Environmental Tax Evaluation
What can be learnt so far?

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Abstract

Energy and carbon taxes play a key role in many countries when aiming to meet their international climate targets. The design of these taxes varies substantially across countries. In 2012, according to the OECD, effective tax rates on carbon range from USD 3.10 to USD 117.70 per tonne of CO_2. Countries with explicit carbon taxes, e.g. Sweden, Switzerland, Norway and Denmark, tend to have a higher effective carbon taxation. Within countries, there are often differences in the tax base and exempted sectors. For instance, Switzerland's CO_2 levy does not include motor fuels whereas in Denmark, energy-intensive industries are largely exempted if they enter a voluntary agreement on energy efficiency. Although these taxes have been in place for many years, there is little information available today on how well these did in fact perform.

The main aim of this paper is to review the existing literature of ex-post evaluations of explicit carbon taxes as well as describing the most popular of the various evaluation methods and naming their benefits and drawbacks. In addition, an overview of the design of carbon and energy tax schemes is provided in order to understand the impact of the design on the evaluation method. To begin with, we assess the review literature on energy and carbon tax schemes as to select the countries and tax schemes to be reviewed. Each tax scheme is described accordingly to specific characteristics such as the targeted sectors and the tax base, the participants, the tax rate, possible exemptions and the resulting evidence of a reduction in greenhouse gas emissions. Furthermore, a literature review on existing ex-post evaluations is undertaken in order to compare different methods and to identify the data that is needed for a robust interpretation of the impacts of these tax schemes. Based on those examples, we illustrate the limitation of carbon tax evaluations, e.g. counterfactual and selection bias issues as well as spillover and rebound effects. Finally, we discuss options of how to improve existing studies and what requirement for the data would be necessary to do so.

To sum up, both the evaluated results and their critical analysis will help to specify the focus of evaluation effort in the future. The systematic evaluation of the framework will help researchers in designing new ex-post evaluations of environmental and energy tax schemes. It should also inform upcoming debates on evaluation methods and data issues, providing important information to be used by political decision makers when introducing such tax schemes.

1 Introduction

An important source of greenhouse gas (GHG) emissions and air pollution originates from burning fossil fuels to generate energy. Environmental taxes are a cost-effective way to reduce negative externalities of energy use. Several countries have introduced explicit carbon tax schemes of which some have been evaluated. This paper aims to provide an overview of existing ex-post evaluations on explicit carbon taxes to deduct the merits and drawbacks of different approaches. In order to be as comprehensive as possible with regard to evaluation approaches, studies on environmental taxes other than carbon dioxide (CO_2) have also been included.

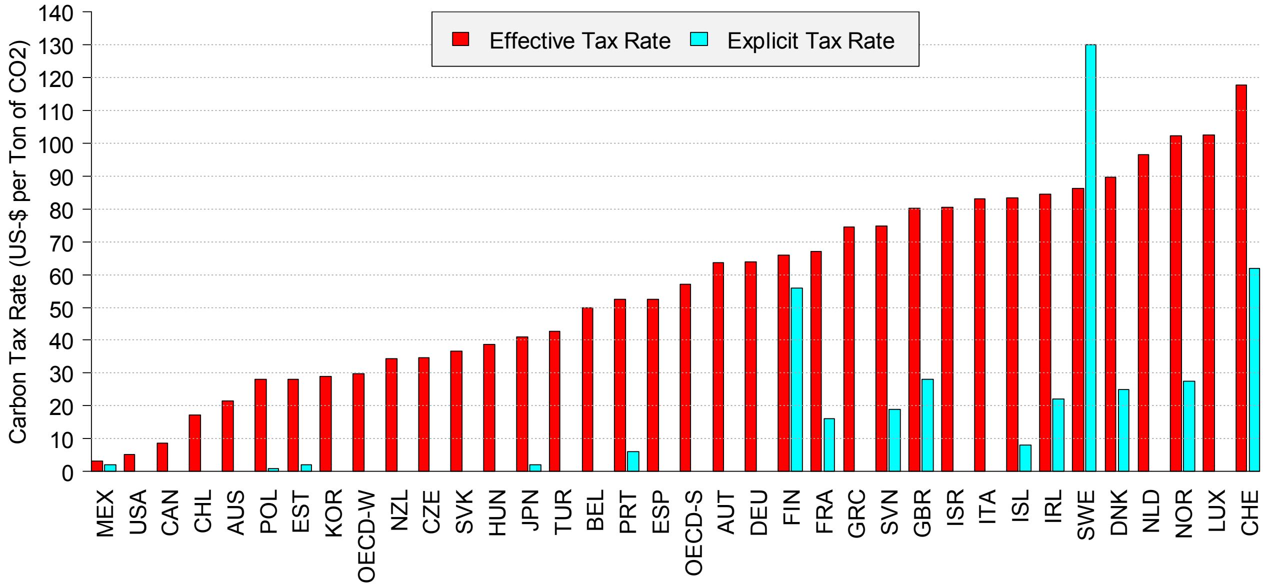
1.1 Definition of Environmental Taxes

We use the definitions of Eurostat to distinguish between environmental taxes and its subcategories. In its statistical guide for environmental taxes, Eurostat gives the following definition of environmental taxes: "A tax whose tax base is a physical unit (or a proxy of a physical unit) of something that has a proven, specific negative impact on the environment, and which is identified in the European System of Accounts (ESA) as a tax." (European Union, 2013, p. 9). This definition of environmental taxes requires the tax base to have a specific negative impact on the environment. According to Eurostat, the tax base is seen as the only objective basis for identifying environmental taxes for the purpose of international comparisons. Other purposes for introducing such taxes will be discussed in the next section but are less suitable and are, therefore, not part of this definition. Eurostat classifies environmental tax bases into the following four main categories: (i) energy taxes (including fuel for transport), (ii) transport taxes (excluding fuel for transport), (iii) pollution taxes and (iv) resource taxes (for details see European Union, 2013, p. 12 ff.). The category "energy taxes" includes taxes on energy production and on energy products used for both transport and stationary purposes. Carbon dioxide taxes are also included in this category. Since CO_2 taxes are often integrated with energy taxes and are partly introduced as a substitute for other energy taxes, they are often given as a separate category. Carbon tax rates are expressed as a value per tonne of CO_2 equivalent (per tCO_2eq). Such a broad definition of environmental tax bases opens, in fact, the field for many different tax schemes and evaluation methods that are often difficult to compare.

1.2 Explicit, Implicit and Effective Carbon Tax Rates

The tax base of explicit CO_2 taxes should either be directly linked to the level of CO_2 emissions or via close proxies and the tax rate is the price on each tonne of CO_2 emitted. If the tax rate equals the marginal damage cost of a tonne of CO_2, the market outcome is efficient as Pigou (1920) showed. In practice, the correct level of tax is difficult to determine and may be set with other motives in mind, which implicitly put a price on energy, respectively carbon. Hence, the effective tax rate - the sum of the explicit and the implicit tax rate - may be higher or lower than the marginal damage from the production or consumption of energy products. As already mentioned, besides helping to reduce carbon emissions, there are several additional purposes for taxing energy. Given that the energy demand by consumers and firms is relatively price inelastic in the short-term, energy taxes may be introduced as a means of raising revenues without causing a considerable welfare loss. According to Ramsey (1927) such a taxation implies that tax rates above Pigouvian levels may be optimal. In the long-term, substitution processes - due to high taxes on fossil fuels - may work and lead the economy towards less carbon intensive energy sources whilst helping to reduce oil dependency. Standards and regulations, in addition to explicit CO_2 taxes, may influence the price of CO_2 as well (see OECD, 2013a, p. 23). All these taxes together, whether levied for carbon pricing or motives that have nothing to do with internalizing the social cost of greenhouse gas emissions, put a price on carbon. A comparison of the tax rates among the countries is therefore difficult.

An OECD study has calculated the effective carbon tax rates on carbon in the energy sector (see OECD, 2013b). In this study, tax rates, which are usually set in monetary units per physical quantity of fuel (e.g. litres, kilograms, kilowatt-hours), are recalculated as effective tax rates per gigajoule of energy and per tonne CO_2 emissions. As illustrated in Figure 1 the effective tax rates (red bars) range from USD 3.10 per tonne of CO_2 in Mexico to USD 117.70 in Switzerland. In order to select the relevant countries which levy also explicit carbon taxes (blue bars), we combine Figure 1 with the findings of a recent World Bank report (Kossoy et al., 2015). Countries with the highest effective tax rates are often countries with explicit carbon taxes, e.g. Sweden, Switzerland, Norway and Denmark. Note that the effective and the explicit tax rates are not directly comparable. While the effective tax rates on carbon are calculated on an economy-wide basis, the tax base of explicit carbon tax rates is often very specific and contains many exemptions (see Table 1). However, explicit tax rates are generally a subset of effective tax rates, the peerlessness of the effective and the explicit tax rate in Figure 1 can result in such, at a first glance, strange results as for Sweden, where the explicit carbon tax rate is actually higher than the effective tax rate. This review focuses on explicit and identifiable taxes that are linked to the level of CO_2 or other air pollutions.



Note: Overall average effective tax rate, are calculated on a weighted basis on CO_2 emissions from energy use and are originally given in Euros. Tax rates are as of 1 April 2012 (except 1 July 2012 for AUS).
The currency conversion rates to change from Euros to Dollars are taken from the OECD (1 August 2015).
OECD-S = Simple average effective tax rate, OECD-W: weighted average effective tax rate.
Source: OECD (2013b)[1] and Kossoy et al. (2015).

Figure 1: Overall average effective and explicit tax rates on CO_2 from energy in OECD countries

1.3 Explicit Carbon Taxes around the World

According to Kossoy et al. (2015) as of August 31, 2015, 39 national and 23 subnational jurisdictions have already implemented or are considering to implement explicit carbon pricing (trading systems or carbon taxes) of global greenhouse gas emissions. A carbon tax is implemented or scheduled for implementation in the following 19 national or subnational jurisdictions: British Columbia, Chile, Denmark, Estonia, Finland, France, Iceland, Ireland, Japan, Latvia, Mexico, Norway, Poland, Portugal, Slovenia, South Africa, Sweden, Switzerland and the United Kingdom. Table 1 gives an overview of the details on the above-mentioned explicit carbon tax schemes. The table shows the most important characteristics of the specific carbon tax for the sixteen countries and one jurisdiction where sufficient information is available. The starting year reveals that Chile and South Africa have not yet implemented the carbon tax. Therefore, information especially for the exemptions is not available for these countries. The columns "Sector / Tax Base" and "Physical Unit Taxed" contains a very brief description of the physical unit and specific details of the underlying tax, for instance revenue neutrality of recycling back to the economy. In addition, the most important exemptions are also shown in the column "Exemptions". Kossoy et al. (2015, p. 78) explain that these exemptions are driven by either practical difficulties, by political sensitivities or by the high transaction costs of covering certain sectors. They state: "While exemptions are effective in addressing leakage and administratively easy to implement, they fundamentally undermine the abatement incentives of carbon pricing. Reducing the effective carbon price means that abatement incentives are reduced as well." The last column indicates whether the tax scheme has already been evaluated or not. This is certainly not the case for tax schemes that have been established quite recently.

[1] Data on effective carbon tax rate is available from the OECD: http://dx.doi.org/10.1787/888932765598

Table 1: Overview of existing national and subnational jurisdictions that have introduced explicit carbon taxes

Country/Jurisdiction [1]	**Starting Year**	**Sector / Tax Base**	**Physical Unit Taxed**	**Explicit Tax Rate: (US$ per tCO_2eq)** [2]	**Exemptions**	**(Ex-post) Evaluation**
British Columbia (CAN)	2008	The carbon tax applies to the purchase or use of fuels within the province. The carbon tax is revenue neutral; all funds generated by the tax are returned to citizens through reductions in other taxes.	All fossil fuels	US$ 23	No exemptions.	✓
Chile (CHL)	2017	The carbon tax applies to all stationary sources with a thermal input capacity greater than 50 megawatts (MW). The value of this tax is denominated in U.S. dollars, which means that tax liabilities in the local currency will depend on the prevailing exchange rate on the day of payment.	Thermal energy production	US$ 5		
Denmark (DNK)	1992	The carbon tax covers all consumption of fossil fuels (natural gas, oil, and coal).	All fossil fuels	US$ 25	Operators covered by the EU ETS are partly exempt from the taxes and will only be taxed at the minimum rate as specified in the EU Energy Taxation Directive. Energy-intensive industries are largely exempt if they enter a voluntary agreement on energy efficiency. Fuels used for electricity production are not taxed, but instead a tax on electricity production applies.	✓
Estonia (EST)	2000	The carbon tax covers the generation of thermal energy.	Thermal energy production	US$ 2		
Finland (FIN)	1990	The carbon tax was originally based only on carbon content for all consumers of fossil fuels. It was subsequently changed to a combination carbon/energy tax. Initially, it covered only heat and electricity production but was later expanded to cover transportation and heating fuels.	Electricity production Transportation and heating fuels	US$ 64 (transport fuels) US$ 48 (heating fuels)	Certain industries or certain fuel uses are (partially) exempt from the carbon tax. Fuels for electricity production, commercial aviation and commercial yachting are exempt as well.	✓
France (FRA)	2014	The carbon tax is a domestic consumption tax on energy products based on the content of CO_2 on fossil fuel consumption not covered by the EU ETS. A carbon tax was introduced from April 1, 2014 on the use of gas, heavy fuel oil, and coal. From 2015 onwards, the carbon tax will be extended to transport fuels and heating oil. The law on the Energy Transition to Green Growth sets a trajectory for the country's carbon tax level to rise to US$ 61/tCO_2eq in 2020, and US$ 110/tCO_2eq) in 2030.	Transportation and heating fuels	US$ 16	Operators covered by the EU ETS are partly exempt from the taxes and will only be taxed at the minimum rate as specified in the EU Energy Taxation Directive.	✓
Iceland (ISL)	2010	The carbon tax applies to all importers of liquid fossil fuels (gas and diesel oils, petrol, aircraft and jet fuels and fuel oils) regardless of whether it is for retail or personal use. A carbon tax for	All fossil fuels	US$ 8		

Country/Jurisdiction [1)]	Starting Year	Sector / Tax Base	Physical Unit Taxed	Explicit Tax Rate: (US$ per tCO_2eq) [2)]	Exemptions	(Ex-post) Evaluation
		liquid fossil fuels is paid to the treasury, with (since 2011) the rates reflecting a carbon price equivalent to 75 percent of the current price in the EU ETS scheme.				
Ireland (IRL)	2010	The carbon tax applies to petrol, heavy oil, auto-diesel, kerosene, liquid petroleum gas (LPG), fuel oil, natural gas, coal and peat, as well as aviation gasoline.	All fossil fuels	US$ 22	Operators covered by the EU ETS are partly exempt from the taxes and will only be taxed at the minimum rate as specified in the EU Energy Taxation Directive Most emissions from farming is excluded from the carbon tax.	✓
Japan (JPN)	2012	The carbon tax applies to all consumers of fossil fuels such as oil, natural gas, and coal, depending on their CO_2 emissions. In particular, by using a CO_2 emission factor for each sector, the tax rate per unit quantity is set so that each tax burden is equal to US$2/$tCO_2$ (as of April 2014).	All fossil fuels	US$ 2	Exemptions and tax returns apply for certain parts of the agriculture, transport and industry sectors	✓
Mexico (MEX)	2014	The carbon tax covers fossil fuel sales and imports by manufacturers, producers, and importers. It is not a tax on the full carbon content of fuels, but rather on the additional amount of emissions that would be generated if the fossil fuel were used instead of natural gas. Natural gas therefore is not subject to the carbon tax, though it could be in the future. The tax rate is capped at 3% of the sales price of the fuel.	All fossil fuels except natural gas	<US$ 1 (lower) US$ 3 (upper)* *Depending on fossil fuel type.	Companies liable to pay the tax may choose to pay the carbon tax with credits from CDM projects developed in Mexico, equivalent to the value of the credits at the time of paying the tax.	
Norway (NOR)	1991	The carbon tax applies to consumers of mineral oil, gasoline and natural gas. Both the EU ETS and the CO_2 tax is imposed on offshore production and distribution of oil and gas. The highest tax rate applies to the production of gas and oil offshore in order to encourage the use of electricity generated onshore instead of electricity generated on the petroleum platforms.	Mineral oil, gasoline and natural gas	US$ 3 (lower) US$ 52 (upper)* *Depending on fossil fuel type and usage.	Operators not in the offshore petroleum business and covered by the EU ETS and certain other industries are (partially) exempt from the carbon tax to preserve their competitive position.	✓
Portugal (PRT)	2015	The carbon tax applies applies to all energy products used in non-EU ETS sectors. The tax rate will be determined annually, based on the average EU allowance auction-clearing price in the preceding years. The full green tax reform package aims to be fiscally neutral and the revenues from the carbon tax and other taxes will be redistributed in the form of income tax relief to lower- income families.	Energy production	US$ 6	Applicable to selected, non-EU ETS sectors.	
Slovenia (SVN)	1996	The carbon tax applies to CO_2 emissions resulting from the combustion of fossil fuels and incineration of combustible organic substances. Since July 2012, the CO_2 tax also applies to the transport sector and to emissions from landfills.	Combustion of fossil fuels and Transportation	US$ 19	EU ETS participants and some cogeneration facilities are exempt from this tax.	

Country/Jurisdiction [1]	Starting Year	Sector / Tax Base	Physical Unit Taxed	Explicit Tax Rate: (US$ per tCO_2eq) [2]	Exemptions	(Ex-post) Evaluation
		The tax rate is calculated based on the number of "environmental pollution units" (equivalent to 1kg CO_2), set by decree for each substance, and the CO_2 price which is regularly updated.				
South Africa (ZAF)	2016	The carbon tax is proposed to a fuel input tax based on the carbon content of the fuel. It was agreed that emissions factors and/or procedures are available to quantify CO_2eq emissions with a relatively high level of accuracy for different processes and sectors. The carbon tax will cover all direct GHG emissions from both fuel combustion as well as non-energy industrial process emissions and is expected to start in January 2016.	Combustion of fossil fuels	US$ 19	Highly trade-exposed and energy-intensive industries	✓
Sweden (SWE)	1991	The carbon tax covers all fossil fuels used for heating that are not covered by the EU ETS and motor fuels.	All fossil fuels	US$ 130	Operators covered by the EU ETS are partly exempt from these taxes and will only be taxed at the minimum rate as specified in the EU Energy Taxation Directive, except for heat production. Non-EU ETS installations, as well as the agriculture and forestry sectors receive tax rebates for their use of fossil heating fuels. Under new rules considered for introduction by 2016 tax rebates would be abolished.	✓
Switzerland (CHE)	2008	The carbon tax applies to thermal fuels only. It will be raised from the current rate of US62/tCO_2 to US87/tCO_2 on January 1, 2016. The maximum level of the tax rate is US$125/$tCO_2$. Two thirds of the carbon tax is revenue is returned to the country's citizens through lower health insurance payments and to business via the social security contributions. A third of the revenue (maximum of CHF 300 million) goes into an energy refurbishment fund for buildings.	All thermal fuels	US$ 62* *This tax will be increased following a GHG emissions trajectory, depending on the evolution of Switzerland's GHG emissions trajectory.	Gasoline and diesel fuels are not affected by the CO_2 tax, but manufacturers and importers of these fuels are obliged by 2020 to domestically offset 10% of CO_2 emissions resulting from the energetic use of motor fuels over the period 2013 to 2020. Swiss companies can be exempt from the tax if they participate in the country's ETS.	✓
United Kingdom (GBR)	2013	The Carbon Price Floor is a tax on fossil fuels used to generate electricity. It aims to reduce the volatility of EUA prices by adding a carbon price support rate as an additional levy on the electricity bill. The carbon price support rate is the difference between the EUA price and the annual Carbon Price Floor target (starting from £16/tCO_2eq in 2013, linearly increasing to £30/tCO_2eq by 2020), and is updated annually	Fossil fuels used to generate electricity	US$ 28* *Changing each year depending on the EUA price.		✓

1) For Latvia and Poland, there was no publicly information available.
2) Nominal prices on August 1, 2015 (Kossoy et al., 2015, p. 24). Prices are illustrative and not necessarily comparable between carbon pricing instruments because of differences in the number of sectors covered and allocation methods applied specific exemptions, and different compensation methods.
Sources: Ecologic Institut (2014), Ecofys; World Bank (2013), Kossoy et al. (2015), OECD (2013b)

2 Overview of Evaluation Methods: Their Advantages and Drawbacks

The design of environmentally related taxation can have a significant impact on its environmental effectiveness. The most important factor is the level of the tax. Furthermore, the proximity to the source of pollution plays an important role. However, administrative difficulties in implementing a tax scheme as well as political economy issues, considerations about trade-exposed sectors or distributional concerns may all also influence the tax design. This section aims to discuss the various methods for evaluating environmental tax schemes. The first part of this section is a discussion of what makes an evaluation a "good" one. The second part summarizes the various methods for ex-post evaluation, also illustrating their individual advantages and drawbacks. It is aimed to develop a framework that is used to classify the various evaluation methods employed in the studies of this review.

2.1 What is a Good Evaluation?

The focus of any evaluation is to estimate the effect of the tax on one or more variables of interest[2] and to isolate the outcome from other potential factors that might have an impact on the variable of interest. The methods range from qualitative to quantitative ones as well as ex-ante and ex-post assessments. In contrast to evaluation, monitoring is about identifying goals and defining key indicators to compare with these goals. In addition, monitoring sets targets to quantify the levels of indicators that are to be achieved by a given date. This review does not focus on monitoring but on evaluations as a systematic and quantitative assessment of whether the changes of the outcomes of a carbon tax scheme are indeed due to the intervention and not to other factors. "Evaluation seeks to prove that changes in targets are due only to the specific policies undertaken." (Khandker et al., 2010, p. 8). Finally, this section provides an overview of the main challenges that researchers of evaluation studies are facing.

2.1.1 The Counterfactual

Finding the outcome if tax had not been imposed is the main challenge of an impact evaluation. The impact of the tax can be identified by comparing actual and counterfactual outcomes. The counterfactual is an estimate of what would have been the outcome in the absence of the tax. Since the counterfactual outcome cannot be directly observed, the problem of evaluation is to create a convincing and reasonable comparison group in order to be able to assess the impact of the tax independently of other factors. A simple estimate would be measuring e.g. the CO_2 emissions of the same observational unit (household, firm, sector, country) before and after the introduction of the tax. The "Before-and-After" method is explained in Figure 2. Comparing pre-tax emissions (Q_1) with after tax emissions (Q_3) the mitigation effect of the tax might be estimated as $Q_1 - Q_3$. This approach is referred to as the "reflexive method". Such comparisons are useful in evaluations of nationwide policies or programs that cover the entire population and hence the counterfactual is defined as the outcome of the participants before the tax. However, simply taking the pre-tax emissions as comparison group can be a "counterfeit" counterfactual and probably not give a realistic effect of the tax. The measured impact of

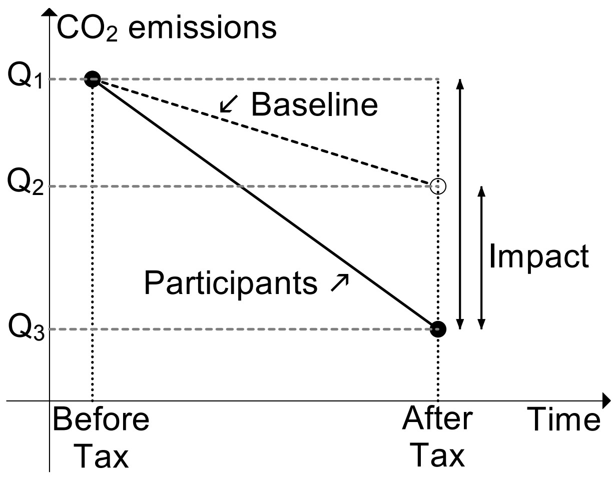


Figure 2: Comparison with a Baseline as a Counterfactual

[2] In the context of this review, the variable of interest is mostly the amount of greenhouse gas emissions, other hazardous substances or energy use.

the tax would only be accurate if there were no other exogenous factors affecting CO_2 emissions. By not controlling for the many other factors influencing emissions, one would thus falsely give the effect of the policy in absence of the tax as $Q_1 – Q_3$ instead of $Q_2 – Q_3$. Therefore, a broad baseline study is always to be used as a counterfactual in order to control the many other factors changing over time and influencing emissions.

Since controlling for all exogenous factors is difficult and sometimes not possible, following an experimental or quasi-experimental approach might be a more accurate estimate of the tax effect. The evaluation problem then is finding a proper comparison or control group consisting of non-participants. Figure 3 provides an illustration. The amount of measured CO_2 emissions of the participants is Q_2 before a carbon tax was introduced and Q_5 after its introduction. The observed mitigation effect of this simple Before-and-After measure method would be $Q_2 – Q_5$. However, is this reduction due to the tax? In order to identify the tax effect, it is necessary to create a reasonable comparison group. Compared to the emissions of the control group, the mitigation effect decreases to $Q_3 – Q_5$. Nevertheless, without having further information about the participation it is not possible to know whether Q_3 is the right counterfactual. It might be the case that emissions are different across the participants and the control group before the introduction of the tax. If, as depicted in Figure 3, the CO_2 emissions of the control group before and after the tax is (Q_1, Q_3), then the correct counterfactual emissions to compare with is (Q_2, Q_4). The resulting mitigation effect of the tax decreases again to $Q_4 – Q_5$. In this example, the counterfeit counterfactual leads to on overestimation of the tax effect. Note that also an underestimation would be possible if the control group at the beginning of the measure emitted less CO_2 than the participants.

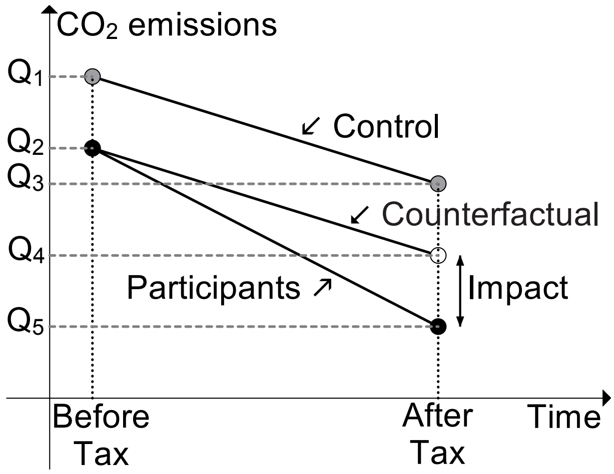


Figure 3: Comparison with a Control Group as a Counterfactual

2.1.2 Selection Bias

As shown in the previous section, it is vital to find an appropriate group of non-participants to serve as a comparison group since one cannot observe the outcome of participants if they did not participate. The evaluation problem is then summarized in the following Equation 1 for observation i:

Equation 1: $$Y_i = \alpha X_i + \beta T_i + \varepsilon_i$$

T is a dummy variable equal to 1 for participating individuals and 0 for non-participants. X is the set of other characteristics of the individuals. The error term ε reflects unobserved characteristics influencing emissions Y. The key problem is the assignment of the participants to one of the two groups, which is often not a random procedure. The reason for this might be the fact that there are unobservable factors that influence whether one participates or not. If such self-selection is determined by unobserved factors, the error term in the estimating equation will contain variables that are also correlated with the treatment dummy T. This, in turn, leads to the unobserved selection bias. If $Cov(T,\varepsilon) \neq 0$, the OLS estimators will be biased and inconsistent. If the treated and the non-treated groups do not share the same characteristics prior to the tax intervention, then the expected difference between the two groups may not be entirely due to the tax effects. This leads to the question whether the results of the evaluation can be generalized and applied to other, apparently similar, policies. For example, if individuals or firms with high environmental awareness or with high price-responsiveness are more likely to participate, the evaluation may overestimate the true impact of the tax. This is due to the fact that a part of the participants would have taken action in the form of energy savings or emissions reduction anyhow – that is also in the absence of such environmental policies. These people are known as "free-riders", as their intrinsic motivation to save energy or reduce emissions would have been sufficient without financial incentives. Similarly, if the participants react differently to energy prices, the comparison between the two groups produces inaccurate estimates of the tax effect. In practice, self-selection could occur e.g. in the design of the Swiss climate policy. The CO_2 levy is a key instrument in achieving the statutory CO_2 emission targets of Switzerland. However, under the CO_2 Act energy-intensive companies can be exempted from the CO_2 levy if they commit themselves to reducing emissions in return. Another instrument is the Swiss emissions trading scheme (ETS), which is mandatory for large energy-intensive companies. Besides, companies may as well voluntarily participate in the ETS under certain conditions (opt-in). If total emissions in the previous three years have been below 25,000 tonnes CO_2eq in each year, the company may apply to the Federal Office for the Environment for an exemption from the ETS obligation (opt-out), but then has to pay the CO_2 tax, unless it is exempted from the tax. Hence, the affected companies can, quasi "à la carte", choose between three different policy instruments as described in Krysiak and Oberauner (2010).

2.1.3 Spillover and Rebound Effects

Another problem concerns spillover and rebound effects. Participants with higher environmental awareness could be willing to make additional energy savings or to take emission reduction actions, respectively. In addition, non-participant spillovers could occur if these people become aware of energy saving opportunities and, thus, decide to invest in an energy efficiency measure. Policies that raise energy prices such as carbon or energy taxation encourage energy efficiency measures, which make the consumption of energy relatively cheaper. Thus, direct rebound effects may occur as some individuals will spend more on energy as well as indirect rebounds since some individuals will spend the saved money on other environmentally relevant goods and services. The net effect is the difference between the reduction of energy use caused by the higher energy prices and the rebound effects caused by the higher energy efficiency. This net effect is difficult to determine and could again lead to a non-accurate estimate of the tax effect.

2.2 Methods for Ex-post Evaluation Analysis

A wide range of evaluation methods and econometric techniques are available. In fact, the data quality defines which method should be best chosen. Gertler et al. (2011) define evaluations as follows: "Evaluations are periodic, objective assessments of a planned, ongoing, or completed project, program, or policy. Evaluations are used to answer specific questions, often related to design, implementation, and results." This review focuses on ex-post evaluations, which measure actual impacts accrued by an environmental tax, such as a tax on carbon emissions[3]. OECD (2010) published a guide for policy makers on how to take all the important considerations to design effective environmental taxes into account. Referring back to the counterfactual discussion in section 2.1, one has to distinguish between non-experimental, quasi-experimental, experimental designs and modelling. Non-experimental designs are easy to implement but they lack a counterfactual and, therefore, the selection bias is an issue. Wade and Eyre (2015) distinguish between four ex-post evaluation methods. We will present their adequate econometric techniques. The reviewed studies will then be allocated to one of these mentioned techniques. The chosen order of the following methods is based on the degree of how well these methods address the counterfactual issue. In addition, modelling methods are also included. However, model approaches do not fit in this order since they can as well be used for ex-ante evaluations and are, therefore, considered as a separate category. Table 2 at the end of this section summarizes the results in terms of the above-mentioned criteria.

[3] Ex-ante impact evaluations attempt to measure the intended impacts of future policies. They are generally based on assumptions of structural models. Since many environmental tax evaluation studies are based on computable general equilibrium models, they are discussed as well in section 2.2.5.

2.2.1 Engineering Estimates / Bottom-up Models

The simple engineering estimates are based on the number of measures installed as a consequence of the tax. Here, the hours of use of these technologies are estimated before and after the introduction of the tax. More complex engineering approaches use technology-specific data. The following inaccuracies may arise: Exogenous influences, participant spillover and rebound effects will not be accounted for. The advantage of engineering estimates is that they require relatively few data and are cheaper and easier to implement than other methods.

2.2.2 Before-After Comparisons for Participants

Before-after comparisons simply define the counterfactual as the energy use or the emissions of the participants before the tax is introduced. With this method, spillover effects of the participants are captured. However, as shown in section 2.1.1, exogenous influences might not be taken into account and free-ridership will also not be addressed. The period before and after should cover at least 12 months in order to account for seasonal variations. Some sort of normalization should be carried out.

2.2.3 Quasi-Experimental Approaches

Quasi-experimental approaches may be applied when experimental designs are not possible. This might be the case when there are data constraints or when a tax is implemented without considering future evaluations. These approaches use various econometric techniques, usually multivariate regression analysis. The easiest approach is to compare after tax energy use of participants with a comparison group. These methods do all account for the counterfactual issues and produce valid estimates. However, the selection bias may be an issue since the group assignment is often not randomly determined as in a pure experimental approach but rather in a manner that is beyond the researcher's control e.g. by politics or choice of the actors themselves. If selection characteristics were known, participants and non-participants could be matched so that to minimize selection bias. According to Khandker et al. (2010, p. 27) the most important methods are the following ones[4]:

Double Difference or "Difference-in-Differences" (DiD) methods are a popular approach to quasi-experimental evaluations. DD compares the change in the participants' outcome with the change in the non-participants' outcome over the relevant period by defining the variables as the change from one time period to the next. The selection bias is controlled under the assumption that unobservable factors, which determine selection, are fixed over time (time invariant)[5].

Fixed Effect Estimation (FE) uses the fixed effects transformation, for example, by first differencing, to remove unobserved time invariant heterogeneity prior to the estimation.

Instrumental Variables Estimation (IV) is a method to solve the problem of omitted time-varying variables that are correlated with explanatory variables. The IV approach involves finding a variable that must be correlated with the endogenous explanatory variables, but not with the error term in the explanatory equation. In terms of Equation 1, the aim is to find an instrumental variable Z that is correlated with the participation dummy T and uncorrelated with the error term ε [$Cov(Z,T) \neq 0$ and $Cov(Z,\varepsilon) = 0$].

Propensity Score Matching (PSM) uses the observable covariates to calculate the probability, respectively the propensity score, of participation. On the basis of similarity of the probabilities, participants are matched with non-participants (see Rosenbaum and Rubin, 1983). The difference between PSM and a pure experiment is that the latter also assures that the treatment and comparison groups are identical in terms of the distribution of unobserved characteristics.

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[4] Discrete choice models specify the probability that an individual chooses an option among a set of alternatives, e.g. choosing between modes of transport (private car, public transport, bike). Since they are relatively seldom applied in evaluations of environmental taxes, they are not further discussed here.

[5] Referring to Figure 3 in section 2.1.1 this double difference is exactly the impact of the tax and equals $(Q_3 - Q_5) - (Q_1 - Q_2)$.

2.2.4 Experiments

Experimental approaches can provide the most accurate estimates. Especially "Randomised Control Trials" (RCT), where the participants with an equal chance are randomly assigned to participants and control groups, are considered the most robust method to estimate the counterfactual. In partial randomization designs, the treatment and control samples are also chosen randomly, but their group assignment depends also on some observable characteristics. With a sufficiently large sample, the process of random assignment ensures equivalence in both observed and unobserved characteristics between the treatment and control groups, thereby avoiding any self-selection bias. The experimental approach also accounts for spillover, rebound as well as for free-ridership issues. Data requirement is very similar to quasi-experimental designs.

2.2.5 Computable General Equilibrium Models

Unfortunately, adequate data is often not sufficiently available – especially time series data are scarce or not relevant. In such cases, computable general equilibrium models (CGE models) can estimate the impact of a tax change or another change in policy. CGE models consist of a set of micro-founded equations describing the economy. The assumptions about preferences, technology and budget constraints tend to be neo-classical. The database consists of an input-output table, which covers the whole economy of a country and a number of sectors or specific sub-sectors. A model which is based only on a restricted range of data is a partial equilibrium (CGE-P). In this case, the ceteris paribus is assumed for the rest of the economy. The drawback of such models is that they depend on the assumptions made, especially on the choice which variables are endogenous or exogenous ones.

2.2.6 Summary of the Evaluation Methods

This section starts with a summary of the findings in table form and some concluding remarks.

Table 2: Summary of Evaluation Methods and Drawbacks

Method	Issues that the method accounts for					Main Advantage	Main Drawback
	Exogenous effects	Spillover	Rebound	Selection Bias	Free-ridership		
Engineering estimates						Cheap data collection.	Inaccurate because of missing counterfactual.
Before-after comparisons		(✓)	(✓)	✓		Only participant group.	Exogenous influences are not accounted for.
Difference-in-differences	(✓)	✓	✓	(✓)		Exogenous influences are accounted for.	Comparison group is needed (non-participant spillover).
Fixed Effect Estimation	(✓)	✓	✓	(✓)		Can solve for time invariant effects.	Comparison group is needed (non-participant spillover).
Instrumental Variables estimation	✓	✓	✓	(✓)		Can solve the self-selection bias.	Comparison group is needed (non-participant spillover).
Propensity score matching	✓	✓	✓	✓		Can solve the self-selection bias.	More data is required.
Experiments	✓	✓	✓	✓	✓	Can provide the most accurate estimates.	Implementation must be controlled.
Computable general / partial equilibrium	✓		(✓)	✓		Can be applied if only limited data is available. In the case of CGE models, economy-wide changes are analysed.	Results depend on the assumptions made.

Source: This table is based on Table 2.1 of Wade and Eyre (2015) added with CGE models.

Randomized selection models are considered the "gold standard" of an impact evaluation. In practice, they are quasi inexistent in carbon tax evaluation studies. Quasi-experimental approaches are the most popular methods. When panel data is available, the fixed effect estimation or the difference-in-difference approach is a suitable way to account for the challenges facing an ex-post evaluation. CGE and CGE-P techniques are applied as well. These techniques and their accompanying sub-techniques are the most widespread. The reason for this is explained in detail in the next section.

3 Description of ex-post evaluation studies

This section provides an overview on existing environmental tax evaluations. In addition, the appendix presents a short summary of a selection of typical ex-post evaluations and reviews by referring to details such as the aim, the underlying data, the method and the main results.

Table 3 gives a summary of environmental tax evaluations based on the countries with evaluation studies mentioned in Table 1, as well as four additional countries/jurisdictions (New South Wales (AUS), Italy, Netherlands and New Zealand) at the end. These four countries, while not quoted in the World Bank report of Kossoy et al. (2015) due to lack of carbon taxes, do have environmental taxation and have been included in this review to improve the comprehensiveness of approaches. The evaluation methods are listed according to the description given in section 2.2. If there are several studies available for carbon tax in one country, the order of the studies follows the publication year. To be as comprehensive as possible, some important reviews are as well included.

Column four of Table 3 describes the tax base or the research topic of studies that do not investigate tax schemes, but rather energy efficiency programs or GHG emissions of certain sectors as transportation or buildings. Column five of Table 3 refers to section 2.2 with the chosen evaluation method. Often, there are mixed evaluation approaches so that the stated method can be seen as a comprehensive term of different statistical techniques. The key findings of columns 6 and 7 are grouped into the two subcategories: "Tax Effects Found" and "Other Benefits and / or Drawbacks". To avoid repetition, the findings in the last column refer to the discussion of the methodology and their drawbacks in section 2.2.

The reviewed studies in Table 3 show that there is a variation in tax bases evaluated. However, most evaluations focus on CO_2 or GHG emissions in different sectors or economy-wide depending on the underlying policy instrument.

The dominating evaluation methods are the Difference-in-differences and CGE approaches. This might reflect the limitations with regard to data. Both methods can be applied with a limited number of data, whereas more data is necessary to be able to conduct sound experiments. Therefore, in order to improve the quality of ex-post evaluations in the future, it is recommended that the evaluation process should already be considered in the planning phase of a new policy. Thus, policy makers and researchers together can ensure that the data needed for a proper counterfactual analysis is collected. As our review has revealed, this is almost never the case. The reality often differs from the ideal process. A policy is implemented yet its evaluation is only thought of years later. Given the available data situation, DiD or CGE approaches have to be usually applied. Since DiD requires, in its most basic form, only two time periods, a treatment and a control group, it can be applied defining an appropriate control group serving as counterfactual. The double difference and comparable control variables that occur in both groups might give good estimation results according to the OLS assumptions. Exogenous factors that change only in one group at the same time are a violation of the assumption. Lack of randomization can make it difficult to find a convincing and reasonable comparison group as well. In such case, CGE or CGE-P models might step into the breach. As an example of a pragmatic evaluation, very similar to the approaches just having been described, is the ex-post evaluation of the Swiss CO_2 levy (see Ecoplan et al., 2015 and appendix). Here, the researchers applied two models. Model A is a time series analysis based on aggregate data from the overall energy statistics. This model is a partial analysis with the two sectors households and economy (industry and services). They calculate two scenarios: a reference scenario including the CO_2 levy from 2008 to 2013 and a hypothetical scenario without CO_2 levy as a counterfactual for the same period. The extrapolation for these two scenarios is based on data that reaches back to 1978. The mitigation effect of the levy is the difference between the reference scenario and the counterfactual. Model B calculates the counterfactual using a CGE approach with 18 sectors (GEMINI-E3). The estimation results of the two models give an upper respectively lower bound of the CO_2 mitigation that varies between 2.5% to 6%.

With panel data available, fixed effect estimations are quite popular as well. In conclusion it can be said that the chosen methods generally depend on the available data, which is not really surprising.

Referring to the key findings, tax effects are often significant. The levels of significance vary from less than 1% to 10%. Usually, the higher the aggregation level of the data is, the lower the level of significance. However, there are many exceptions so that a general rule cannot be formulated. Yet, when taking a careful look at the regression results, the drawbacks of these studies are revealed. Sometimes they are valid only for a subcategory of the tax base. Alternatively, the counterfactual is defined in a way so that small deviations from it suffice to result in significant estimators, in absolute or relative terms. Since most countries apply a policy mix aiming to reach their carbon emissions target, special attention must be paid to interactions between different policies (e.g. emission trading systems, feed in tariffs). As mentioned in section 1.2, besides explicit carbon taxation as a means of internalizing external costs, many other factors do implicitly put a price on carbon. It is those factors that need to be controlled for as much as possible.

Table 3: Summary of Evaluations Studies, their Methods and Key Findings

Country/Jurisdiction	Starting Year	Study	Tax Base / Research Topic	Evaluation Method(s)	Key Findings: Tax Effects Found	Key Findings: Other Benefits and / or Drawbacks
British Columbia (CAN)	2008	Rivers and Schaufele (2012)	GHG emissions in the province British Columbia.	Fixed effect and instrumental variables estimation.	10.6% reduction in per capita gasoline sales.	Individuals respond more elastic to a five percent increase in the carbon tax, than a five percent increase in the market price.
		Elgie and McClay (2013)		Difference-in-differences with no additional controls.	9% reduction in per capita greenhouse gas emissions.	Easy data availability. No control of exogenous effects.
		Murray and Rivers (2015)		Review	-	-
Denmark (DNK)	1992	Johannsen (2002)	Danish agreement scheme on energy efficiency in industry in order to qualify for a lower CO_2 tax rate.	Descriptive comparison of policies	Due to asymmetric and incomplete information, the energy audit does not guarantee an efficient allocation of energy savings.	No control of potentially free riding of the companies.
		Wier et al. (2005)	Regressive effects of CO_2 taxes.	Input-output-model (CGE)	Danish CO_2 taxes are regressive.	See section 2.2.5
		Lin and Li (2011)	CO_2 emissions	Difference-in-differences	The effects of the carbon tax CO_2 in Denmark, Sweden and Netherlands are negative but not significant and in Finland negative and significant.	The selection of the countries for the control group (countries that introduced the CO_2 tax later than Scandinavian countries) could influence the results.
Finland (FIN)	1990	Lin and Li (2011)	CO_2 emissions	Difference-in-differences	See Denmark	See Denmark
France (FRA)	1990	Millock and Nauges (2006)	Air pollution (SO_2, NO_x, HCl, VOC)	Fixed effect estimation	The tax had a significant negative impact on emissions.	See section 2.2.3
Ireland (IRL)	2008	Leinert et al. (2013)	CHG emissions in the transport sector	Computable partial equilibrium model	A significant decline in new-car specific emissions, due to a switch in purchasing behaviour to diesel vehicles rather than a move to smaller and less powerful vehicles.	See section 2.2.5
Japan (JPN)	2012	Amano et al. (2010)	CO_2 / Optimal renewal planning of energy supply system for office buildings.	Computable partial equilibrium model	Doubling carbon tax rate, the optimal renewal year becomes 1 year earlier in order to decrease the CO_2 emission and to reduce the carbon tax.	See section 2.2.5
Norway (NOR)	1991	Bruvoll and Larsen (2004)	CO_2 emissions	Computable general equilibrium model	The carbon taxes contributed to only 2 percent of the CO_2 reduc-	See section 2.2.5

Country/Jurisdiction	Starting Year	Study	Tax Base / Research Topic	Evaluation Method(s)	Key Findings: Tax Effects Found	Key Findings: Other Benefits and / or Drawbacks
					tion of 14 percent. Tax exemptions and relatively inelastic demand in the sectors are responsible for this result.	
		Lin and Li (2011)	CO_2 emissions	Difference-in-differences	See Denmark	See Denmark
South Africa (ZAF)	2016	Alton et al. (2014)	CO_2 emissions / Ex-ante evaluation of the planned CO_2 tax	Computable general equilibrium model	A carbon tax of about US$3 per ton in 2012 rising linearly to US$30 per ton by 2022 reduces emissions to targeted levels.	See section 2.2.5 A challenge was to identify an appropriate baseline scenario (counterfactual).
Sweden (SWE)	1991	Lin and Li (2011)	CO_2 emissions	Difference-in-differences	See Denmark	See Denmark
Switzerland (CHE)	2008	Ecoplan et al. (2015)	CO_2 emissions on heating and process fuels	A: Partial analysis based on time series (not discussed in section 2.2) B: Computable general equilibrium model	The CO_2 levy reduced the CO_2 emissions on fossil fuels between 2.5 to 6% measured against the relevant CO_2 emissions of fossil fuels in 2013.	The calculation of the baseline scenario (counterfactual) of model A was challenging because of data problems (aggregated data, structural breaks)
United Kingdom (GBR)	2013	Tovar (2011)	Evaluation of the dieselisation policies for household's car in order to increase energy efficiency in the transport sector.	Discrete choice model based on survey data.	Taxes on fuel prices is the most effective policy combination to reduce the total amount of energy consumption and CO_2 emissions.	Availability of detailed survey datasets on the research data.
New South Wales (AUS)	1999	Ancev et al. (2012)	NO_x emissions	Fixed effect estimation	Due to too low environmental taxes in NSW, the incentives for generators to reduce their emission intensities across air pollutants are not sufficient.	See section 2.2.3
		Contreras et al. (2014)	NO_x, SO_x, FPM and CPM emissions	Fixed effect estimation		See section 2.2.3
Italy (ITA)	2002	Cellura et al. (2013)	Tax deduction for energy retrofit actions of buildings	Input-output-model (CGE)	The rebound effect can partially avoid the obtained benefits.	See section 2.2.5
Netherlands (NLD)	1990	Lin and Li (2011)	CO_2 emissions	Difference-in-differences	See Denmark	See Denmark
New Zealand (NZL)	2002	Scrimgeour et al. (2005)	Energy, carbon, petroleum	Computable general equilibrium model	An energy tax based on the energy content of fossil fuel would be an effective instrument to reduce carbon emissions although the energy tax is not as effective as a carbon tax.	See section 2.2.5
Several Countries		Pilavachi et al. (2008)	Ex-post evaluation of the results Modèle de prospective de la demande énergeétique à long terme	Ex-post evaluation of the results CGE Models.	For three main reasons, the energy models were unable to pro-	See section 2.2.5

Country/Jurisdiction	Starting Year	Study	Tax Base / Research Topic	Evaluation Method(s)	Key Findings	
					Tax Effects Found	Other Benefits and / or Drawbacks
			(MEDEE) and Energy flow optimization (EFOM) for 10 EC member states		vide with precise forecasts: unanticipated strong political decisions, Unexpected energy requirements, the definition and availability of statistical data.	
		Cames and Helmers (2013)	Critical evaluation of the European diesel car boom	Engineering estimates	The European diesel car boom did not cool down the atmosphere. Moreover, toxic NO_x emissions of diesel cars have been underestimated up to 20-fold in officially announced data.	See section 2.2.1
		Ó Broin et al. (2015)	Empirical analysis of the more than 250 space heating-focused energy efficiency policies in 14 EU Countries	Fixed effect estimation with panel data.	Regulatory policies reduce demand in the year in which they are introduced and for at least 7 years thereafter.	Comparable data is obtained from the MURE policy database (see http://www.measures-odyssee-mure.eu)
Reviews (Several Countries)			CO_2 emissions	Review	See appendix	See appendix
		Ürge-Vorsatz et al. (2007)	CO_2 emissions in the building sector	Review	Appliance standards, building codes, tax exemptions and voluntary labelling were found to be the most effective policy instruments.	
		Auld et al. (2014)	Development and use of low carbon technologies	Review	See appendix	See appendix

4 Discussion and Outlook

Comparing explicit carbon tax schemes around the world is challenging. As has been shown, effective tax rates may be much higher compared to explicit ones. Furthermore, there is a great variety in designs of explicit carbon tax schemes having been implemented or intended to be implemented around the world. They vary widely concerning their applied tax base, the tax rate, the use of the tax revenues, time periods as well as the measures to prevent emissions leakage. Data from the World Bank, covering around 40 countries, reveals that applied explicit tax rates range from less than US$ 1 in Mexico to US$ 130 in Sweden. In addition, it is often the case that industries, which have already been covered by other environmental policies (e.g. an emission trading system), are fully or at least partly exempted from an explicit CO_2 tax. Tax exemptions differ from country to country and are often coupled with alternative policy choices. If the choice of policies is left to the regulated entities, selection bias issues are likely to occur and need to be addressed in the evaluation. Those and other policy design choices influence the approach that is best suited to evaluate the tax impact. What is more, the use of the tax revenues may also affect the evaluation of the tax impact. If the tax revenues are earmarked, e.g. used to subsidise energy efficiency measures as in various building programs, those effects need to be separated from the original tax effect.

For countries that introduced environmental tax schemes at the beginning of the carbon discussion in the nineties, mainly Scandinavian countries, there are a substantial number of ex-post evaluations and even reviews available. Countries that introduced their carbon tax schemes later still lack ex-post evaluations. On the whole, the results of the existing evaluations are mixed. Often, a significant effect on the amount of CO_2 emissions can be detected, however, it is sometimes difficult to assign the effect to the tax since other effects are more important or the tax is too low in order to clearly assign variations in the emissions to the tax. Ex-ante evaluations with CGE models are often more optimistic in detecting a tax effect. The reason for this may be that special influences are not taken into account in those models, such as transaction cost or bounded rationality of actors, which may in reality play a non-negligible role and can actually lead to a lower reaction than those models do in fact predict.

For future evaluations it would be helpful if the responsible policy makers would think about potential evaluations before a new tax scheme is implemented and would prepare for data-gathering well in advance. Accompanying surveys would open the possibility to apply more elaborate statistic techniques such as discrete choice models. In the end, both, a well-prepared panel dataset and a sound evaluation method, can, in turn, greatly improve the robustness and generalization of evaluation results and the controlling for possible interactions between different policies.

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Appendices

The following appendices contain short summaries of a selection of typical ex-post evaluations and reviews referring to details such as the aim, the underlying data, the method and the main results.

1. British Columbia (CAN)

Name of Instrument	BC carbon tax
Year of Introduction	2008
Participants	All consumers of fossil fuels
Tax base	Fossil fuels used within the province, accounting for 70–75% of all GHG emissions in the province.
Tax rate	CAN $ 30/t (2012)
Paper	Murray and Rivers (2015): British Columbia's revenue-neutral carbon tax: A review of the latest "grand experiment" in environmental policy
Aim / Content	Review of existing evidence on the effect of the tax on greenhouse emissions, the economy, and the distribution of income.
Data	Various
Method	Mostly numerical simulation models and econometric approaches, typically difference-in-difference approaches.
Result(s)	Empirical and simulation models suggest that the tax has reduced emissions in the province by between 5% and 15% since being implemented. The tax has had negligible effects on the aggregate economy, despite some evidence that certain emissions-intensive sectors face challenges. Studies differ on the effects of the policy on the distribution of income, however all studies agree that the effects are relatively small in this dimension. Polling data shows that the tax was initially opposed by the majority of the public, but that three years post- implementation, the public generally supported the carbon tax.

2. Norway (NOR)

Name of Instrument	CO_2 Tax
Year of Introduction	1991
Participants	Industry and energy sector.
Tax base	Mineral oil (including auto diesel), petrol, natural gas and LPG. Coke and coal up until January 2003.
Tax rate	Between 0.0060 € and 0.1471 € per assessable unit.
Paper	Bruvoll and Larsen (2004): Greenhouse gas emissions in Norway: do carbon taxes work?
Aim / Content	Revealing the driving forces behind the changes in the three most important climate gases, CO_2, methane and N_2O in the period 1990–1999.
Data	Data on emissions to air, energy use and production are documented in the emissions accounts and the National accounts of Statistics Norway.
Method	i) **Decomposition** of the observed changes in the climate gases CO_2, methane and N_2O from 1990 to 1999 into eight different driving forces, in order to reveal the main driving forces behind the climate gas changes over the last decade. This decomposition provides a detailed description of the total effect of prices, technological progress, policy measures and other factors influencing the economy. ii) **Disaggregated general equilibrium model (AGE model),** which is based on empirical estimates of elasticities to look into the **partial effect of carbon taxes.** iii) **Counterfactual analysis** to compare the model simulations for 1999 with and without carbon taxes.
Result(s)	The model simulations indicate a tax contribution to the CHG in emissions reduction of 2.3 percent. The small effects are partly related to the exemption from the carbon tax for a broad range of fossil fuel intensive industries.

3. Switzerland (CHE)

Paper	Ecoplan et al. (2015): Wirkungsabschätzung CO_2-Abgabe
Aim / Content	Impact evaluation of the Swiss CO_2 levy on heating and process fuels. The levy was introduced at an initial rate of CHF 12 per ton of CO_2. It was gradually increased to CHF 84 by 2016.
Data	Module A: Aggregated Data from the overall energy statistics (Swiss Federal Office of Energy) Module B: Swiss input-output table 2008 comprising 18 sectors and the GTAP database for the other countries.
Method	Module A: Estimation of two scenarios based on a time series analysis. The research design is based on a comparison of two simulation results. The scenario "with levy" is the reference scenario with empirical observable energy demand, whereas the counterfactual is a hypothetical energy demand "without levy". Module B: Historical versus counterfactual analysis of CO_2 emissions if no CO_2 levy had been implemented based on the macroeconomic GEMINI-E3 model.

Result(s)	The CO_2 levy has reduced the CO_2 emissions on fossil fuels between 2.5 to 6% measured against the relevant CO_2 emissions of fossil fuels in 2013. The largest portion of this reduction is coming from substitution effects towards less CO_2 intensive respectively or CO_2 free energy sources. The increase of the levy intensified this substitution effect.

4. New South Wales (AUS)

Name of Instrument	Load-based licensing (LBL)
Year of Introduction	1999
Participants	85 industrial facilities
Tax base	NO_x emissions
Tax rate	0.0251 € per kg assessable load / 0.3533 € per kg assessable load above the fee rate threshold
Paper	Ancev et al. (2012): The New South Wales load based licensing scheme for NO_x: Lessons learnt after a decade of operation
Aim / Content	Evaluation of the effects of a Load based licensing (LBL) taxation on emissions of NO_x by licensed emitters in NSW. Emitters either pay the load-based fee or abate. Short run, long run responsiveness depends on the costs between investing in end-of-pipe technology and adjusting the existing production process and the on the way emissions are monitored and reported.
Data	Source: NSW Department of Environment, Climate Change, and Water (DECCW) Annual NO_x emissions, physical output, components of the load based fee formula, the administration fee paid, emission-monitoring practices, and participation in pollution reduction projects for 85 industrial facilities (hereafter referred to as licensees) licensed to emit NO_x in NSW over the period 2000 to 2009. Licensees are classified into fifteen activity groups (industries) according to the primary purpose of the activity that results with NO_x emissions (Table 1, page 73). Dataset: Unbalanced Panel Data with 637 observations
Method	Standard Panel data analysis with unobserved licence-specific fixed effects. These effects are assumed time in invariant (fixed effects estimation)
Result(s)	The variation in NO_x emissions cannot be clearly attributed to the effects of the LBL scheme.

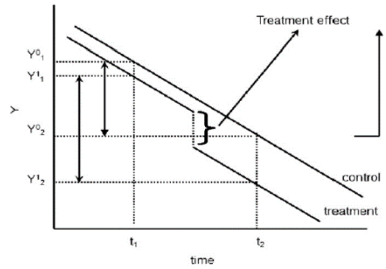
Name of Instrument	Load-based licensing (LBL)
Year of Introduction	1999
Participants	electricity generation industry
Tax base	NO_x, SO_x, FPM and Coarse Particulate Matter (CPM) emissions
Tax rate	0.0062 € - 0.1767 € per kg assessable load / 0.0122 € - 0.7066 € per kg assessable load above the fee rate threshold.
Paper	Contreras et al. (2014): Evaluation of Environmental Taxation on Multiple Air Pollutants in the Electricity Generation Sector - Evidence from New South Wales, Australia
Aim / Content	Evaluation of the effectiveness of environmental policy under the NSW LBL scheme to reduce air pollution, focusing on the joint effect on Nitrogen Oxides (NO_x), Sulphur Oxides (SO_x), Coarse Particulate Matter (CPM) and Fine Particulate Matter (FPM) from electricity generators in New South Wales (NSW), Australia.
Data	Source: NSW Department of Environment, Climate Change, and Water (DECCW) Dataset: Panel Data with 263 observations for ten individual power plants in NSW over 1999 to 2009
Method	Seemingly unrelated regression (SUR) model with generator-specific fixed effects. The model includes a lagged term (Δefftax) to account for likely physical or financial constraints that generators face in responding to tax increases or other price developments.
Result(s)	The environmental taxes in NSW have been too low compared with marginal abatement cost estimates and so, they have not created sufficient incentives for generators to reduce their emission intensities across air pollutants.

5. New Zealand (NZL)

Name of Instrument	Combination of energy taxes, fuel taxes, carbon taxes and other measures
Year of Introduction	2002 onwards
Participants	Multi-Sectors
Tax base	Energy, carbon, petroleum
Tax rate	The rate of taxation in is set so that each type tax collects revenue equivalent to 0.6% of GDP in the base-case.
Paper	Scrimgeour et al. (2005): Reducing carbon emissions? The relative effectiveness of different types of environmental tax: The case of New Zealand

Aim / Content	The paper shows simulation results that show the impact of alternative carbon, energy and petroleum taxes on the New Zealand economy and the competitiveness of industry sectors including energy intensive industries.
Data	Simulation model (CGE)
Method	Enhanced computable general equilibrium model (CGE) where there is an emphasis on modelling an energy sector, which allows inter-fuel and capital-energy substitution possibilities.
Result(s)	An energy tax based on the energy content of fossil fuel would be an effective instrument to reduce carbon emissions although the energy tax is not as effective as a carbon tax. Policy instruments such as a carbon tax would adversely affect capital stocks. The reduction in the economy's capital stock would ceteris paribus lead to reductions in GDP, household consumption (an indicator of welfare change) exports and investment. This highlights the existence of some important trade-offs which require consideration by policy makers.

6. Denmark, Finland, Sweden, Netherlands, Norway

Paper	Lin and Li (2011): The effect of carbon tax on per capita CO_2 emissions
Aim / Content	Estimation of the real mitigation effects of carbon tax on Denmark, Finland, Sweden, Netherlands and Norway, which were the first adopters of carbon tax.
Data	Panel data of Denmark, Finland, Sweden, Netherlands, Norway as treatment group and Austria, Belgium, Czech Republic, France, Greece, Hungary, Iceland, Ireland, Luxembourg, Poland, Portugal, Slovakia and Spain as control group. The period is 1981 to 2008.
Method	**Difference-in-difference** approach. This approach identifies the treatment effects of a policy from two angles, the **cross-sectional difference** and the **time-series difference.** The group that is influenced is called **treatment groups (Denmark, Finland, Sweden, Netherlands and Norway),** and the one that is not influenced is the **control group (Austria, Belgium, Czech Republic, France, Greece, Hungary, Iceland, Ireland, Luxembourg, Poland, Portugal, Slovakia and Spain).** The significant changes in emissions difference between the two groups after time t implies the **effectiveness of the policy.**  In order to control the heterogeneity between the control and treatment group, **other control variables (GDP per capita, industry structure, urbanization level, technological factor and energy price)** are introduced into the model.
Result(s)	The results indicate that carbon tax in Finland imposes a significant and negative impact on the growth of its per capita CO_2 emissions. Meanwhile, the effects of carbon tax in Denmark, Sweden and Netherlands are negative but not significant. The mitigation effects of carbon tax are weakened due to the tax exemption policies on certain energy intensive industries in these countries.

7. 10 EC member states (EC-10): Belgium, Denmark, Germany, Greece, France, Ireland, Italy, Luxembourg, Netherlands, United Kingdom

Paper	Pilavachi et al. (2008): Ex-post evaluation of European energy models
Aim / Content	The paper investigates and compares the assumptions and the results from a European study carried out in the middle of the eighties with the combination of the so-called Modèle de prospective de la demande énergétique à long terme (MEDEE) and Energy flow optimization (EFOM) models with the targeted year of 2000 as presented in the ''ENERGY 2000'' study.
Data	Eurostat, 2007
Method	The combination of the two energy models and its forecasts are compared with actual data of energy consumption obtained from Eurostat (2007). The comparison between forecasts and reality obtained from statistical data evaluates these scenarios and determines the accuracy of the model results.
Result(s)	In some cases, the energy models were unable to provide with precise forecasts for three main reasons: i) Unanticipated strong political decisions such as closing of mines in the UK, Feed-in tariffs in Germany and World Climate Change concerns. ii) Unexpected energy requirements, like the transport behaviour and the ''Rush for gas''. iii) The definition and availability of statistical data.

8. 14 EU countries (EU-15, excluding Luxembourg)

Paper	Ó Broin et al. (2015): Energy efficiency policies for space heating in EU countries: A panel data analysis for the period 1990–2010.
Aim / Content	The impacts of more than 250 space heating-focused energy efficiency policies that have been in force at the EU and national levels in the period 1990–2010 are examined
Data	**MURE Policy Database**, which allows a **semi-quantitative impact (SQI) ranking** of each policy.

Method	Energy savings conferred by the policy portfolio in place across the EU are estimated using a **panel data regression approach** with fixed effects**.** The following explanatory variables of energy demand are defined: Energy price, personal income, outdoor climate, penetration of central heating in the building stock, time trend, which is a linear approximation of other effects that have occurred over the studied period. The latter include autonomous technical progress, fuel switching, and structural changes. EP: Aggregation of relevant policies and measures introduced at the EU and national levels since the 1970's (Categories: regulatory, financial, information). Dependent variable: unit consumption (kWh/m^2/year)
Result(s)	Regulatory policies have a strong impact already in the year of introduction, and this impact is consistent over the years that follow. Financial policies show a low impact in the year of introduction, and require a number of years before they reduce demand by >0.1% and reach statistical significance. Information policies show the opposite effect, with an increasing coefficient but falling statistical significance after being in force for 1 year.

9. Survey of 20 existing ex-post studies for Denmark, Finland, Norway, Sweden

Paper	Andersen (2004): Vikings and virtues: a decade of CO_2 taxation
Aim / Content	Review of ex-post evaluation studies on carbon taxes. The review of the literature has identified 68 evaluation studies, most of them ex-ante assessments based on various economic models. Of the ex-post evaluation studies, approximately 20 draw to some degree on the historical data concerning the response to the taxes.
Data	Various
Method	Different methods have been used for ex-post evaluations, ranging from casual interview techniques to rather complex economic models (page 19). Case studies of company responses based on interviews and some hard data. Detailed technological assessments of changes in energy technology and marginal abatement costs for particular sectors. Surveys covering a larger sample of companies using a standard questionnaire. Comparative studies using simple time-series analysis. Panel databases with statistical analysis. Bottom-up energy systems modelling. Calibration of general equilibrium models and macroeconomic modelling with historical data. Combinations of models and surveys or combinations of in-depth interviews, technological assessments and surveys.
Result(s)	The studies appear to show that emissions have been curbed when compared to business as-usual forecasts, while absolute CO_2 reduction remains the exception. The choice of methodology for ex-post analysis is obviously constrained by the resources available.

10. Review of 165 empirical, ex post studies

Paper	Auld et al. (2014): Evaluating the effects of policy innovations: Lessons from a systematic review of policies promoting low-carbon technology
Aim / Content	The paper reports on an original systematic review of **165 empirical, ex post** studies examining policies that promote the development and use of low-carbon technologies. **Policy is defined broadly** to include diverse instruments (e.g., eco-labels, voluntary agreements, emission credits, and taxes), developed, administered, and promoted by state and non-state actors (e.g., cities, states, corporations, business associations, and non-governmental organizations) that are relevant to climate change. **Aims:** i) Assessing whether policy innovations have **"lasting consequences".** ii) **Disaggregating policy designs** to understand the features and the context of policy that is associated with effectiveness. iii) The **analysis** helps to better understand the entwining of s**ociety-led and state-led policy interventions.**
Data	165 studies focused on policies promoting the development or use of low carbon technology. With 292 low-carbon policies were reviewed (Table 3, p. 449).
Method	The analytic framework comprises three components: **context, policy design, evaluation.** **Context:** Processes by which a policy problem arrived on the government agenda. **Policy design:** Focus on the 4 main policy design characteristics: i) Source of authority ii) Type of instrument: regulation (prohibition of certain types of behaviour or permission), expenditure (incentives or disincentives) and information provision (change the behaviour through providing information) iii) Policy Target: citizens, firms, governments iv) Stage of activity the policy targets: Planning, acting, and performance stages.

	Evaluation: Studies for lessons relevant to three types of evaluation: i) Process: Evaluation of implementation procedures. ii) Impact: Had the policy accomplished its own goal? iii) Efficiency: Does the outcome of a policy justify the associated costs? iv) Accountability: Responsibility to answer, to explain, and to justify specific actions. **Policy evaluation is an inherently normative act (p. 447).** The systematic review should help identify research gaps.
Design And Analysis of the review	**Databases:** academic databases (e.g., Energy Citation Database, Scopus, and Web of Science); international organizations (e.g., World Bank, UNEP, and OCED); and government reports (e.g., reports from the Auditor General's office in Canada and equivalent in other countries). Search for research published since 1970. **Keyword search in 3 steps:** Search protocol on page448 **Data collection and coding:** **Data description:** the grey literature was skewed towards positive evaluations compared to the academic literature. **Analysis:** Summary statistics for how the contextual and design characteristics co-vary with the evaluation outcomes.
Result(s)	There are differences in the evaluation results for **academic versus grey literature,** indicating that further work is needed to understand the reasons for these differences and their potential consequences. The analyzed sample is skewed towards empirically evaluate policies. **2 key findings:** i) Built-in flexibility, defined time frames, and expenditure instruments all tended to result in more positive evaluations. ii) Trade-offs across the different evaluation criteria. Voluntary reporting mechanisms in the presence of costly emission reductions provided insufficient incentives for compliance on the part of firms to use of low carbon technologies. **Issues that demand further research:** i) Interactions among government policies and those directed by NGOs and businesses require more systematic attention. ii) The need for a comprehensive approach to climate change governance and the warning that new policies need to align with existing goals and policy styles in a given jurisdiction.