in cents.

⁵¹The World Bank (2020) counts seven CO₂ taxes in 2003, with the highest in Sweden (\$89.65), followed by Norway (\$44.53). The German eco-tax is not classified.

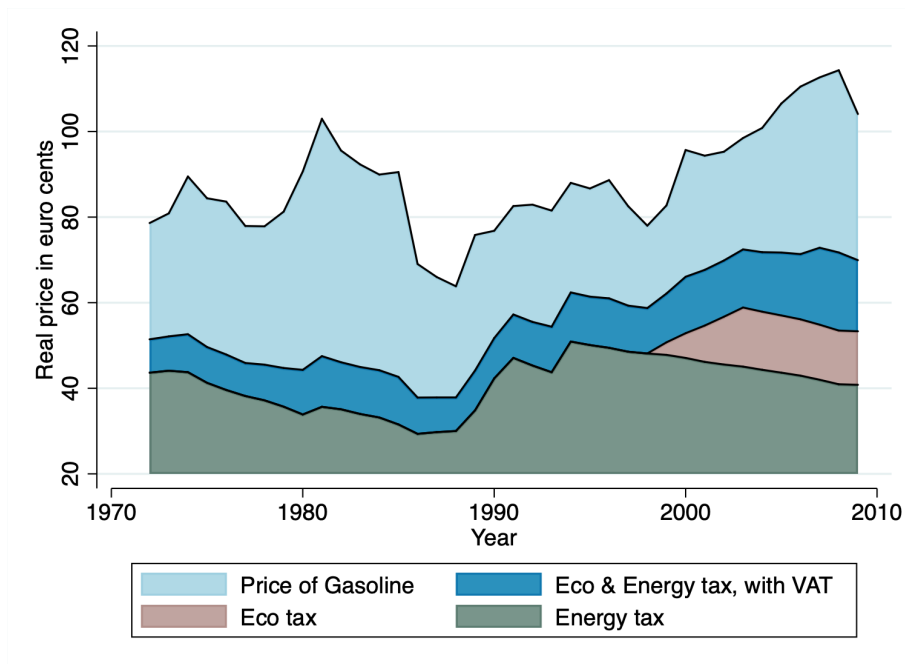


Figure A.2: Real price of gasoline and its tax components from 1972-2009. Prices are in 1995€. Own Calculation.

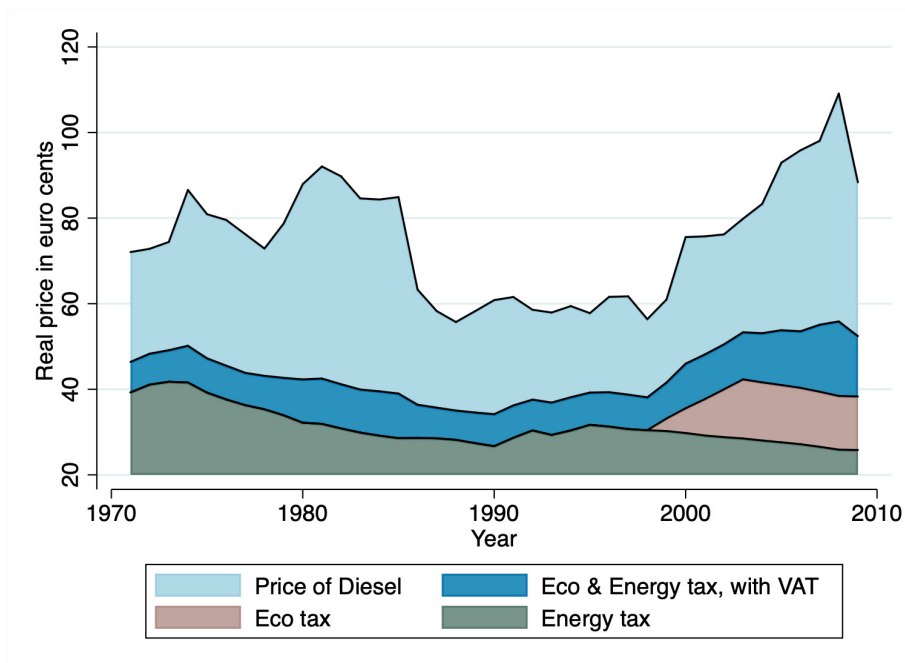


Figure A.3: Real price of Diesel and its tax components from 1971-2009. Prices are in 1995€. Own Calculation.

Appendix B Data Sources

Table B.1: Data Sources

Variable	Source	URL
CO2 emissions from transport (% of total fuel combustion)	Data downloaded from World Bank (their source is the IEA)	https://databank.worldbank.org/reports.aspx?source=2&series=EN.CO2.TRAN.ZS
CO2 emissions from fuel combustion	IEA	https://webstore.iea.org/co2-emissions-from-fuel-combustion-2019-highlights
Population	World Bank	https://databank.worldbank.org/reports.aspx?source=2&series=SP.POP.TOTL
Expenditure-side real GDP at current PPPs (in mil. 2011US\$)	Penn World Tables	www.ggdnc.net/pwt
Urban population (% of total population)	World Bank	https://databank.worldbank.org/reports.aspx?source=2&series=SP.URB.TOTL.IN.ZS
Road sector diesel fuel consumption per capita (kg of oil equivalent)	World Bank	https://databank.worldbank.org/reports.aspx?source=1277&series=IS.ROAD.DESL.PC#
Road sector gasoline fuel consumption per capita (kg of oil equivalent)	World Bank	https://databank.worldbank.org/reports.aspx?source=1277&series=IS.ROAD.DESL.PC#

Table B.2: Data Sources

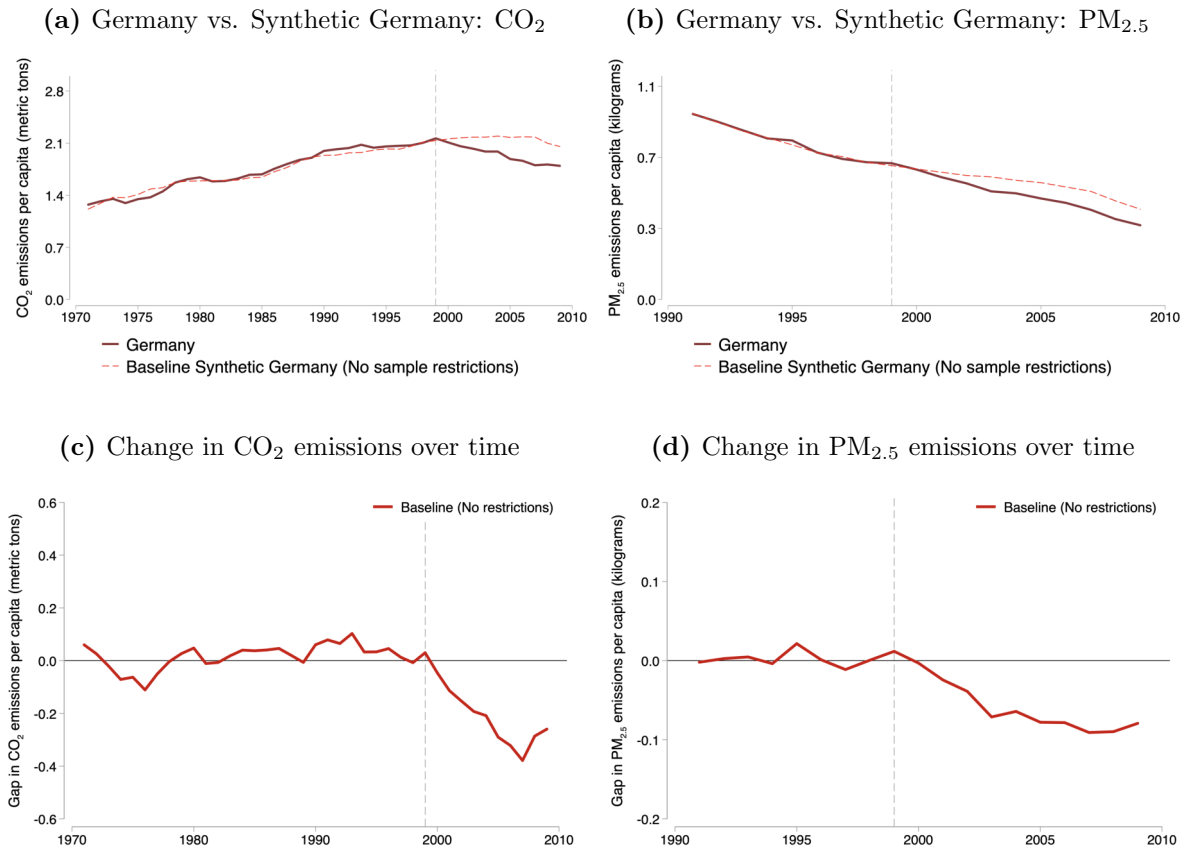
Variable	Source	URL
Vehicles ownership per 1,000 people	Received from Prof. Gately	Dargay, J., Gately, D., & Sommer, M. (2007). Vehicle ownership and income growth, worldwide: 1960-2030. <i>The energy journal</i> , 28(4), 163-190.
Nominal price for gasoline and diesel in Germany. (VAT inclusive in cent/litre)	Mineralwirtschaftsverband (MWV)	https://www.mwv.de/statistiken/verbraucherpreise/
Consumer price index for Germany (1995=100)	Statistisches Bundesamt (Destatis)	https://www.destatis.de/DE/Themen/Wirtschaft/Preise/Verbraucherpreisindex/Publikationen/Downloads-Verbraucherpreise/verbraucherpreisindex-lange-reihen-pdf-5611103.pdf?__blob=publicationFile
Consumer price index for Germany (2015=100)	Statistisches Bundesamt (Destatis)	https://www.destatis.de/DE/Themen/Wirtschaft/Preise/Verbraucherpreisindex/Publikationen/Downloads-Verbraucherpreise/verbraucherpreisindex-lange-reihen-pdf-5611103.pdf?__blob=publicationFile
Strategic Reserve for Gasoline and Diesel in DM/t	Erdölbevorratungsverband	https://www.ebv-oil.org/cms/pdf/beisatz.pdf
Energy Tax for diesel and gasoline in cents per litre	Bundesministerium für Finanzen	https://web.archive.org/web/20141030103421/http://www.bundesfinanzministerium.de/Content/DE/Standardartikel/Themen/Zoll/Energiebesteuerung/Entwicklung_der_Energie_und_Stromsteuersaetze/2009-05-05-geschichte-energie-stromsteuersaetze.pdf?__blob=publicationFile&v=3
Eco Tax for diesel and gasoline in cents per litre	Bundesministerium für Finanzen	https://web.archive.org/web/20141030103421/http://www.bundesfinanzministerium.de/Content/DE/Standardartikel/Themen/Zoll/Energiebesteuerung/Entwicklung_der_Energie_und_Stromsteuersaetze/2009-05-05-geschichte-energie-stromsteuersaetze.pdf?__blob=publicationFile&v=3

Table B.3: Data Sources

Variable	Source	URL
Value-added tax rate	Statista	https://de.statista.com/statistik/daten/studie/164066/umfrage/entwicklung-des-mehrwertsteuersatzes-in-deutschland-ab-1968/
Unemployment Rate in relation to the dependant civilian labour force. Prior to 1991, this data relates to Western Germany only.	Bundesagentur für Arbeit	https://www.google.com/url?sa=t&rcct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwiay5G95e_rAhWEC0wKHUerCxIQFjAAegQIBhAB&url=https%3A%2F%2Fstatistik.arbeitsagentur.de%2Fstatistikdaten%2FDetail%2FAktuell%2Fiia4%2Falo-zeitreihe-dwo%2Falo-zeitreihe-dwo-b-0-xlsx.xlsx&usg=A0vVaw2iaxEeVjgd-tNBXDSQBM04
U.S. Crude Oil First Purchase Price (Dollars per Barrel)	EIA	https://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=F000000_3&f=A
Euro/ECU exchange rates - annual data	Eurostat	http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=ert_bil_eur_a
Officially reported emissions of air pollutants: PM _{2.5} and NO _x	EMEP & EEA	https://www.eea.europa.eu/publications/emep-eea-guidebook-2019
Environmental Stringency Index	OECD	https://stats.oecd.org/Index.aspx?DataSetCode=EPS
Passenger Cars per 1,000	Eurostat	https://ec.europa.eu/eurostat/data/browser/view/ROAD_EQS_CARHAB__custom_4652168/default/table?lang=en
Alternative dataset on NO _x emissions	OECD	https://stats.oecd.org/viewhtml.aspx?datasetcode=AIR_EMISSIONS&lang=en
Emissions from EDGAR	EDGAR	https://edgar.jrc.ec.europa.eu/emissions_data_and_maps

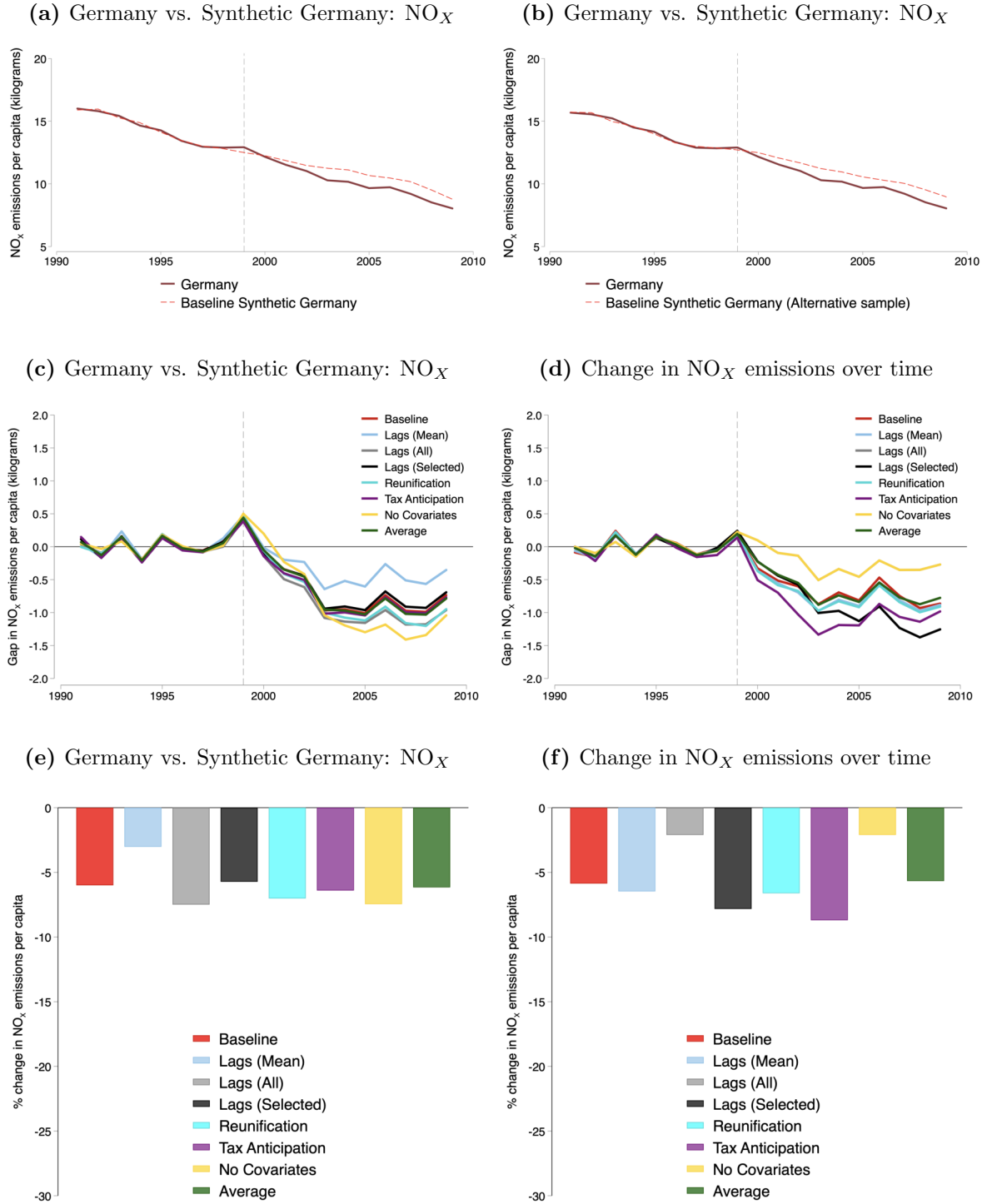
Appendix C Synthetic Control Method: Additional results

Figure C.1: Synthetic Control Method results with no sample restrictions



Notes: The figure plots the estimated reductions in CO₂ and PM_{2.5} emissions relative to a (synthetic) counterfactual development. Panels (a) and (c) refer to reductions in CO₂ emissions per capita expressed in metric tons. Panels (b) and (d) refer to reductions in PM_{2.5} emissions per capita expressed in kilograms. Panels (a) and (b) plot the absolute paths of CO₂ and PM_{2.5} emissions, respectively, in Germany and Synthetic Germany for our *Baseline* specification (see Table 1) when no sample restrictions are applied. Panels (c) and (d) report gaps in CO₂ and PM_{2.5} emissions over time relative to the synthetic counterfactual development. More details on the choice of the predictors used to construct different Synthetic Germanys can be found in Table 1.

Figure C.2: Synthetic Control Method results for NO_X emissions



Notes: The figure plots the estimated reductions in NO_X emissions relative to a (synthetic) counterfactual development. Panels (a) - (d) refer to reductions in NO_X emissions per capita expressed in kilograms. Panels (e) - (f) refer to reductions in NO_X emissions per capita expressed in percentage terms. Panels (a) and (b) plot the absolute paths of NO_X emissions, retrieved from EMEP and the OECD, respectively, in Germany and Synthetic Germany for our *Baseline* specification (see Table 1). Panels (c) and (d) report gaps in NO_X emissions over time relative to the synthetic counterfactual development. Panels (e) and (f) plot the mean percentage reductions in NO_X emissions per capita across the 10 post-treatment years for each specification. More details on the choice of the predictors used to construct different Synthetic Germanies can be found in Table 1.

Table C.1: SCM for CO₂: Pre-Treatment Predictor Means for Germany, Baseline Synthetic Germany and the Sample Average

Variables	Germany	Synthetic	Sample Mean
GDP per capita	22,197.42	23,615.94	17,972.24
Diesel consumption per capita	185.23	185.27	130.29
Gasoline consumption per capita	332.55	332.77	343.23
Share of urban population	0.73	0.73	0.73
Number of vehicles per 1,000 people	410.34	410.48	290.14
CO2 from transport in 1998	2.10	2.10	2.12

All variables except lagged CO₂ per capita are averaged from 1971-1998. GDP per capita is measured at current PPPs in million 2011 US dollars. Gasoline and diesel consumption is measured in kilograms of oil equivalent. Share of urban population is measured as a percentage of total population. CO₂ emissions are measured in metric tons per capita.

Table C.2: SCM for CO₂: Weights of the Donor Countries

Country	Weight	Country	Weight	Country	Weight	Country	Weight
Australia	0.000	Belgium	0.000	Canada	0.000	Chile	0.000
Colombia	0.000	Denmark	0.000	France	0.648	Greece	0.000
Hungary	0.000	Iceland	0.000	Israel	0.000	Korea	0.000
Mexico	0.000	New Zealand	0.066	Poland	0.065	Portugal	0.014
Switzerland	0.203	Turkey	0.000	United States	0.004		

Table C.3: SCM for CO₂ (no sample restrictions): Pre-Treatment Predictor Means for Germany, Synthetic Germany and the Sample Average

Variables	Germany	Synthetic	Sample Mean
GDP per capita	22,197.42	22,183.10	19,678.48
Diesel consumption per capita	185.23	165.46	166.14
Gasoline consumption per capita	332.55	332.29	343.89
Share of urban population	0.73	0.74	0.73
Number of vehicles per 1,000 people	410.34	409.94	320.18
CO2 from transport in 1998	2.10	2.10	2.38

All variables except lagged CO₂ per capita are averaged from 1971-1998. GDP per capita is measured at current PPPs in million 2011 US dollars. Gasoline and diesel consumption is measured in kilograms of oil equivalent. Share of urban population is measured as a percentage of total population. CO₂ emissions are measured in metric tons per capita.

Table C.4: SCM for CO₂ (no sample restrictions): Weights of the Donor Countries

Country	Weight	Country	Weight	Country	Weight	Country	Weight
Australia	0.000	Austria	0.000	Belgium	0.000	Canada	0.000
Chile	0.000	Colombia	0.000	Denmark	0.000	Finland	0.000
France	0.291	Greece	0.000	Hungary	0.000	Ireland	0.000
Iceland	0.098	Israel	0.000	Italy	0.199	Japan	0.000
Korea	0.000	Luxembourg	0.000	Mexico	0.000	Netherlands	0.000
Norway	0.000	New Zealand	0.168	Poland	0.106	Portugal	0.000
Spain	0.000	Sweden	0.000	Switzerland	0.000	Turkey	0.000
United Kingdom	0.000	United States	0.000				

Table C.5: SCM for CO₂ (EDGAR data): Pre-Treatment Predictor Means for Germany, Baseline Synthetic Germany and the Sample Average

Variables	Germany	EDGAR data	Sample Mean
GDP per capita	22,197.42	22,182.2	17,972.24
Diesel consumption per capita	185.23	185.02	130.29
Gasoline consumption per capita	332.55	330.17	343.23
Share of urban population	0.73	0.73	0.73
Number of vehicles per 1,000 people	410.34	409.85	290.14
CO2 from transport in 1998	2.03	2.03	1.87

All variables except lagged CO₂ US dollars. Gasoline and diesel consumption is measured in kilograms of oil equivalent. Share of urban population is measured as a percentage of total population. CO₂ emissions are measured in metric tons per capita and are retrieved from the EDGAR v7.0 database.

Table C.6: SCM for CO₂ (EDGAR data): Weights of the Donor Countries

Country	Weight	Country	Weight	Country	Weight	Country	Weight
Australia	0.008	Belgium	0.003	Canada	0.008	Chile	0.003
Colombia	0.002	Denmark	0.008	France	0.556	Greece	0.005
Hungary	0.005	Iceland	0.133	Israel	0.004	Korea	0.003
Mexico	0.003	New Zealand	0.056	Poland	0.004	Portugal	0.119
Switzerland	0.065	Turkey	0.003	United States	0.011		

Table C.7: SCM for PM_{2.5}: Pre-Treatment Predictor Means for Germany, Baseline Synthetic Germany and the Sample Average

Variables	Treated	Synthetic	Sample Mean
GDP per capita	28,838.54	33,632.16	19,806.97
Diesel consumption per capita	264.03	259.88	176.44
Gasoline consumption per capita	373.79	410.03	251.35
Share of urban population	0.74	0.85	0.70
Non-market stringency	2.5	2.3	1.0
Passenger cars per 1,000 people	480.143	437.95	300.48
PM _{2.5} from transport in 1998	0.676	0.696	0.593

All variables except lagged PM_{2.5} per capita are averaged from 1991-1998. GDP per capita is measured at current PPPs in million 2011 US dollars. Gasoline and diesel consumption is measured in kilograms of oil equivalent. Share of urban population is measured as a percentage of total population. PM_{2.5} emissions are measured in kilograms per capita.

Table C.8: SCM for PM_{2.5}: Weights of the Donor Countries

Country	Weight	Country	Weight	Country	Weight	Country	Weight
Belgium	0.474	Czechia	0.000	Denmark	0.000	Estonia	0.000
France	0.000	Greece	0.000	Hungary	0.000	Iceland	0.000
Poland	0.000	Portugal	0.000	Slovakia	0.000	Slovenia	0.000
Turkey	0.000	Switzerland	0.526				

Table C.9: SCM for PM_{2.5} (no sample restrictions): Pre-Treatment Predictor Means for Germany, Synthetic Germany and the Sample Average

Variables	Treated	Synthetic	Sample Mean
GDP per capita	28,838.54	28,814.77	23,535.79
Diesel consumption per capita	264.03	248.97	263.28
Gasoline consumption per capita	373.79	372.10	324.89
Share of urban population	0.74	0.74	0.72
Non-market stringency	2.5	2.5	1.29
Passenger cars per 1,000 people	480.143	406.10	341.97
PM _{2.5} from transport in 1998	0.676	0.675	0.739

All variables except lagged PM_{2.5} per capita are averaged from 1991-1998. GDP per capita is measured at current PPPs in million 2011 US dollars. Gasoline and diesel consumption is measured in kilograms of oil equivalent. Share of urban population is measured as a percentage of total population. PM_{2.5} emissions are measured in kilograms per capita.

Table C.10: SCM for PM_{2.5} (no sample restrictions): Weights of the Donor Countries

Country	Weight	Country	Weight	Country	Weight	Country	Weight
Austria	0.185	Belgium	0.004	Czechia	0.000	Denmark	0.000
Estonia	0.000	Finland	0.258	France	0.000	Greece	0.000
Hungary	0.000	Ireland	0.000	Iceland	0.000	Italy	0.008
Luxembourg	0.000	Netherlands	0.000	Norway	0.000	Poland	0.000
Portugal	0.000	Slovakia	0.000	Slovenia	0.000	Spain	0.237
Sweden	0.000	Switzerland	0.307	Turkey	0.000	United Kingdom	0.000

Table C.11: SCM for PM_{2.5} (EDGAR data): Pre-Treatment Predictor Means for Germany, Synthetic Germany and the Sample Average

Variables	Germany	EDGAR data	Sample Mean
GDP per capita	22,197.42	22,194.45	17,972.24
Diesel consumption per capita	185.23	168.78	130.29
Gasoline consumption per capita	332.55	431.94	343.23
Share of urban population	0.73	0.73	0.73
Number of vehicles per 1,000 people	410.34	407.03	290.14
PM _{2.5} from transport in 1998	0.58	0.59	0.58

All variables except lagged PM_{2.5} per capita are averaged from 1971-1998. GDP per capita is measured at current PPPs in million 2011 US dollars. Gasoline and diesel consumption is measured in kilograms of oil equivalent. Share of urban population is measured as a percentage of total population. PM_{2.5} emissions are measured in kilograms per capita and are retrieved from the EDGAR v6.1 database.

Table C.12: SCM for PM_{2.5} (EDGAR data): Weights of the Donor Countries

Country	Weight	Country	Weight	Country	Weight	Country	Weight
Australia	0.000	Belgium	0.181	Canada	0.000	Chile	0.000
Colombia	0.000	Denmark	0.000	France	0.000	Greece	0.000
Hungary	0.000	Iceland	0.288	Israel	0.000	Korea	0.000
Mexico	0.000	New Zealand	0.000	Poland	0.000	Portugal	0.284
Switzerland	0.025	Turkey	0.054	United States	0.168		

Table C.13: SCM for NO_X: Pre-Treatment Predictor Means for Germany, Baseline Synthetic Germany and the Sample Average

Variables	Treated	Synthetic	Sample Mean
GDP per capita	28,838.54	29,170.32	19,806.97
Diesel consumption per capita	264.03	256.06	176.44
Gasoline consumption per capita	373.79	349.89	251.35
Share of urban population	0.74	0.78	0.70
Non-market stringency	2.5	2	1.0
Passenger cars per 1,000 people	480.143	403.25	300.48
PM _{2.5} from transport in 1998	0.676	0.72	0.593
NO _X from transport in 1998	12.9	12.8	12.3

All variables except lagged NO_X per capita are averaged from 1991-1998. GDP per capita is measured at current PPPs in million 2011 US dollars. Gasoline and diesel consumption is measured in kilograms of oil equivalent. Share of urban population is measured as a percentage of total population. NO_X emissions are measured in kilograms per capita.

Table C.14: SCM for NO_X: Weights of the Donor Countries

Country	Weight	Country	Weight	Country	Weight	Country	Weight
Belgium	0.309	Czechia	0.000	Denmark	0.160	Estonia	0.000
France	0.000	Greece	0.000	Hungary	0.000	Iceland	0.000
Poland	0.000	Portugal	0.210	Slovakia	0.000	Slovenia	0.000
Turkey	0.000	Switzerland	0.321				

Table C.15: SCM for NO_X (OECD data): Pre-Treatment Predictor Means for Germany, Synthetic Germany and the Sample Average

Variables	Treated	Synthetic	Sample Mean
GDP per capita	28,838.54	28,843.38	24,338.29
Diesel consumption per capita	264.03	261.22	213.97
Gasoline consumption per capita	373.79	364.88	431.56
Share of urban population	0.74	0.74	0.76
Non-market stringency	2.5	1.9	0.97
Number of vehicles per 1,000 people	527.18	504.7	442.86
NO _X from transport in 1998	12.84	12.87	15.68

All variables except lagged NO_X per capita are averaged from 1991-1998. GDP per capita is measured at current PPPs in million 2011 US dollars. Gasoline and diesel consumption is measured in kilograms of oil equivalent. Share of urban population is measured as a percentage of total population. NO_X emissions are measured in kilograms per capita and are retrieved from the OECD.

Table C.16: SCM for NO_X (OECD data): Weights of the Donor Countries

Country	Weight	Country	Weight	Country	Weight	Country	Weight
Australia	0.000	Belgium	0.086	Canada	0.000	Denmark	0.000
France	0.370	Greece	0.000	Hungary	0.000	Iceland	0.000
New Zealand	0.078	Poland	0.000	Portugal	0.137	Turkey	0.000
Switzerland	0.329	United States	0.000				

Table C.17: SCM for NO_X (EDGAR data): Pre-Treatment Predictor Means for Germany, Synthetic Germany and the Sample Average

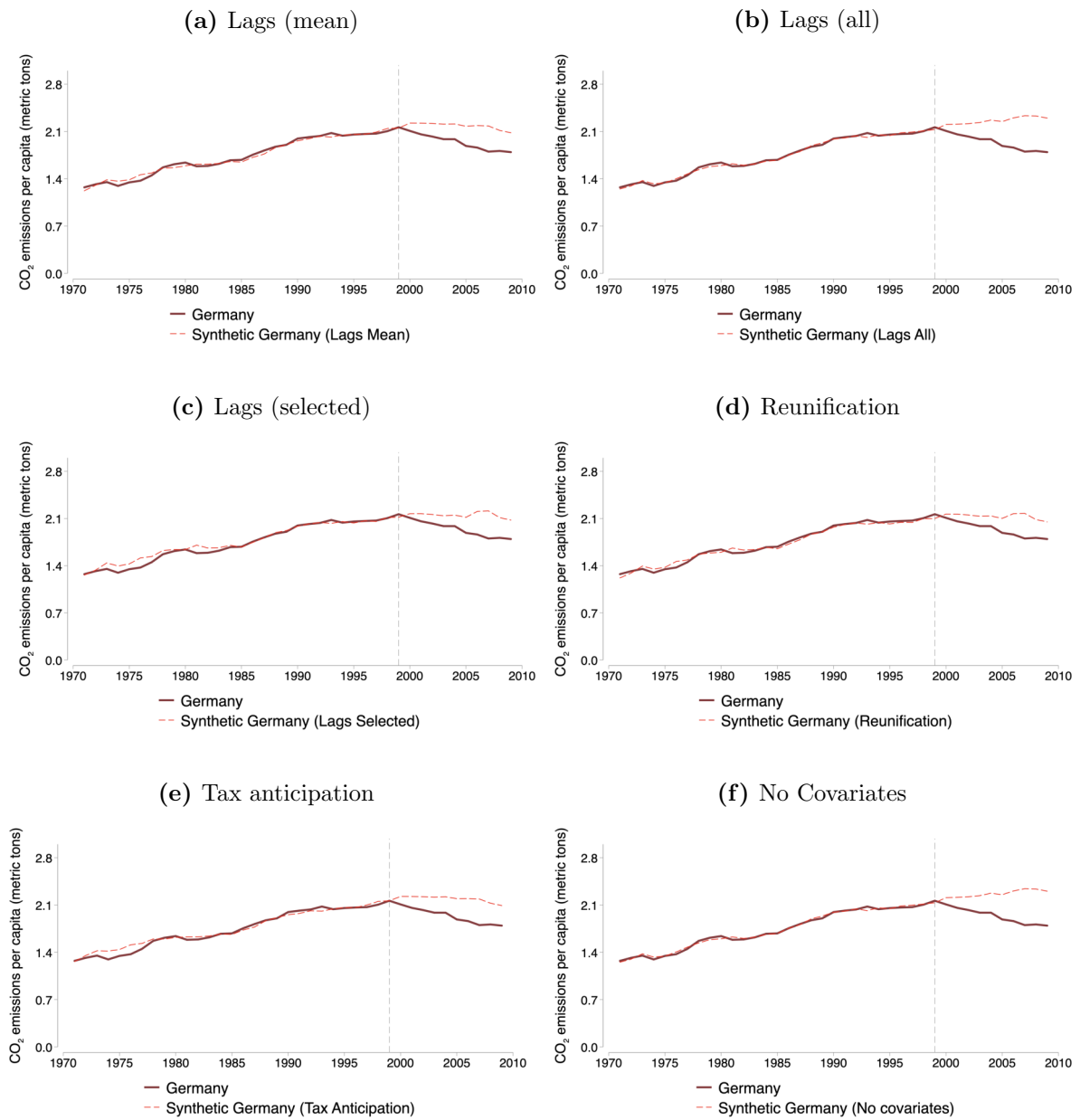
Variables	Germany	EDGAR data	Sample Mean
GDP per capita	22,197.42	23,978.59	17,972.24
Diesel consumption per capita	185.23	170.13	130.29
Gasoline consumption per capita	332.55	323.02	343.23
Share of urban population	0.73	0.73	0.73
Number of vehicles per 1,000 people	410.34	370.51	290.14
PM _{2.5} from transport in 1998	0.58	0.59	0.58
NO _X from transport in 1998	14.13	14.37	16.72

All variables except lagged NO_X per capita are averaged from 1971-1998. GDP per capita is measured at current PPPs in million 2011 US dollars. Gasoline and diesel consumption is measured in kilograms of oil equivalent. Share of urban population is measured as a percentage of total population. NO_X emissions are measured in kilograms per capita and are retrieved from the EDGAR v6.1 database.

Table C.18: SCM for NO_X (EDGAR data): Weights of the Donor Countries

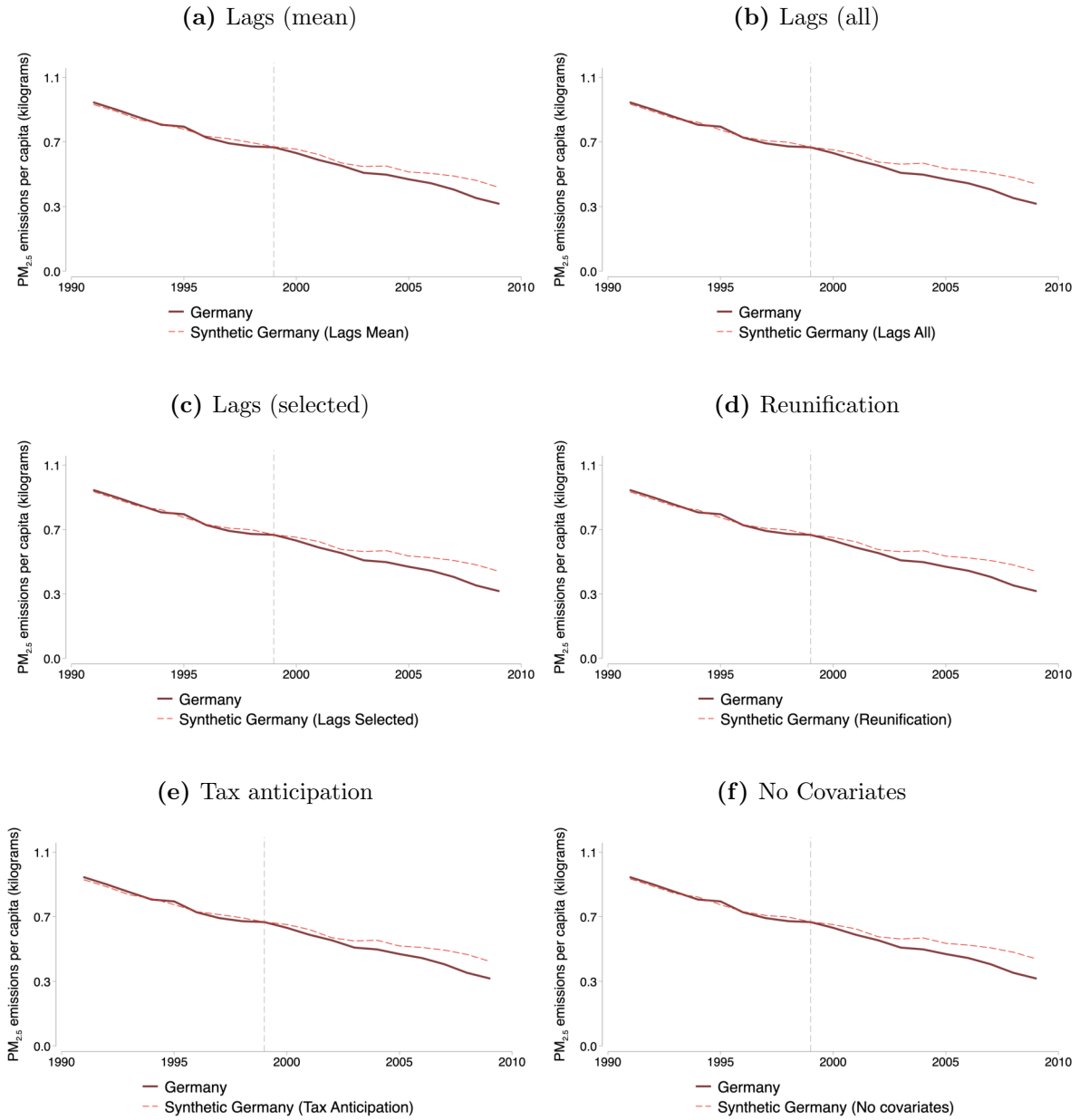
Country	Weight	Country	Weight	Country	Weight	Country	Weight
Australia	0.000	Belgium	0.341	Canada	0.000	Chile	0.000
Colombia	0.000	Denmark	0.000	France	0.016	Greece	0.000
Hungary	0.000	Iceland	0.000	Israel	0.000	Korea	0.000
Mexico	0.000	New Zealand	0.000	Poland	0.000	Portugal	0.288
Switzerland	0.322	Turkey	0.003	United States	0.032		

Figure C.3: Synthetic Control Method CO₂ path plots for different specifications



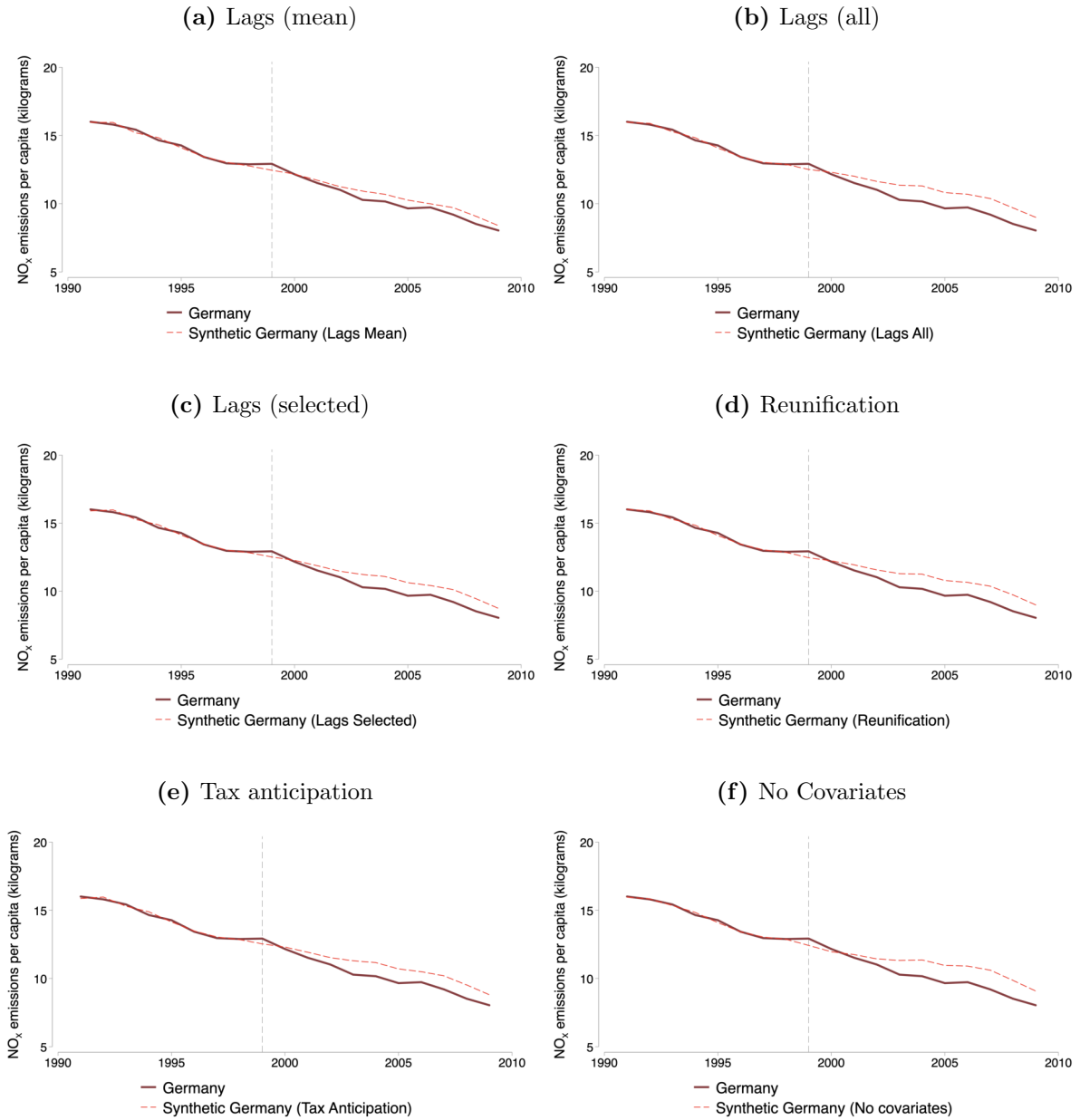
Notes: The figure plots the estimated reductions in CO₂ emissions expressed in metric tons per capita relative to a (synthetic) counterfactual development. Panels (a) and (f) plot the absolute paths of CO₂ emissions in Germany and Synthetic Germany for our set of additional specifications (see Table 1). More details on the choice of the predictors used to construct different Synthetic Germanies can be found in Table 1.

Figure C.4: Synthetic Control Method $PM_{2.5}$ path plots for different specifications



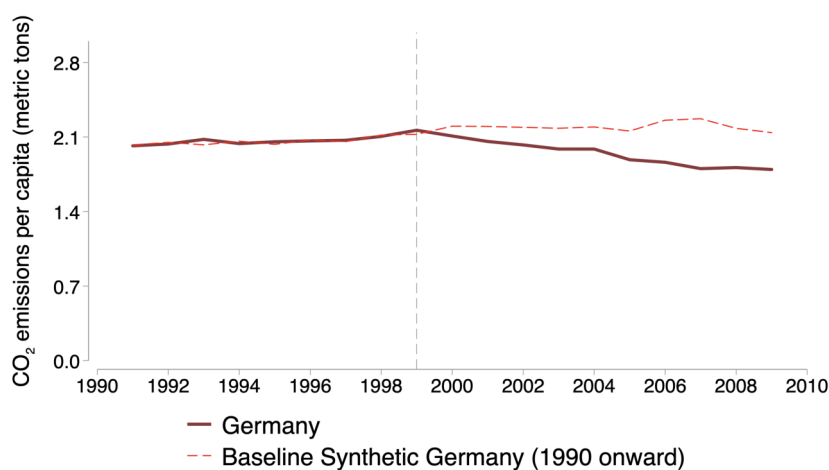
Notes: The figure plots the estimated reductions in $PM_{2.5}$ emissions expressed in metric tons per capita relative to a (synthetic) counterfactual development. Panels (a) and (f) plot the absolute paths of $PM_{2.5}$ emissions in Germany and Synthetic Germany for our set of additional specifications (see Table 1). More details on the choice of the predictors used to construct different Synthetic Germanies can be found in Table 1.

Figure C.5: Synthetic Control Method NO_x path plots for different specifications



Notes: The figure plots the estimated reductions in NO_x emissions expressed in metric tons per capita relative to a (synthetic) counterfactual development. Panels (a) and (f) plot the absolute paths of NO_x emissions in Germany and Synthetic Germany for our set of additional specifications (see Table 1). More details on the choice of the predictors used to construct different Synthetic Germanies can be found in Table 1.

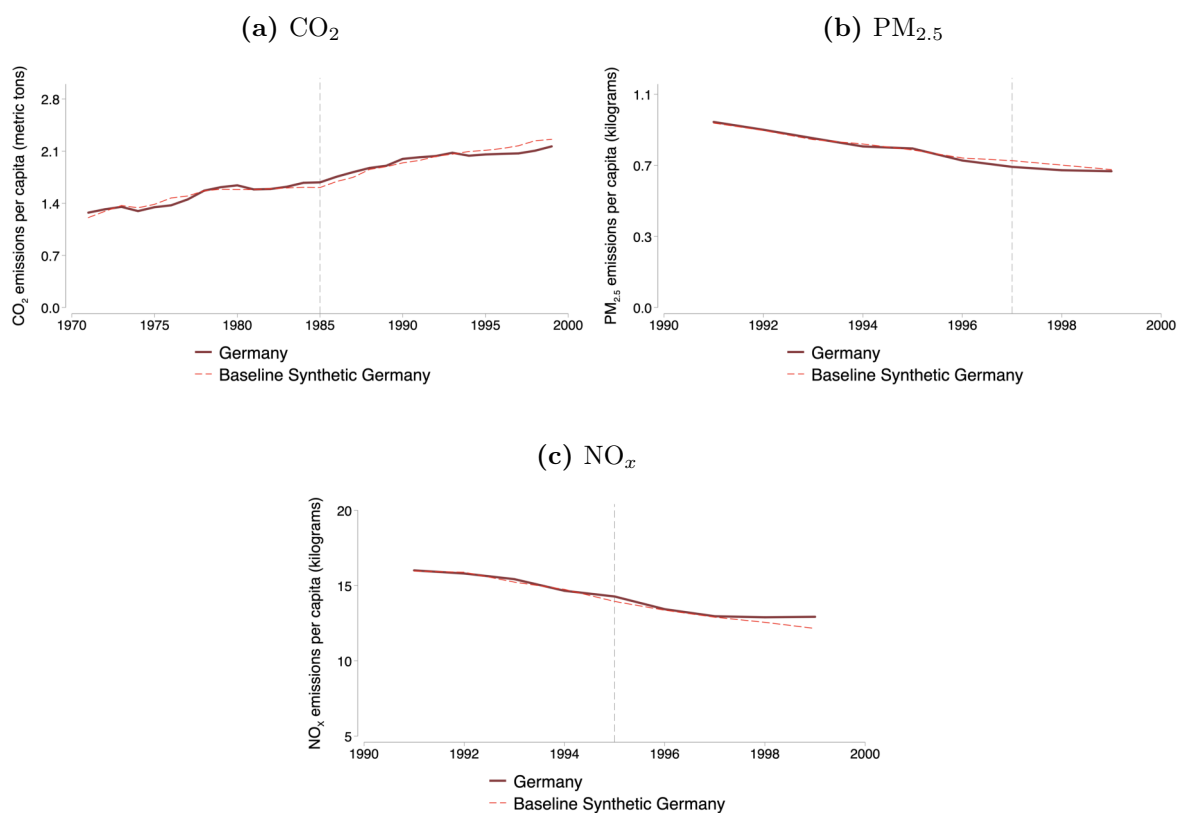
Figure C.6: Shorter time frame for CO₂ effects



Notes: The figure plots the estimated reductions in NO_x emissions expressed in metric tons per capita relative to a (synthetic) counterfactual development. The figure above plots the absolute paths of CO₂ emissions in Germany and Baseline Synthetic Germany relying on a shorter pre-treatment period that spans from 1991 to 1998.

C.1 Placebo in time

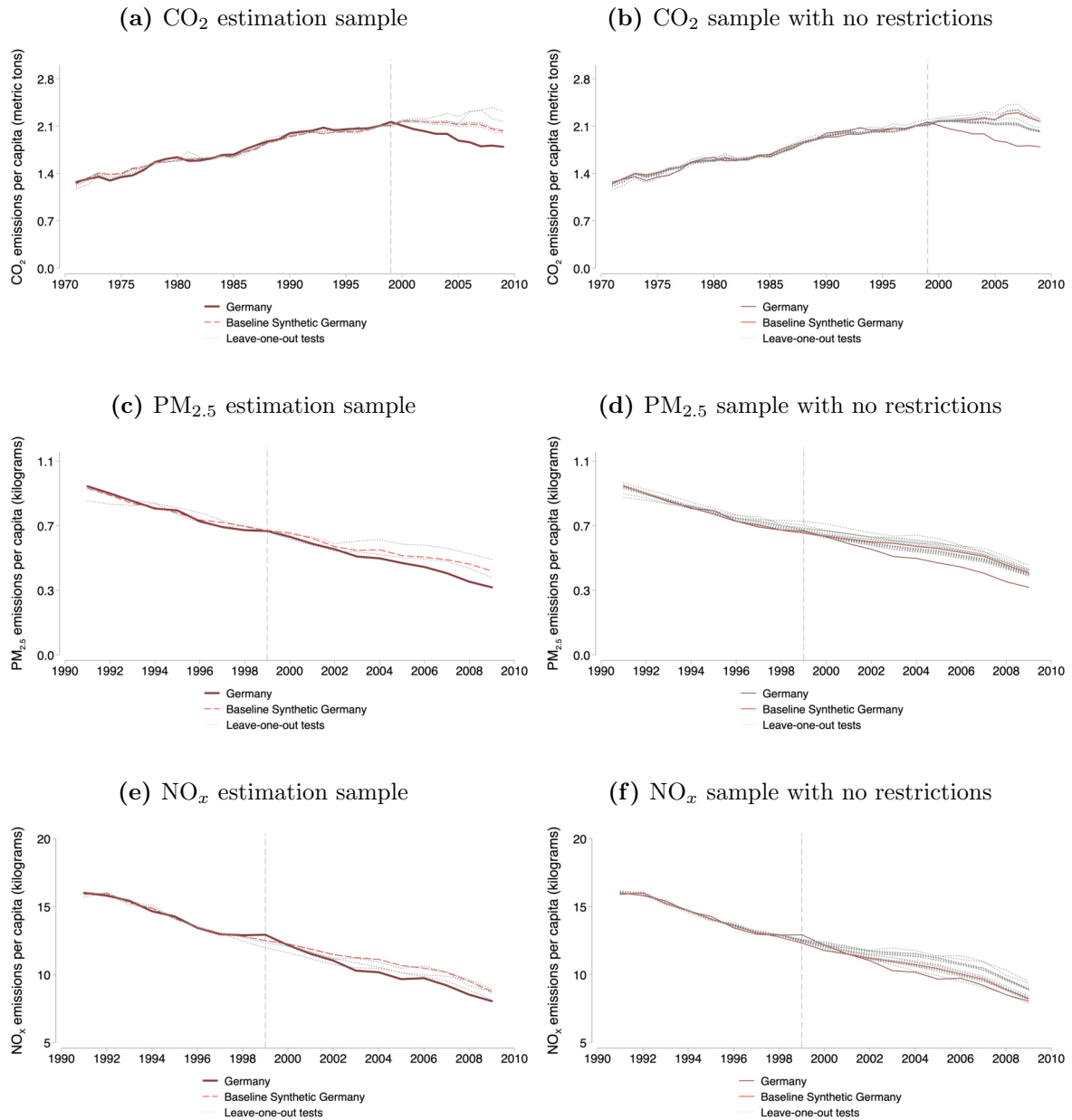
Figure C.7: In-time placebos



Notes: The figure plots the in-time placebo for our results on (a) CO₂, (b) PM_{2.5}, and (c) NO_x emissions. Panel (a) assigns the placebo treatment in 1985. Panel (b) assigns the placebo treatment in 1997. Panel (c) assigns the placebo treatment in 1995.

C.2 Leave-one-out tests

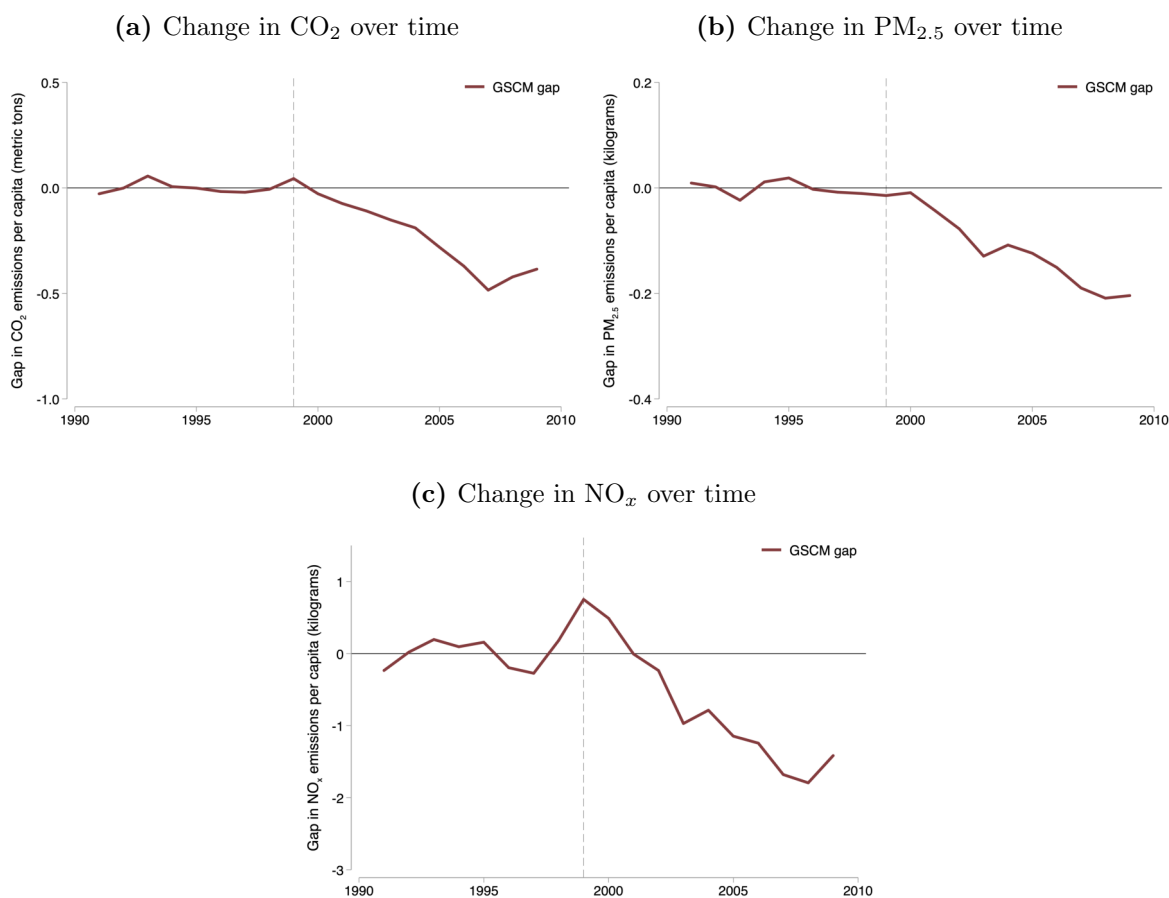
Figure C.8: Leave-one-out tests



Notes: The figure plots leave-one-out tests following [Abadie et al. \(2015\)](#). Panel (a), (c), and (d) are based on the estimation sample and iteratively exclude countries that receive at least a 1% in the construction of the synthetic counterfactual. Panels (b), (d), and (f) are based on the unrestricted sample and sequentially exclude each country in the donor pool. More details can be found in Section 4.1.

C.3 Generalized Synthetic Control Method (GSCM)

Figure C.9: GSCM with Interactive Fixed Effects Models



Notes: The figure plots the estimated gaps in emissions relative to a synthetic counterfactual development based on a Generalized Synthetic Control Method with interactive fixed effects models [Xu \(2017\)](#).

C.4 SCM results with EDGAR data (1971-2009)

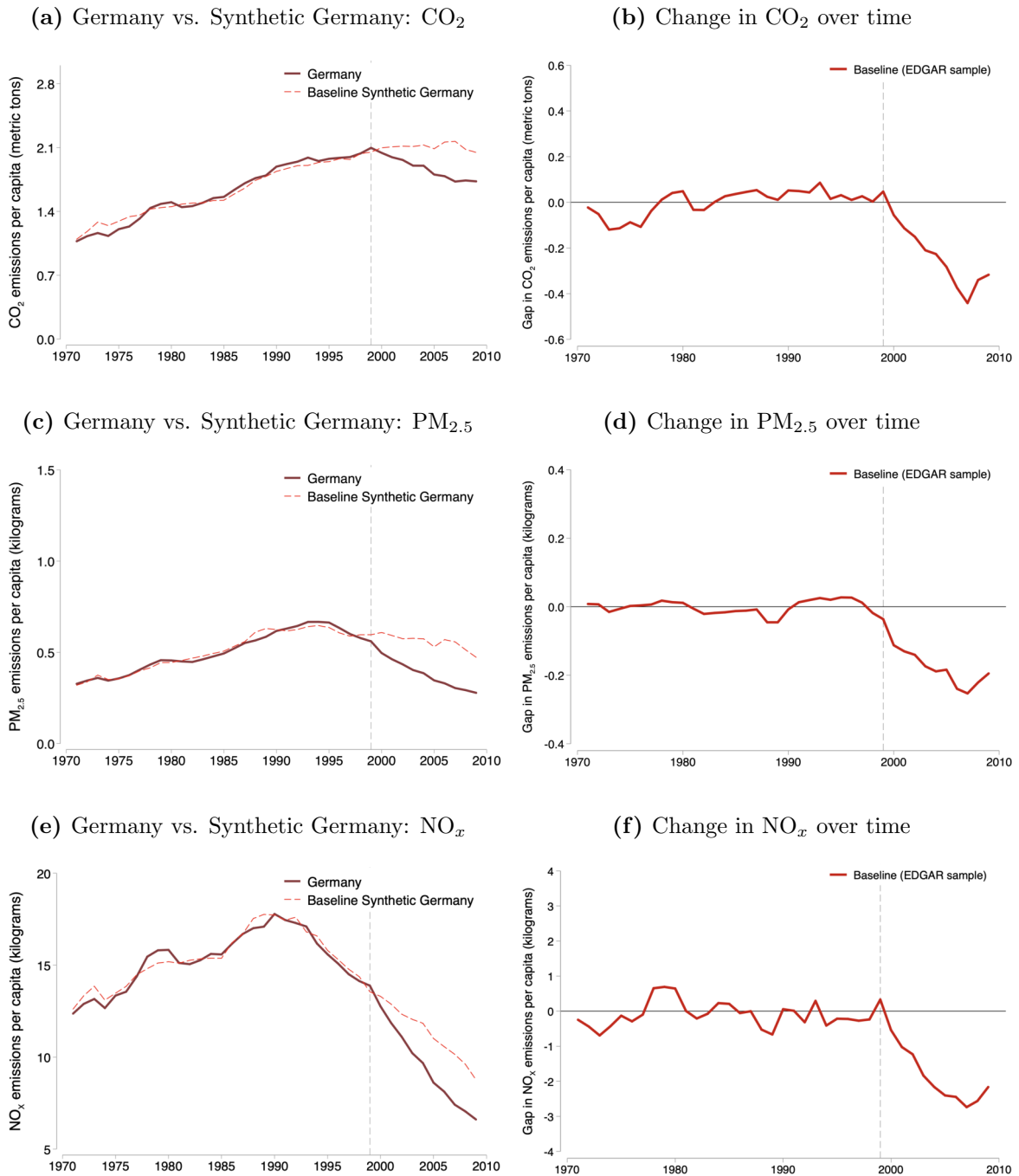
Figure [C.10](#) and [C.11](#) report our SCM results (c.f. Section [2.1](#)) based on emission data retrieved from the EDGAR v6.1 (for air pollutants) and v7.0 (for carbon emissions) database.

The EDGAR database compiles greenhouse gas (GHG) and air pollutant emissions from all countries worldwide, covering all anthropogenic activities except for Land Use, Change and Forestry (LULUCF). It follows a consistent methodology and employs a bottom-up approach to quantify emissions drawing on multiple sources. Independent global sets of activity data, such as the IEA's energy balances, provide detailed fuel usage information, including up to 68 vectors for road transport. This data is available

for 155 countries, while figures for the remaining countries are reported at the regional level. To scale down emissions from regions to national levels, data from the Energy Information Administration (EIA) is utilized, using country-level shares in total regional fuel consumption data for aggregated fuel categories.

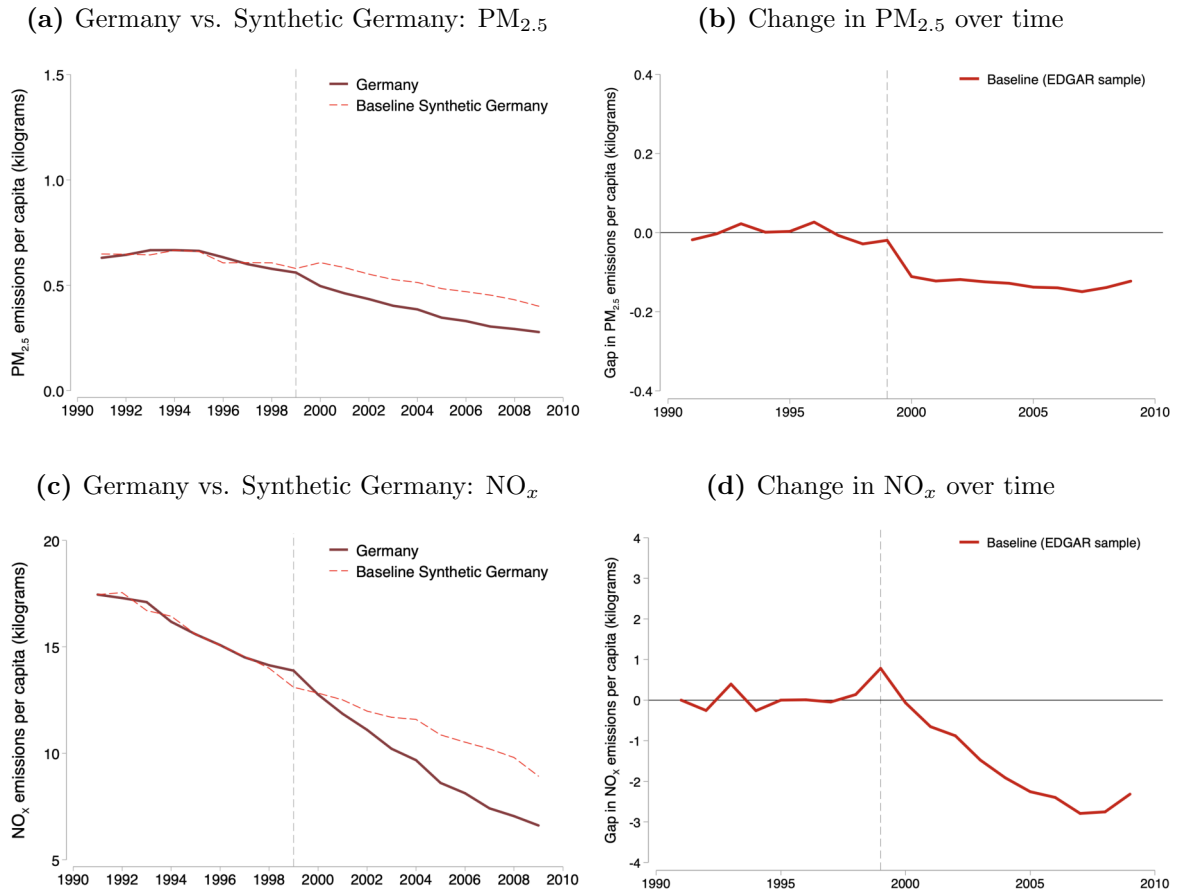
In the EDGAR database, emission factors are selected to be as representative as possible. Whenever available, technology-based emission factors tailored to specific countries or regions (Tier 2) are incorporated. In their absence, fuel-specific or globally based values suggested in the IPCC Guidelines for National Greenhouse Gas Inventories from 1996 and 2006 are considered. For more detailed information on the EDGAR v6.1 database, additional details can be found here: https://edgar.jrc.ec.europa.eu/dataset_ap61#sources.

Figure C.10: Synthetic Control method with EDGAR data



Notes: The figure plots the estimated reductions in CO₂, PM_{2.5}, and NO_x emissions relative to a (synthetic) counterfactual development constructed by relying on the EDGAR v6.1 database. Panels (a) and (b) refer to reductions in CO₂ emissions per capita expressed in metric tons. Panels (c) and (d) refer to reductions in PM_{2.5} emissions per capita expressed in kilograms. Panels (e) and (f) refer to reductions in NO_x emissions per capita expressed in kilograms. Panels (a), (c), and (e) plot the absolute paths of CO₂, PM_{2.5}, and NO_x emissions, respectively, in Germany and Synthetic Germany for our *Baseline* specification (see Table 1) when relying on the EDGAR database. Panels (b), (d), and (f) report the associated gaps in emissions over time relative to the synthetic counterfactual development. More details on the choice of the predictors used to construct different Synthetic Germanys can be found in Table 1.

Figure C.11: Synthetic Control method with EDGAR data (1991-2009)



Notes: The figure plots the estimated reductions in $PM_{2.5}$ and NO_x emissions relative to a (synthetic) counterfactual development constructed by relying on the EDGAR v6.1 database. Panels (a) and (b) refer to reductions in $PM_{2.5}$ emissions per capita expressed in kilograms. Panels (c) and (d) refer to reductions in NO_x emissions per capita expressed in kilograms. Panels (a) and (c) plot the absolute paths of $PM_{2.5}$ and NO_x emissions, respectively, in Germany and Synthetic Germany for our *Baseline* specification (see Table 1) when relying on a shorter pre-intervention period that spans from 1991 to 1998. Panels (b) and (d) report the associated gaps in emissions over time relative to the synthetic counterfactual development. More details on the choice of the predictors used to construct different Synthetic Germanies can be found in Table 1.

Appendix D Elasticities

Table D.1: Comparison of Gasoline Elasticities: Real Price Elasticity, Aggregate Tax Elasticity, and Eco-Tax Elasticity. The dependent variable is the log of gasoline demand. OLS regression results are displayed for all specifications; A,B and C. All prices are in real terms in 1995€ and include the VAT. Newey-West standard errors in parenthesis, lags are calculated using the [Newey and West \(1994\)](#) method. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.010$.

	Real Price Elasticity	Specification B	Specification C
Real price of Gasoline	-0.00603** (0.00279)		
Gasoline price (only VAT)		-0.00584* (0.00323)	-0.00357* (0.00197)
Energy + Eco Tax		-0.00798* (0.00430)	
Energy Tax on Gasoline			-0.00242 (0.00503)
Eco Tax on Gasoline			-0.0306*** (0.00774)
Dummy Eco Tax	-0.154 (0.130)	-0.144 (0.133)	0.104** (0.0409)
Trend	0.00158 (0.0139)	-0.00328 (0.0122)	0.0240 (0.0219)
GDP per capita	0.000000174 (0.0000116)	0.00000893 (0.0000168)	-0.0000245 (0.0000320)
Unemployment rate	0.0292 (0.0178)	0.0311* (0.0174)	0.00902 (0.0243)
N	38	38	38

Table D.2: Real Price Elasticity of Gasoline demand from 1991-2009. Dependent variable is the log of gasoline consumption in liters per capita. Prices are in 1995€. Column 4 shows the results for the IV regression, using the Brent crude oil price as an instrument for the real gasoline price. Newey-West standard errors in parenthesis. $p < 0.10$, ** $p < 0.05$, *** $p < 0.010$.

	OLS	OLS	OLS	IV
Real price of Gasoline	-0.00698*** (0.00141)	-0.00693*** (0.00145)	-0.00510*** (0.000554)	-0.00531*** (0.000640)
Dummy Eco Tax	0.105*** (0.0350)	0.106*** (0.0318)	0.106*** (0.0144)	0.106*** (0.0135)
Trend	-0.0237*** (0.00691)	-0.0217* (0.0105)	-0.0336*** (0.00483)	-0.0332*** (0.00505)
GDP per capita		-0.00000311 (0.00000624)	0.00000795 (0.00000545)	0.00000793 (0.00000575)
Unemployment rate			0.0181*** (0.00251)	0.0178*** (0.00268)
N	19	19	19	19

Table D.3: Comparison of Diesel Elasticities: Real Price Elasticity, Aggregate Tax Elasticity, and Eco-tax Elasticity. The dependent variable is the log of gasoline demand. OLS regression results are displayed for all specifications; A,B and C. All prices are in real terms in 1995€ and include the VAT. Newey-West standard errors in parenthesis, lags are calculated using the [Newey and West \(1994\)](#) method. $p < 0.10$, ** $p < 0.05$, *** $p < 0.010$.

	Real Price Elasticity	Specification B	Specification C
Real price of Diesel	-0.00440*** (0.00103)		
Diesel price (only VAT)		-0.00384*** (0.000901)	-0.00346*** (0.00104)
Energy + Eco Tax		-0.0111*** (0.00139)	
Energy Tax on Diesel			-0.00729** (0.00284)
Eco Tax on Diesel			-0.0143*** (0.00361)
Dummy Eco Tax	-0.0205 (0.0564)	0.0574* (0.0307)	0.0794*** (0.0172)
Trend	0.0189*** (0.00587)	0.0104** (0.00430)	0.0187** (0.00752)
GDP per capita	0.0000177*** (0.00000522)	0.0000287*** (0.00000677)	0.0000201*** (0.00000724)
Unemployment rate	0.0107* (0.00560)	0.0104* (0.00525)	0.00651 (0.00811)
N	39	39	39

Table D.4: Real Price Elasticity of Diesel demand from 1991-2009. Dependent variable is the log of diesel consumption in liters per capita. Prices are in 1995€. Column 4 shows the results for the IV regression, using the brent crude oil price as an instrument for the real diesel price. Newey-West standard errors in parenthesis. $p < 0.10$, ** $p < 0.05$, *** $p < 0.010$.

	(1)	(2)	(3)	(4)
	OLS	OLS	OLS	IV
Real price of Diesel	-0.00404** (0.00159)	-0.00456*** (0.00111)	-0.00358*** (0.000320)	-0.00317*** (0.000315)
Dummy Eco Tax	0.0687*** (0.0144)	0.0635*** (0.0159)	0.0634*** (0.0102)	0.0632*** (0.00961)
Trend	0.0206*** (0.00591)	0.0108 (0.00664)	0.00457* (0.00254)	0.00384* (0.00227)
GDP per capita		0.0000172*** (0.00000382)	0.0000217*** (0.00000343)	0.0000211*** (0.00000235)
Unemployment rate			0.0104** (0.00373)	0.0113*** (0.00378)
N	19	19	19	19

Figure D.1: Total fuel consumption over time

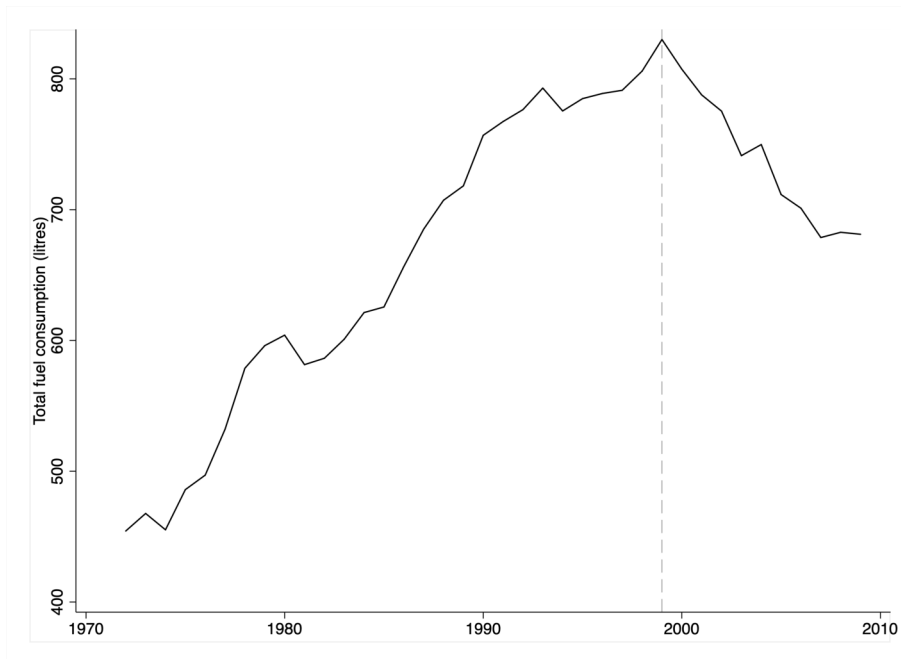


Figure D.2: Total fuel consumption by fuel type

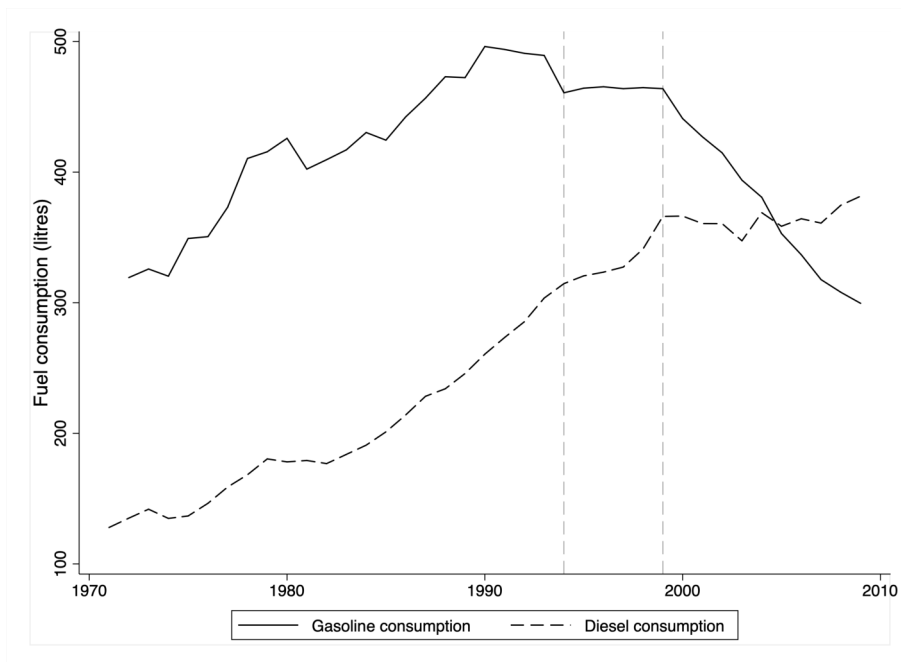


Figure D.3: Diesel-to-gasoline ratio

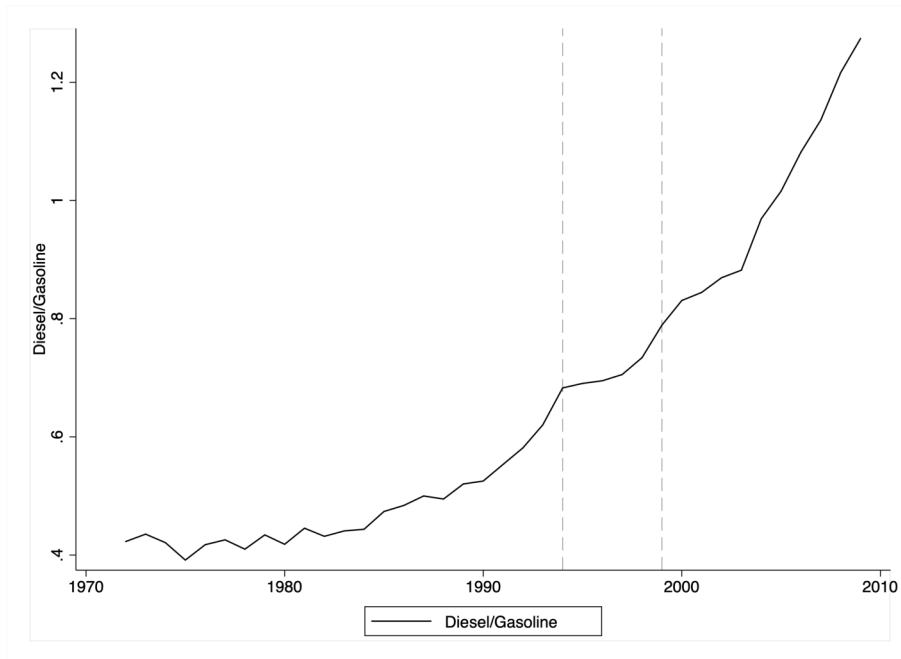


Figure D.4: Share of diesel and gasoline consumption

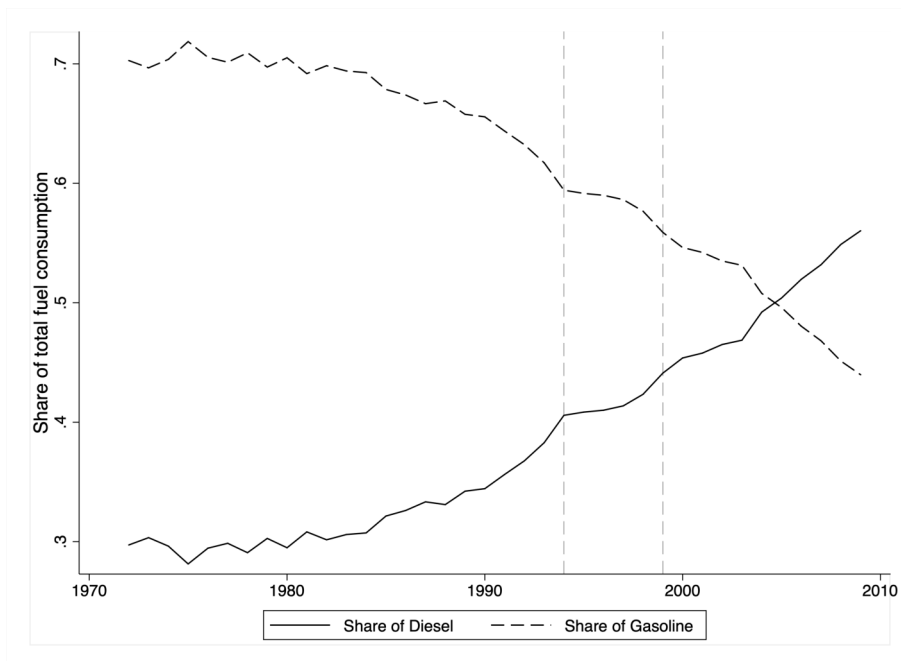
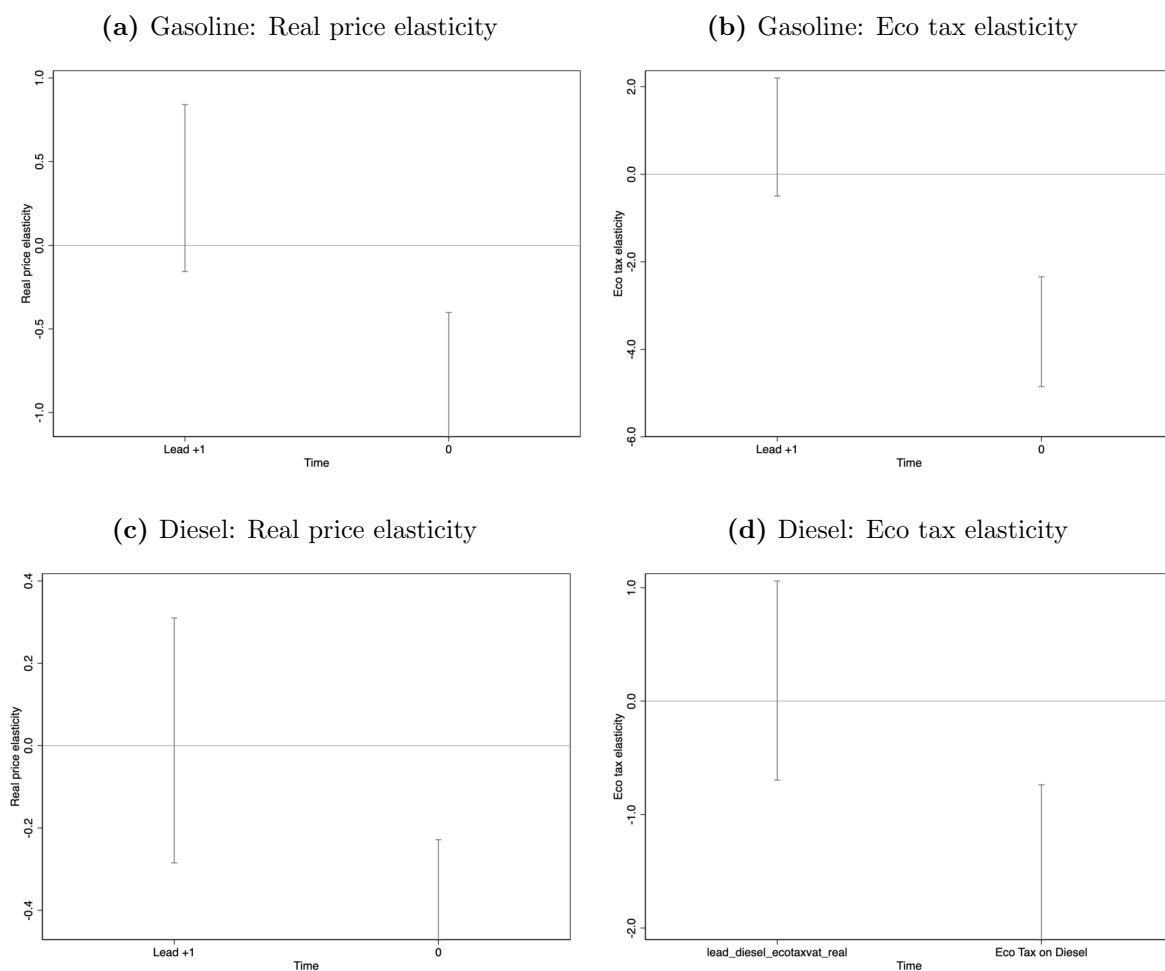
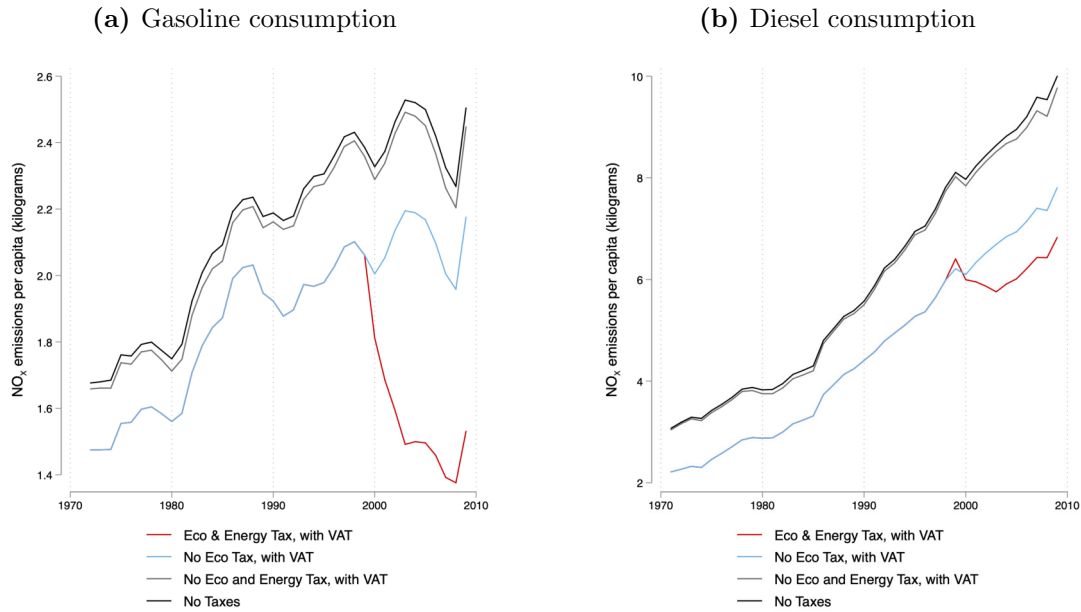


Figure D.5: Diesel and gasoline real price and eco tax elasticities with a lead



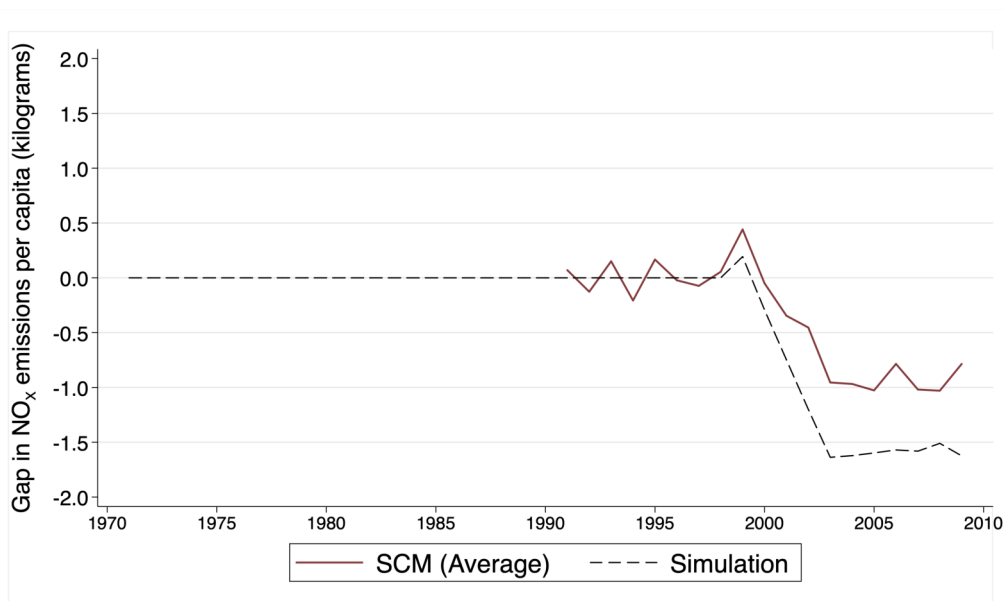
Notes: The figure plots the estimated fuel-specific elasticities of gasoline and diesel demand by amending our log-level semi-elasticity models with the introduction of a lead (c.f. Section 2.2). Specifically, Panel (a) and (c) show the real price elasticity of gasoline and diesel demand respectively (c.f. Table 2b and 2a). Panel (b) and (d) display the gasoline and diesel eco tax elasticities (c.f. Table 3b and 3a). Prices are in 1995€. Results for gasoline consumption refer to 1972-2009 due to missing price data prior to 1972. Unemployment is measured as percentage of total labor force. Confidence intervals are based on Newey-West standard errors are heteroskedasticity and autocorrelation robust. Standard errors are calculated relying on the automatic bandwidth selection procedure following Newey and West (1994). * $p < 0.05$, ** $p < 0.01$, ***

Figure D.6: Estimated NO_x emissions by fuel under different taxation scenarios



Notes: The figures above plot predicted emissions from the eco-tax specification of our log-level semi-elasticity models (c.f. Section 2.2) under different taxation scenarios. We rely the estimated fuel-specific price and tax elasticities computed from our estimates from column (3) in Tables 3a and 3b. Panel (a) refers to predicted emissions from gasoline consumption, while Panel (b) covers diesel consumption. In each panel the y-axis refers to per capita NO_x in kilograms. The top black line displays predicted emissions when the eco and energy tax elasticities are set to zero, and VAT is deducted from the fuel price. For the gray line, the eco and energy tax elasticities are set to zero but VAT is included. The light blue line shows how predicted emissions change when the eco tax is set to zero, but we include the energy tax and VAT. The red line provides predicted emissions using the full model with differentiated tax and price elasticities.

Figure D.7: Gap in per capita NO_x emissions: SCM vs Simulation Approach



Notes: The figure above plot the estimated average gap in per capita NO_x emissions from our synthetic control experiment (c.f. Section 2.1) and the simulation approach based on our log-level semi-elasticity models (c.f. Section 2.2). Nationwide reductions in emissions in the simulation approach have been computed by accounting for predicted emission reductions from both gasoline and diesel.

Table D.5: Fuel substitution: Diesel-to-Gasoline ratio

	(1)	(2)	(3)
	Diesel/Gasoline	Diesel/Gasoline	Diesel/Gasoline
Gasoline price, only VAT	0.00187 (0.00245)	0.00185 (0.00126)	0.00184 (0.00128)
Energy Tax on Gasoline	0.00471*** (0.00123)	-0.000316 (0.00263)	0.000991 (0.00235)
Eco Tax on Gasoline	0.0175*** (0.00628)	0.0157*** (0.00462)	0.0126** (0.00493)
Dummy Eco Tax	-0.0108 (0.0254)	-0.0619** (0.0287)	-0.0377 (0.0235)
Trend	0.0126*** (0.00312)	-0.00700 (0.00701)	0.00671 (0.0151)
GDP per capita		0.0000372** (0.0000151)	0.0000214 (0.0000186)
Unemployment rate			-0.0142 (0.0173)
N	38	38	38

Notes: Dependent variable is the ratio of diesel-to-gasoline consumption in litres per capita. Prices are in 1995€. Results for gasoline consumption refer to 1972-2009 due to missing price data prior to 1972. Unemployment is measured as percentage of total labor force. Newey-West standard errors in parentheses are heteroskedasticity and autocorrelation robust. Standard errors are calculated relying on the automatic bandwidth selection procedure following [Newey and West \(1994\)](#). * $p < 0.05$, ** $p < 0.01$, ***

Table D.6: Fuel substitution: Share of Diesel

	(1)	(2)	(3)
	Share of Diesel	Share of Diesel	Share of Diesel
Gasoline price, only VAT	0.000255 (0.000574)	0.000250 (0.000319)	0.000248 (0.000321)
Energy Tax on Gasoline	0.00179*** (0.000393)	0.000697 (0.000649)	0.000917 (0.000713)
Eco Tax on Gasoline	0.00415*** (0.00143)	0.00376*** (0.00109)	0.00325*** (0.00110)
Dummy Eco Tax	0.00367 (0.00578)	-0.00746 (0.00723)	-0.00339 (0.00617)
Trend	0.00482*** (0.000744)	0.000554 (0.00169)	0.00286 (0.00379)
GDP per capita		0.00000810** (0.00000357)	0.00000546 (0.00000493)
Unemployment rate			-0.00239 (0.00425)
N	38	38	38

Notes: Dependent variable is the share of diesel of total fuel consumption (in percentage points). Prices are in 1995€. Results for gasoline consumption refer to 1972-2009 due to missing price data prior to 1972. Unemployment is measured as percentage of total labor force. Newey-West standard errors in parentheses are heteroskedasticity and autocorrelation robust. Standard errors are calculated relying on the automatic bandwidth selection procedure following [Newey and West \(1994\)](#). * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Appendix E Salience analysis

The following section provides additional information on the salience analysis conducted in Section 5.4. This Appendix is structured in three parts. First, we report the different search strategies that were used to extract frequency counts of newspapers' articles from Factiva. Second, we provide a detailed description of the construction of our set of newspaper-based indices that were employed in the empirical analysis. Finally, we present a set of robustness checks for our empirical analysis of salience effects presented in Section 5.4.

E.1 Search strategies

Here below, we report the three different search strategies that were developed to download articles' count used in the construction of our indices. A brief description of each strategy will follow. *Strategy 1* is an empty search to capture the total number of articles published by each newspaper in a given year (i.e., general newspaper-specific publishing trends). We use these newspaper-specific counts to observe fluctuations in publishing trends over time and produce descriptive evidence to guide the time focus of our empirical analyses. *Strategy 2* restricts our search to articles talking about environmental/ecological taxation. This provides us with a clearer idea of publishing trends directly related to environmental taxation and will be used to scale frequency counts of a more targeted search strategy that specifically captures price salience. Finally, *Strategy 3* is employed to identify articles talking about environmental/ecological taxation *and* resulting increases in fuel prices. Here, we use a double AND operator to impose that at least one keyword from each of the brackets that come after the operator must appear in the article.

Strategy 1: Publishing trends. Total number of articles published in a given newspaper.

Strategy 2: Environmental taxation trends. (Ökosteuer* or "Ökologische Steuerreform" or Umweltsteuer* or "Ökologische Finanzreform" or Umweltabgabe*)

Strategy 3: Eco tax price salience. (Ökosteuer* or "Ökologische Steuerreform")

or Umweltsteuer* or "Ökologische Finanzreform" or Umweltabgabe*) AND (Dieselpreis or Benzinpreis) AND (Preissteigerung or Preisanstieg or Preiserhöhung or Anstieg or ansteigen or steigen or zunehmen or Zunahme or Erhöhung or erhöhen or anheben or aufschlagen or Aufschlag or angestiegen or zugenommen or erhöht* or angehoben or aufgeschlagen)

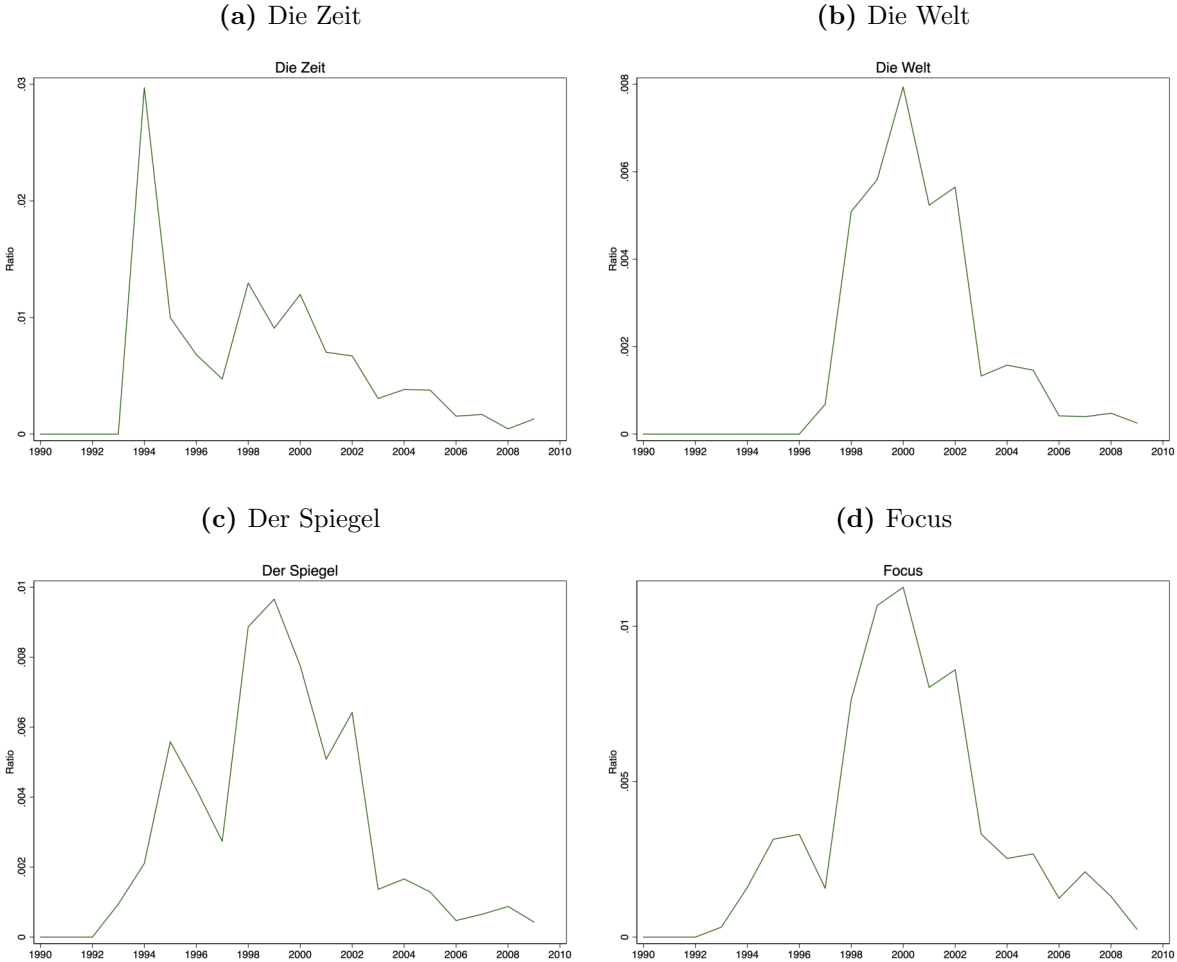
E.2 Using information in newspaper articles as an indicator of salience

For each newspaper, we separately downloaded the annual count of articles that are picked up by our search strategies as well as the total number of articles published by the outlet. To account for potential trends in publishing over the years, we begin by computing a simple newspaper-specific ratio of articles matching a given search strategy over the publish trend of the newspaper. Figure E.1 plots the ratio of articles discussing environment taxation out of total articles published by outlet. These ratios show that the discussion of environmental taxation in German news media has been primarily concentrated in the years prior and following the eco tax reform (i.e., around 1997 - 2003), peaking in 2000 for most newspapers. A challenge with these raw article ratios is that the number of articles varies a lot across newspapers and time, making it difficult to simply average the ratios across several newspapers in a given country. We, therefore, apply the standardization approach of Baker et al. (2016) to obtain our salience index.

We begin with the simple ratio of articles matching *Strategy #2* divided by the total article counts for each newspaper, and then divide this ratio by the newspaper-specific standard deviation across all years. This creates a newspaper-specific time series with a unit standard deviation across the entire time interval, which ensures that the volatility of the index is not driven by the higher volatility of a particular newspaper. We then average these standardized series across all newspapers within each country by year. Lastly, we normalize the yearly series to a mean of 100 over the time interval. This first index provides an overview on the evolution of the general discussion of environmental taxation within German news media (see Figure E.2), which we refer to as our index of publishing

trends. We then repeat the same procedure to develop our main salience index. In this case, however, we rely on the ratio of articles matching *Strategy #3* divided by the number articles discussing environmental taxation (*Strategy #2*) for each newspaper. This allows us to explicitly capture variation over time in price salience of the eco tax while accounting for newspaper-specific publishing trends specific to the topic of environmental taxation.

Figure E.1: Environmental taxation trends (#2) to total articles (#1) ratio over time



Notes: Based on yearly series from 1990 to 2009. Authors' own calculations based on newspaper articles from Factiva.

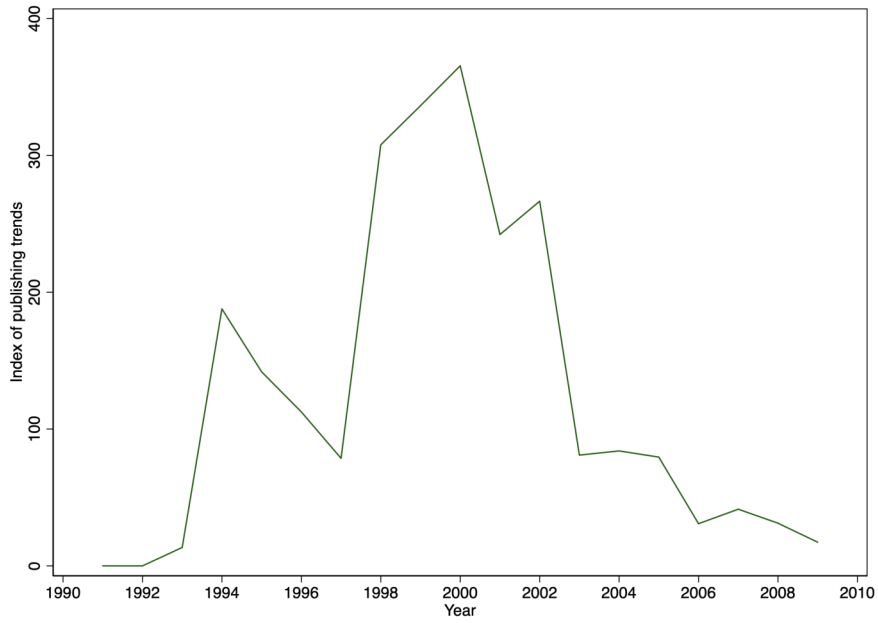


Figure E.2: Evolution of the index of publishing trends

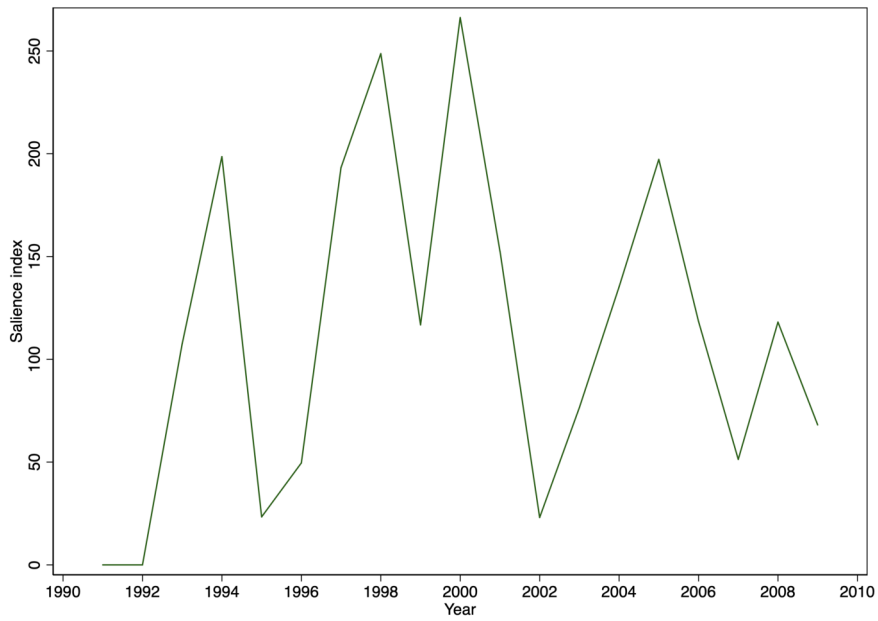


Figure E.3: Evolution of the salience index over time

E.3 Saliency analysis: Robustness checks

Table E.1: Effects of saliency on gasoline consumption.

	(1)	(2)	(3)	(4)
Gasoline price, only VAT	-0.00264 (0.00237)	-0.00280 (0.00177)	-0.00278 (0.00174)	-0.000503 (0.00130)
Energy Tax	-0.00611** (0.00237)	-0.00247 (0.00504)	-0.00340 (0.00489)	-0.00716 (0.00427)
Eco Tax	-0.00556 (0.00495)	-0.00944 (0.00660)	-0.00694 (0.00591)	0.00955 (0.0105)
Eco Tax x Saliency Index	-0.00540*** (0.00133)	-0.00442** (0.00205)	-0.00449** (0.00193) (0.0256)	-0.00195** (0.000753) (0.0215)
L.Eco Tax x Saliency Index				-0.000475 (0.00197)
L2.Eco Tax x Saliency Index				-0.00612*** (0.00207)
Dummy Eco Tax	-0.0266 (0.0403)	0.0285 (0.0867)	0.0101 (0.0748)	-0.196 (0.117)
Trend	0.0153*** (0.00385)	0.0295** (0.0143)	0.0198 (0.0224)	0.0134 (0.0207)
GDP per capita		-0.0000271 (0.0000306)	-0.0000160 (0.0000318)	0.00000920 (0.0000298)
Unemployment rate			0.00998	-0.00301
Fuel	Gasoline	Gasoline	Gasoline	Gasoline
N	38	38	38	37

Notes: The dependent variable is the log of fuel consumption in litres per capita, which refers to total fuel consumption or either gasoline or diesel consumption (as indicated by the column heading). Prices are in 1995€. Results for gasoline consumption refer to 1972-2009 due to missing price data prior to 1972. Unemployment is measured as percentage of total labor force. Newey-West standard errors in parentheses are heteroskedasticity and autocorrelation robust. Standard errors are calculated relying on the automatic bandwidth selection procedure following [Newey and West \(1994\)](#). * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table E.2: Effects of salience on diesel consumption.

	(1)	(2)	(3)	(4)
Diesel price, only VAT	-0.00305*** (0.000753)	-0.00318*** (0.00103)	-0.00325*** (0.00103)	-0.00197*** (0.000656)
Energy Tax	-0.00102 (0.00284)	-0.00537 (0.00327)	-0.00722** (0.00269)	-0.00774** (0.00328)
Eco Tax	-0.0117*** (0.00135)	-0.00975*** (0.00241)	-0.00802*** (0.00179)	0.000453 (0.00304)
Eco Tax x Salience Index	-0.00102** (0.000491)	-0.00125* (0.000735)	-0.00122* (0.000706)	0.000372 (0.000349)
L.Eco Tax x Salience Index			(0.00852)	-0.00166** (0.000709)
L2.Eco Tax x Salience Index				-0.00184* (0.000946)
Dummy Eco Tax	0.0813*** (0.0203)	0.0637** (0.0309)	0.0551** (0.0241)	-0.0409 (0.0266)
Trend	0.0356*** (0.00170)	0.0262*** (0.00607)	0.0185** (0.00741)	0.0176 (0.0104)
GDP per capita		0.0000131 (0.0000101)	0.0000209*** (0.00000692)	0.0000272*** (0.00000964)
Unemployment rate			0.00630	0.00141
Fuel	Diesel	Diesel	Diesel	Diesel
N	39	39	39	37

Notes: The dependent variable is the log of fuel consumption in litres per capita, which refers to total fuel consumption or either gasoline or diesel consumption (as indicated by the column heading). Prices are in 1995€. Results for gasoline consumption refer to 1972-2009 due to missing price data prior to 1972. Unemployment is measured as percentage of total labor force. Newey-West standard errors in parentheses are heteroskedasticity and autocorrelation robust. Standard errors are calculated relying on the automatic bandwidth selection procedure following [Newey and West \(1994\)](#). * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.