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# Essays on the Economics of Carbon Taxation

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by

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# IMPRIMATUR POUR LA THÈSE

Essays on the Economics of Carbon Taxation

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FACULTÉ DES SCIENCES ÉCONOMIQUES

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*In memoriam Margrit ac Reinhard.*

# Abstract

In this thesis, three different issues related to the taxation of $CO_2$ emissions are investigated. The first one, analyzed in Chapter 1, is the fact that carbon taxes are not sustainable sources of fiscal revenue in the long term because such taxes are meant to shrink their base, and even to eventually reach carbon neutrality with the help complementary measures. The public finance issue arises when a jurisdiction that implemented a carbon tax uses the revenue it generates to lower preexisting distortionary taxes on factors of production as part of an environmental tax reform project, with the final goal of both acting against the causes of climate change and benefiting from improved economic efficiency—the double dividend hypothesis. The solution proposed in this chapter is to progressively tax renewable energy sources as the use of fossil fuels decreases, so that overall energy use constitutes the tax base instead of only fossil energy. Such a measure would also encourage lower energy use through improvements in energy efficiency, which is beneficial to society, as even renewables cause negative externalities. A theoretical model is constructed on the basis of an energy-based production function, which treats energy as a necessary input to capital. Energy is modeled as being generated from fossil and renewable sources, with distinctive U-shaped unit cost functions. Taxes are levied on both energy sources, as well as on consumption. Numerical simulations are run as illustrations, and they show that increasing taxes on both sources of energy at different rates can push to a transition away from fossil fuels, while at the same time reducing the consumption tax rate. However, improvements in energy efficiency might be required not to face a detrimental impact on production, because energy use is tied to the level of capital used, so that taxing energy amounts to indirectly taxing a factor of production.

The second issue, which is investigated in Chapter 2, is the effectiveness of the Swiss $CO_2$ levy. This chapter analyzes the short-term response of Swiss households to the 2016 and 2018 increases in the $CO_2$ levy rate regarding their fossil fuel consumption for heating and warm water. Data from the *Swiss Household Energy Demand Survey* collected between 2016 and 2020 are used to compare the trajectories of two groups: the treatment group, which consists in households whose heating systems rely on fossil fuels (heating oil or natural gas), and the control group, which contains all households whose heating systems use non-fossil technologies such as heat pumps or wood. A difference-in-difference regression model is run to estimate the impact of the two $CO_2$ levy rate increases. Inverse probability of treatment weights are included in the estimation procedure to improve the balance of the distribution of observable covariates between the treatment and control groups, as their compositions are not fully comparable. Although overall heating and warm water consumption seems to have declined since 2016, results fail to identify any specific effect on fossil fuel users in comparison to non-fossil fuel users. This lack of results suggests that taxing $CO_2$ emissions from households is not effective to push them to lower their heating and warm water consumption, at least in the short term. An explanation

could be that the levy's price signal is not salient enough. In addition, many households lack decision power over their heating consumption and the choice of their heating system because they are tenants, or they live in apartments, or both. The design of the $CO_2$ levy is thus not well adapted to their situation.

The last issue studied in this thesis is public opinion on carbon taxes, which is the topic of Chapter 3. To gather enough support to be implemented and to survive and develop through time, carbon taxes need to be accepted by the population. Elements of design as well as personal characteristics of individuals shape preferences regarding $CO_2$ tax proposals and their heterogeneity. To analyze these preferences, data from a discrete choice experiment are used. This experiment has been conducted in 2019 on the basis of the then under discussion reform of the Swiss $CO_2$ levy. Results from the econometric analysis of these data with a latent class approach show that two distinct preference profiles emerge: the *Pro-tax reform*, who support a reform of the $CO_2$ levy with an increased rate, and the *Anti-tax reform*, who stick to the *status quo* of the already existing tax. The first group is generally more left-leaning and environmentally concerned, whereas the second is more neutral regarding environmental matters and self-identify more with the right of the political spectrum. The outcome of a referendum on a reform of the $CO_2$ levy is hard to predict from these data given the relatively even split of the population between those two groups. The actual referendum that took place on June 13, 2021, ended up in a rejection of the reform by a short margin, which is consistent with the results of the choice experiment.

**Keywords:** Carbon tax, Swiss $CO_2$ levy, environmental tax reform, policy evaluation, household behavior, energy demand, fossil fuel, renewable energy, public opinion, heterogeneity, referendum.

**JEL classification:** C21, C25, H23, Q41, Q58, Y40.

# Résumé

Dans cette thèse, trois différentes problématiques liées à l'imposition des émissions de $CO_2$ sont traitées. La première, qui est analysée dans le Chapitre 1, est le fait que les taxes carbones ne constituent pas des sources de revenus fiscaux viables dans le long terme car elles ont pour finalité de réduire leur assiette fiscale, et même de finalement atteindre la neutralité carbone avec l'aide de mesures complémentaires. Ce problème de finance publique survient lorsqu'une juridiction ayant implémenté une taxe carbone, dans le cadre d'un projet de réforme fiscale environnementale, utilise les revenus que celle-ci génère afin de réduire les impôts distortifs préexistants qui touchent les facteurs de production – l'hypothèse du double dividende. La solution proposée dans ce chapitre est de progressivement imposer les sources d'énergie renouvelables à mesure que le recours aux énergies fossiles perd de l'ampleur, ce afin que l'utilisation totale d'énergie constitue l'assiette fiscale au lieu des seules énergies fossiles. Une telle mesure encouragerait également une plus faible consommation d'énergie, ce qui serait bénéfique pour la société, car même les énergies renouvelables causent des externalités négatives. Un modèle théorique est construit sur la base d'une fonction de production fondée sur l'énergie, qui traite cette dernière comme un intrant nécessaire au capital. L'énergie est modélisée comme étant générée à partir de sources fossiles et renouvelables, avec des fonctions de coût unitaire en forme de dôme inversé distinctes. Des impôts sont levés sur les deux sources d'énergies, ainsi que sur la consommation. Des simulations numériques sont utilisées comme illustrations, et celles-ci montrent qu'augmenter les impôts sur les deux sources d'énergie à des taux différents peut soutenir une sortie des énergies fossiles tout en allégeant les impôts sur la consommation. Cependant, des améliorations de l'efficacité énergétique sont requises afin d'éviter un impact négatif sur la production, car l'utilisation d'énergie est liée au niveau du capital utilisé, de sorte qu'imposer l'énergie équivaut à imposer indirectement un facteur de production.

La deuxième problématique, qui est traitée dans le Chapitre 2, est l'efficacité de la taxe $CO_2$ suisse. Ce chapitre analyse la réaction de court terme des ménages suisses aux augmentations du taux de ladite taxe qui ont eu lieu en 2016 et en 2018 quant à leur consommation d'énergies fossiles pour le chauffage et l'eau chaude. Des données issues de l'*Enquête suisse sur la demande d'énergie des ménages* collectées entre 2016 et 2020 sont utilisées pour comparer les trajectoires de deux groupes : le groupe de traitement, qui consiste en l'ensemble des ménages dont le système de chauffage est basé sur les énergies fossiles (mazout ou gaz naturel), et le groupe de contrôle, qui contient tous les ménages dont les systèmes de chauffage n'utilisent pas d'énergies fossiles, comme les pompes à chaleur ou le bois. Un modèle de régression de type « différence dans la différence » est utilisé pour estimer l'impact des deux hausses du taux de la taxe $CO_2$. Une technique de pondération égale à l'inverse de la probabilité de recevoir le traitement est appliquée au groupe de contrôle afin d'améliorer l'équilibre de la distribution des covariables observables entre les deux groupes, dont la composition n'est pas entièrement comparable. Bien que la consommation globale de chauffage et d'eau chaude a diminué depuis 2016, les résultats ne permettent pas d'identifier un quelconque effet touchant spécifiquement les utilisateurs d'énergies fossiles par rapport aux utilisateurs d'énergies non-fossiles. Cette absence de résultat suggère qu'imposer les émissions de $CO_2$ des ménages n'est pas efficace pour les pousser à réduire leur consommation de chauffage et d'eau chaude, du moins dans le court terme. Une explication potentielle est le manque de perceptibilité du signal de prix de la taxe $CO_2$. De plus, de nombreux ménages manquent de pouvoir décisionnel sur leur consommation de chauffage et leur choix de système de chauffage parce qu'ils sont locataires, ou parce qu'ils logent dans des appartements, ou les deux. Le design de la taxe $CO_2$ n'est donc pas adapté à leur situation.

La dernière problématique étudiée dans cette thèse est celle de l'opinion publique à propos des taxes carbones, qui est le sujet du Chapitre 3. Pour obtenir assez de soutien pour être mises en œuvre, ainsi que pour survivre et se développer à travers le temps, les taxes carbones doivent être acceptées par la population. Les différents éléments de leur design ainsi que les caractéristiques personnelles des individus forment les préférences relatives aux propositions de taxe $CO_2$ et leur hétérogénéité. Pour analyser ces préférences, des données issues d'une expérience de choix sont utilisées. Cette expérience a été menée en 2019 sur la base de la révision de la taxe $CO_2$ qui était alors débattue en Suisse. Les résultats de l'analyse économétrique de ces données, qui a été effectuée en suivant une approche fondée sur le concept de classe latente, montrent que deux profils de préférences distincts émergent : les *pro-révisions*, qui soutiennent une révision de la taxe $CO_2$ avec un taux plus élevé, et les *anti-révisions*, qui préfèrent s'en tenir au *statu quo*, c'est-à-dire à la taxe déjà existante. Le premier groupe est composé en moyenne de personnes politiquement plutôt de gauche et préoccupées par l'environnement, tandis que le second est composé de personnes plus de droite avec un point de vue plus neutre sur les problématiques environnementales. Le résultat d'un référendum sur une réforme de la taxe $CO_2$ est difficile à prédire à partir de ces données, étant donné la partition relativement équitable de la population entre ces deux groupes. Le véritable référendum sur la question, qui a eu lieu le 13 juin 2021, a finalement résulté en un rejet de la révision par une courte majorité, ce qui est cohérent par rapport aux résultats de l'expérience de choix.

**Mots-clefs :** Taxe carbone, taxe $CO_2$ suisse, réforme fiscale environnementale, évaluation de politique, comportement des ménages, demande d'énergie, combustible fossile, énergie renouvelable, opinion publique, hétérogénéité, référendum.

**Classification JEL :** C21, C25, H23, Q41, Q58, Y40.

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# List of Abbreviations

| | |
|---|---|
| **2SLC** | two-step latent class model |
| **AIC** | Akaike information criterion |
| **ATE** | average treatment effect |
| **ATT** | average treatment effect on the treated |
| **BIC** | Bayesian information criterion |
| **BC** | British Columbia |
| **CAIC** | consistent Akaike information criterion |
| **CBAM** | Carbon Border Adjustment Mechanism |
| **CBPS** | covariate balancing propensity score |
| **CGE** | computable general equilibrium |
| **CL** | conditional logit |
| **DCE** | discrete choice experiment |
| **DD** | double dividend |
| **DID** | difference-in-differences |
| **E-M** | expectation-maximization |
| **ETR** | environmental tax reform |
| **ETS** | emission trading scheme |
| **EU** | European Union |
| **FOP** | factor of production |
| **GDP** | gross domestic product |
| **GHG** | greenhouse gas |
| **HDD** | heating degree day |
| **HWWE** | heating and warm water expenses |
| **ICT** | information and communication technology |
| **IIA** | independence of irrelevant alternatives |
| **IPCC** | Intergovernmental Panel on Climate Change |
| **IPTW** | inverse probability of treatment weighting |
| **KS** | Kolmogorov-Smirnov |
| **LC** | latent class |

| | |
|---|---|
| **LCA** | latent class analysis |
| **ML** | maximum likelihood |
| **MNL** | multinomial logit |
| **MSD** | marginal social damage |
| **OECD** | Organization for Economic Cooperation and Development |
| **PCP** | posterior class probability |
| **PS** | propensity score |
| **RCT** | randomized control trial |
| **SimLC** | simultaneous latent class model |
| **SQ** | *status quo* |
| **SHEDS** | Swiss Household Energy Demand Survey |
| **$tCO_2$** | tonne of $CO_2$ |
| **UNFCCC** | United Nations Framework Convention on Climate Change |
| **VAT** | value-added tax |

# General introduction

Emissions of carbon dioxide can be considered as a new accounting unit of human activities. Every good or service produced embodies an effect on the concentration of $CO_2$ in the atmosphere, so that consumption decisions are not only a matter of utility and monetary costs anymore: the environment and its future are at stake. Anthropogenic climate change caused by greenhouse gas (GHG) emissions is a primary threat to our ecosystems, but much of its impact on the environment is absent from standard measures of economic activities and welfare. Nevertheless, nowadays, $CO_2$ emissions have become one of the most prominent avatars of the interconnections between the economy and the environment that have been ignored or overlooked in the past. Climate change has entered the realm of economics.

In their first report in 1990, the Intergovernmental Panel on Climate Change (IPCC)[1] already pointed to the fundamental role played by $CO_2$ emissions and the threats they cause to the world's climate and the global economy:

> "Carbon dioxide has been responsible for over half of the enhanced greenhouse effect in the past, and is likely to remain so in the future." (IPCC, 1992, p. 52)
>
> "Any predicted effects of climate change must be viewed in the context of our present dynamic and changing world. Large-scale natural events such as El Niño can cause significant impacts on agriculture and human settlement. The predicted population explosion will produce severe impacts on land use and on the demands for energy, fresh water, food and housing, which will vary from region to region according to national incomes and rates of development. In many cases, the impacts will be felt most severely in regions already under stress, mainly the developing countries. Human-induced climate change due to continued uncontrolled emissions will accentuate these impacts. [...]Increases in atmospheric concentrations of greenhouse gases may lead to irreversible change in the climate which could be detectable by the end of this century." (IPCC, 1992, p. 53)

Over the following three decades, these warnings seem to have had only little impact on total anthropogenic $CO_2$ emissions. If emissions per unit of energy or gross domestic product (GDP) have on average lowered, the global increase in production and energy use have caused an increase in total GHG emissions, as coined by the 2022 IPCC assessment report:

> "Total net anthropogenic GHG emissions have continued to rise during the period 2010–2019, as have cumulative net $CO_2$ emissions since 1850. Average annual GHG

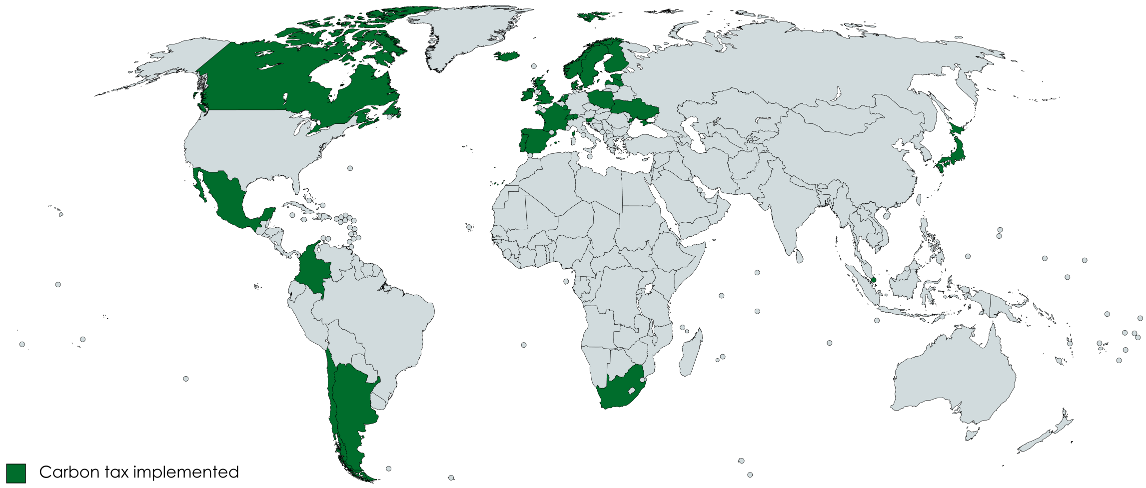
[1] See IPCC (1992) for the version with the 1992 supplement.

> emissions during 2010-2019 were higher than in any previous decade, but the rate of growth between 2010 and 2019 was lower than that between 2000 and 2009." (IPCC, 2022, p. 4)
>
> "Net anthropogenic GHG emissions have increased since 2010 across all major sectors globally. [...]Emissions reductions in $CO_2$ from fossil fuels and industrial processes, due to improvements in energy intensity of GDP and carbon intensity of energy, have been less than emissions increases from rising global activity levels in industry, energy supply, transport, agriculture and buildings." (IPCC, 2022, p. 7)

In today's world, $CO_2$ emissions are thus an unavoidable byproduct of production and economic growth. This type of pollution has indeed become inherent to modern societies because fossil fuels such as coal, oil, and gas have been the ground stones of energy production since the wake of 18th century's industrial revolution. $CO_2$ emissions are a non-monetary additional cost to all purchases; yet, the difference with the usual monetary cost is that it is hardly perceptible from an individual point of view. There is little direct connection between the amount of $CO_2$ emitted by a specific personal decision and the consequences of climate change caused by anthropogenic greenhouse gas emissions, so that individual incentives to abate are close to nil. The decoupling of $CO_2$ emissions from production and consumption is thus a challenge humanity must tackle today.

In this classical, albeit politically and technologically complex to solve, case of negative externality, economists have in their toolbox a few policy instruments to offer. One of them is so old that the very idea of anthropogenic climate change would have sounded like science-fiction at the time of its conceptualization: Pigovian taxes, named after the late British economist Arthur C. Pigou, who first proposed this concept in his 1920 book *The Economics of Welfare*. The intervention from the regulator is simply to give a price to the (here negative) externality with the help of a tax, so that all economic agents account for it in their cost function when taking decisions. The optimal tax rate per unit of externality is equal to the difference between the marginal social cost and the marginal private cost of considered decision, so that social welfare is maximized—that is, the market failure is solved. In the case of $CO_2$ emissions, this difference is an amount of $CO_2$ needing to be priced by a carbon tax expressed in monetary units per tonne of gas. The incentive issue can thus be solved: the externality is no more a vague and unrelatable concept, but a concrete, down-to-earth additional money loss for each decision whose value entirely depends on induced pollution.

Another category of instruments that can be applied to price carbon emissions are emissions trading schemes (ETS). If the principle of giving a monetary cost to the negative externality is the same as for carbon taxes, the conceptual difference comes from the way the price of $CO_2$ is determined. A carbon tax implies that a regulator chooses a tax rate *ex ante* on the basis of available information and an abatement goal—i.e., a top-down approach—whereas an ETS relies on the market to set the price of carbon. The regulator decides on an amount of $CO_2$ that can be emitted during a period, and creates a market where economic agents can trade emission permits, so that the equilibrium price should correspond to the value leading the economy to emit exactly the amount of $CO_2$ decided beforehand. Who can take part to trading and the way permits are initially allocated are the crucial questions that need to be answered: if it can work for enterprises, proper emission trading between individuals might prove close to impossible to achieve. In that regard, carbon taxation has its simplicity and cost-effectiveness of




Source: Carbon Pricing Dashboard (2022). Map created with mapchart.net.

Figure 0.1: National jurisdictions with an implemented carbon tax, 2021

implementation as practical advantages.

It is therefore no surprise that carbon taxes have long been advocated by economic policy advisers thanks to their appealing theoretical grounds and their cheap implementation costs, especially in comparison to "pull" measures such as subsidies for renewable energy production or energy-efficiency investments, which require some management for an efficient allocation and heavily draw on public revenue. The response from policy-makers and the general public has nevertheless been more contrasted regarding the inception of another policy directly affecting the purchasing power of taxpayers and hindering competitiveness.

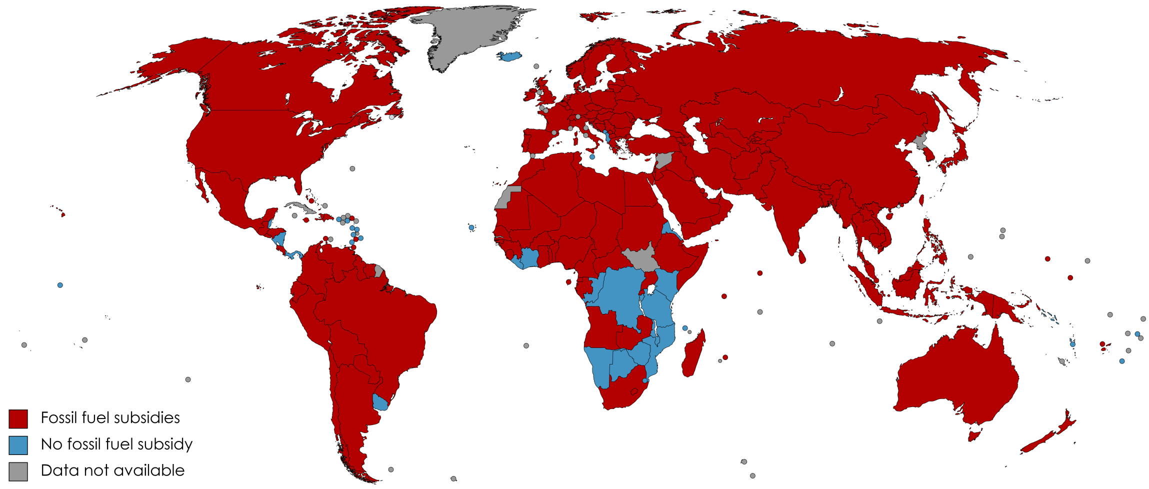
## 0.1 The political economy of carbon taxation

Although the concept of Pigovian taxes on negative environmental externalities is not new, the first proper implementations of carbon taxes as means to limit $CO_2$ emissions only date back from the 1990s. Finland was first, soon followed by the Netherlands[2], Denmark, Sweden, and Slovenia. The introduction of the first carbon taxes was part of a wider discussion on environmental tax reform (ETR), that is, a proposed shift from traditional distortionary taxes on labor and capital to a system based on environmental taxes aiming at both collecting revenue and correcting externalities (see Andersen and Ekins, 2009; Heine and Black, 2018). In 2021, 35 national and regional jurisdictions had a carbon tax implemented, as shown on Figure 0.1, with rates ranging from less than \$1 per tonne of $CO_2$ (e.g., Poland, Ukraine) to more than \$100 (e.g., Sweden, Switzerland).

On the other hand, 153 out of the 191 jurisdictions analyzed by the International Institute for Sustainable Development and the OECD through their *Fossil Fuel Subsidy Tracker* platform[3] directly or indirectly subsidized fossil fuels in 2020, among which all the world's major economies

[2]The Dutch authorities replaced it in 1992 by another tax based on both the carbon and energy content of fuels.

[3]See `https://fossilfuelsubsidytracker.org/` [accessed September 9, 2022].




Source: International Institute for Sustainable Development & OECD (2022). Map created with mapchart.net.

Figure 0.2: National jurisdictions subsidizing fossil fuels, 2020

and most countries that tax $CO_2$ emissions (Figure 0.2). There is therefore a dichotomy between these countries' official goal of curbing carbon emissions and the policies they actually apply: consistency is lacking in that regard. Carbon taxes are unlikely to be as effective as intended in such circumstances.

The political feasibility of carbon taxation can be framed as depending on a balance of preferences regarding the environment on one side, and economic performance on the other. The very purpose of the tax is to limit activities causing $CO_2$ emissions, which implies that there must be restrictions to production and consumption in the short term, before substitutes to polluting technologies are found and used. It is therefore almost certain that there will be transitional costs that will cause a loss of competitiveness *vis-à-vis* other jurisdictions with lower carbon prices. In the long run, sliding away from fossil fuel technology might eventually be beneficial for economic growth as it fosters innovation (Baranzini et al., 2017), but this horizon is uncertain.

Time plays a key role: there is a trade-off between facing economic costs today to lower environmental costs tomorrow, and enjoying economic welfare today at the expense of future generations. This intertemporal cost-benefit analysis only involves today's economic agents, so that there might be a bias toward preferring the present and certain economic benefits to the future and all the unknowns surrounding the concrete consequences of climate change and the extent of the effectiveness of dramatically decreasing $CO_2$ emissions now. The level of social discounting of the future and transgenerational altruism of course matter in this context (see Wesley and Peterson, 1993).

A suggestion to counter negative impacts on performance lies in the *double dividend* (DD) hypothesis, which states that proceeds from carbon taxation should be used to lower the marginal tax rates of other distortionary taxes such as direct taxes on factors of production or indirect taxes on consumption. By doing so, it could be possible to achieve better economic performance than before, or at least to partly or completely compensate for the negative economic effects of taxing fossil fuels. However, the DD argument has been extensively challenged (see, e.g., Goulder, 1995, 2013), so that the extent of its validity remains debated. The existence of this possibility nevertheless gives policy-makers shorter-term benefits to consider when deciding on their conduct of environmental policy.

The design of carbon taxes reflects political and social tensions surrounding them. The impact on competitiveness and overall economic performance is one of the major reasons for the legal sophistication of these policies because it heavily weighs on designing decisions, as underlined by OECD (2017). Marron and Toder (2014) identify three main sources of contention regarding the design of carbon taxes: setting the rate, collecting the tax, and using the revenue—to which the definition of the tax base could be added. The rate of the carbon tax, that is, the market price of $CO_2$ emissions, is of course central, as it determines most of the policy's environmental and economic impacts. If the Pigovian approach concludes that the price of $CO_2$ should correspond to its marginal social cost, determining this cost might be close to impossible in practice, given its invisible and fluctuating nature. Competing interests also play a role, as the competitiveness of some economic sectors that generate a lot of $CO_2$ emissions will be balanced with preferences for the environment.

Whereas tax collection is less controversial as it is mostly a technical matter, the use of revenue has a major influence on the outcome of the political process leading to the introduction of a carbon tax. Revenue recycling can serve to finance general government spending, like in Norway or Sweden (Sumner et al., 2011), but proceeds are often either earmarked for environmental investments (OECD, 2017) or returned to the public through marginal tax rate cuts, like in British Columbia (Harrison, 2013), or transfers, like in Switzerland (Ott and Weber, 2022). Deciding on how revenue should be used is therefore a matter not only of economic efficiency, but also of social preferences, and many different options are available to policy makers (see Marten and van Dender, 2019).

Another element of design identified by OECD (2017) is of prominent importance regarding competitiveness concerns: the coverage of the carbon tax. Differential tax rates and full or partial exemptions are usually included for specific sectors (Sumner et al., 2011), which complicates the policy design and the assessment of the impacts of the tax. $CO_2$ emissions from an economy may thus not have the same price depending on their source to attenuate the negative economic effects on some energy-intensive sectors. The *effective* average price of carbon is thus likely to be significantly lower than the carbon tax rate (see OECD, 2013, 2016, 2018, 2021; Rafaty et al., 2020).

Although competitiveness concerns have a fundamental influence on the rate of the $CO_2$ tax and the sources and emitters it covers, distributional issues are another key parameter to take into account. A worry can be that carbon taxation is regressive, as it increases the price of fossil fuels and hence energy. Because lower income households tend to spend a larger share of their income on energy than more affluent ones, the burden of the tax might hence not be proportional to income, which is equivalent to indirectly levying a regressive income tax. Revenue recycling can be used to compensate for this phenomenon depending on how it is implemented (see Marron and Toder, 2014; OECD, 2017). These concerns therefore shape the political debate on the design of carbon taxation policies.

In a democratic context, the political feasibility of a carbon tax design depends on public opinion toward it. All policy attributes have an influence on its acceptance: in general, higher rates tend to reduce it, earmarking revenue for environmental protection or redistributing it to the public as transfers (and not marginal tax rate cuts) increase it, as do time and experience with carbon taxation (see Carattini et al., 2018). Individual characteristics such as gender, age, education, income, living area, political preferences, or trust in the government and politics, also play a central role (Levi, 2021). Economically and politically optimal designs might thus not have the same features, as they are not the results of the same preference-forming processes between individuals, enterprises, and the authorities.

The design of a carbon tax matters before its implementation as it is a necessary step to its coming into existence. Nevertheless, carbon taxes' impacts on the environment, the economy, and society, are fundamental to their political survival. A large body of computable general equilibrium (CGE) studies have investigated these questions from a macroeconomic perspective. Freire-González (2018) finds that most CGE analyses identify a positive environmental effect (i.e., lower $CO_2$ emissions), whereas economic impacts are ambiguous regarding the possibility of achieving a DD. *Ex-post* empirical (non-CGE) studies reviewed by Green (2021) and Metcalf (2021) generally find only small reductions in carbon emissions—too low in comparison to the ambitions of the 2015 Paris Agreement goals (UNFCCC, 2015). Green (2021) also highlights that ETSs seem to achieve lower levels of emissions abatement than taxes—another argument in favor of the latter.

On distributional issues, existing evidence reviewed by Wang et al. (2016) broadly tends to conclude that carbon taxation is regressive in developed economies, while findings on developing countries are not very conclusive. Concerning households' energy consumption, the effects are generally more regressive regarding fossil fuels used for heating than for transport—progressive effects have even been identified in that sector, especially regarding developing countries (Heine and Black, 2018; Ohlendorf et al., 2021). Concerns apropos distributional effects of $CO_2$ taxes therefore seem to be partly backed by empirical evaluations. Choices on the use of carbon tax proceeds and their redistribution to the population matter in that regard, as they can influence the net impact of $CO_2$ taxes across the distribution of income and wealth in society (see, e.g., Beck et al., 2015).

Finally, political factors frame options in terms of design and implementation possibilities of carbon taxation policies. The association of left-wing ideology with the acceptance of $CO_2$ taxes has been validated by empirical studies (see, e.g., Levi, 2021), which is consistent with the overall association of environmental concern with the left found in the literature, in terms of both individual ideology and party affiliation (Cruz, 2017). The general political orientation of the majority of citizens and its evolution through time open or close opportunities to create and apply carbon taxation. The political context and the appropriation of environmental questions by political groups are also crucial.

In that regard, Harrison (2013) provides an interesting account of the development of British Columbia's carbon tax. This policy finds its origins in the coexistence in 2007 of increased environmental concern among the population, an available alternative to fossil fuels thanks to hydropower, a committed Premier with a relatively strong institutional capacity to put forward new policies, and a favorable balance of political parties. This last element is interesting, in that the proposal of a carbon tax came from a center-right party (the Liberal Party), and not the social democratic opposition (the New Democratic Party). Harrison's (2013) explanation is that there was no significant right-wing opposition to the Liberal Party at that time in British

Columbia, so that attracting centrist voters with such a policy could reinforce the party's position. The outbreak of the 2008 Great Recession also helped the Liberal Party to stay in power given its perceived better ability to handle economic issues, so that the carbon tax survived after the next elections despite the opposition from the New Democratic Party (which found it unfair). This example illustrates the importance of a propitious political context for the successful implementation of a carbon tax, and that many factors can influence its fate.

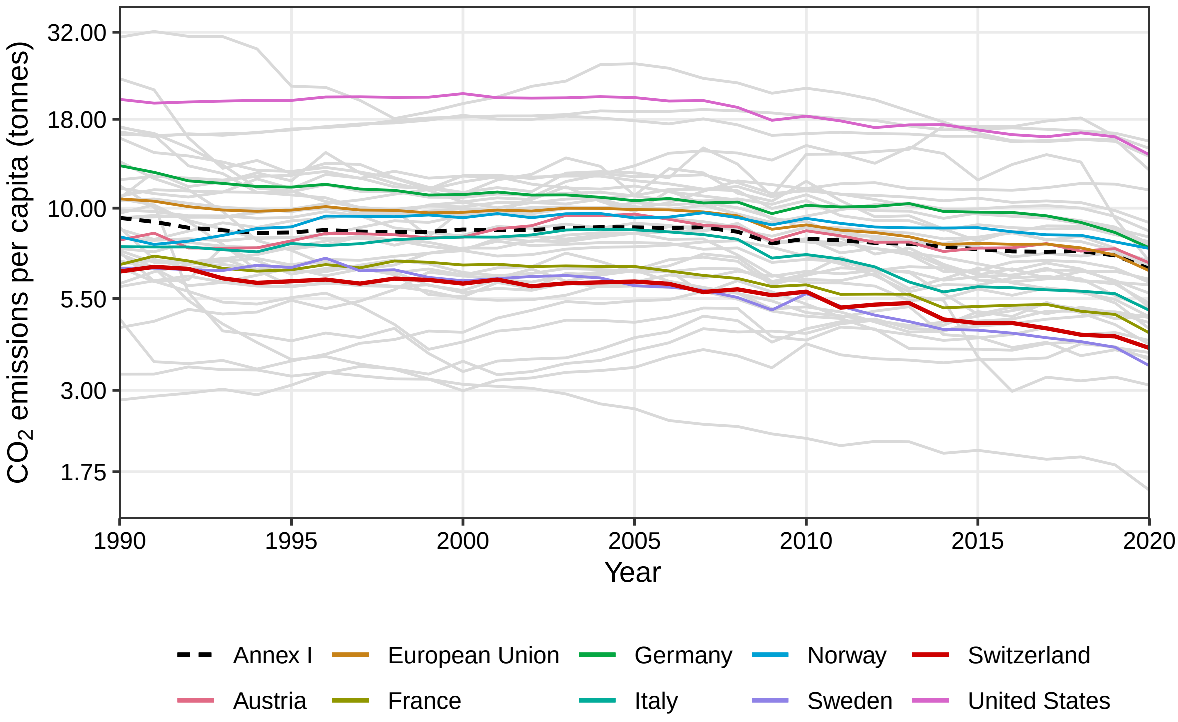
The political economy of the taxation of $CO_2$ emissions is therefore a complex, multifactorial issue, that simultaneously involves positive and normative considerations on its design, contrasted evidence from empirical literature, and a strong influence of political preferences and circumstances on its implementation. From the conceptualization of carbon taxes to their existence and the materialization of their consequences, many parameters play a role, and none of them should be underestimated. The political life cycle of a carbon taxation policy could thus be summarized as a dynamic process composed of the following subsequent steps:

1) Conceptualization: discussion of theoretical considerations regarding carbon taxation.
2) Design: operationalization of theoretical concepts as policy attributes.
3) Adoption: support by political authorities, the population, and other stakeholders of an acceptable policy proposal.
4) Implementation: practical decisions on rules and responsibilities.
5) Application: effective management of the policy and monitoring of its effectiveness.
6) Survival: maintaining a sufficient level of acceptance among stakeholders for the policy to stay in place.
7) Reform: adaptation of the policy to unforeseen events and new needs to maintain its relevance.
8) Demise: removal of the policy when not needed anymore or if proved ineffective.

All the different steps should be considered in the study and the making of carbon taxation policies. The dynamic nature of this process should be acknowledged, in that adaptations of the policy over time require to go back to conceptual and design considerations, meaning that this life cycle loops until either stagnation (nothing changes anymore) or the cancellation of the policy. This is particularly true in Switzerland, where voting processes involving direct democracy are notoriously frequent. Policy makers must therefore pay attention to the adequacy of their policies to the will of the majority, be it at the moment of their first adoption or during their application and reform. The specificity of Switzerland on this regard makes it a very interesting case to study.

## 0.2 Climate policy in Switzerland

Switzerland's climate policy is designed to be in line with the United Nations Framework Convention on Climate Change (UNFCCC). This convention, signed in 1993, led to the subsequent signature of the Kyoto Protocol in 1997 and the Paris Agreement in 2015. The Paris Agreement's primary goals are the following: keeping the increase in the mean global temperature below 2°C (and ideally even below 1.5°C) with respect to pre-industrial levels and reaching zero net $CO_2$ emissions in the second half of the 21$^{st}$ century. Annex I countries of the UNFCCC, which consist in most developed and some in transition economies (mainly in Eastern Europe), and which therefore include Switzerland, commit themselves to take action at the national level to curb




Note: The scale of the vertical axis is logarithmic.

Sources: UNFCCC , World Bank.

Figure 0.3: $CO_2$ emissions per capita in UNFCCC Annex I countries, 1990-2020

GHG emissions to reach these goals. This international commitment is the basis upon which Switzerland constructs its approach to tackle climate change, including the abatement of $CO_2$ emissions.

As can be seen on Figure 0.3, Switzerland generally performs better than most other UNFCCC Annex I countries in terms of $CO_2$ emissions per capita. After having its emissions stagnating a little below their 1990 level until the late 2000s, the country saw an improvement since, with a steady decrease in its $CO_2$ emissions per inhabitant, like many other Annex I countries. The comparatively low level of its emissions per capita, and potentially their decrease, are nevertheless partly due to the fact that Switzerland's carbon footprint is being exported to other countries that perform most of GHG generating tasks for it, like industrial production and agriculture (see Swiss Federal Office for the Environment, 2018). The country's good performance regarding its GHG emissions should thus not be seen only as the result of a sufficiently efficient climate policy. More ambitious national and international actions are still needed to limit climate change.

The Swiss Federal Office for the Environment published in 2018 a report on the implementation of the Paris Agreement goals in Switzerland. The legal basis to reach these goals is the *Federal Act on the Reduction of $CO_2$ Emissions* (the $CO_2$ Act)[4]. The $CO_2$ Act formally defines the country's climate strategy and tools to tackle climate change. The Swiss Federal Office for the Environment's 2018 report presents Switzerland's climate policy in light of the $CO_2$ Act and

[4]The current version of the $CO_2$ Act is available at `https://www.fedlex.admin.ch/eli/cc/2012/855/en` [accessed October 22, 2022].

the Paris Agreement's targets. It provides a summary of the different instruments the country possesses to reach them in four sectors with the highest emissions abatement potential: transport, buildings, industry, and waste management. It also presents seven policy instruments of different natures, each of which applies to one or more of the aforementioned sectors. These instruments fall into three categories: carbon pricing mechanisms[5], regulation, and subsidies.

Two carbon pricing instruments coexist in Switzerland: the $CO_2$ levy—i.e., a carbon tax—and an ETS. The $CO_2$ levy is a tax levied on non-motor fossil fuels, depending on their carbon content, at a current rate of CHF 120 per tonne of $CO_2$. The ETS exists in parallel to the $CO_2$ levy for energy-intensive firms—except waste incineration plants—so that they trade emissions permits instead of paying the carbon tax. Exemptions to the $CO_2$ levy exist for energy-intensive firms in specific sectors that choose to make an agreement with the Swiss authorities on emissions abatement instead of paying the tax. These two instruments are more precisely described and discussed in Section 0.3.

Three instruments belong to the "regulation" category, two of which apply to the transport sector and one to industry and waste management. The first one is the set of limits to $CO_2$ emissions for new vehicles imported to Switzerland. Newly registered cars thus face those restrictions, and their importers are responsible regarding the application of emissions standards. Limits to $CO_2$ emissions are also planned for buildings in the future.

The second regulatory policy is specifically designed for the transport sector: the mandatory compensation of $CO_2$ emissions for fossil motor fuel importers. They must compensate part of $CO_2$ emissions from the transport sector by carrying out their own emissions abatement projects or by purchasing emissions certificates. The compensation price must not exceed 5 cents per liter of fuel. In 2022, 17% of emissions caused by transport must be offset through this mechanism, and this share should increase to 23% in 2024[6].

The third regulatory policy concerns waste incineration plants. As they cannot join the ETS, a sector-specific agreement is concluded between the association of the managers of waste treatment plants and the federal authorities to decide on $CO_2$ emissions abatement measures and carbon capture and storage projects for the future[7]. The preferential treatment of this sector is justified by the fact that these plants have a legal duty to incinerate waste. This implies they have limited room to lower their emissions, because they depend on how much waste households produce.

Finally, two subsidy programs have been set up by federal authorities: the Buildings Program and a technology fund. The Buildings Program is a building refurbishment program funded by part of the proceeds from the $CO_2$ levy that aims to support energy-efficient renovations of existing buildings in Switzerland. The technology fund is a credit guarantee program for firms producing innovative products to lower GHG emissions. It is also funded by the revenue of the $CO_2$ levy.

Overall, Switzerland's climate policy consists in a mix of carrot and stick policies: there is some

[5]For a review of ecological taxes in Switzerland, see Daguet (2014).

[6]See `https://www.bafu.admin.ch/bafu/en/home/topics/climate/info-specialists/reduction-measures/compensation/motor-fuels.html` [accessed October 22, 2022].

[7]See `https://www.admin.ch/gov/fr/accueil/documentation/communiques.msg-id-87605.html` [accessed October 22, 2022].

funding available for projects aiming at lowering $CO_2$ emissions both in the building sector and in industry, but other policies, like the $CO_2$ levy, reflect a more coercive stance on how to push emitters to act and lower their emissions. Nevertheless, this tendency to favor the stick over the carrot might change from 2024, as a reform of the $CO_2$ Act is currently under discussion after a failed first attempt in 2021.

On September 16, 2022, the Federal Council adopted the Message (i.e., a white paper directed to the Federal Assembly) concerning the reform of the $CO_2$ Act (see Swiss Federal Council, 2022). It contains the proposed new Act, with explanations on context, the reform's whereabouts, and the positions of cantonal governments and different political and economic groups in that regard. The final goal of this reform is to pursue the zero net emissions goal by 2050, with intermediary targets to reach by abating emissions nationally (at least 60% of total abatement) and abroad (maximum 40%). It focuses on "carrot"-side measures, like subsidies for energy transition in buildings and industries, the use of a larger share of the $CO_2$ levy proceeds for the Buildings Program, and an extension of the possibility of concluding exemption agreements to all firms. A paradigm change therefore seems under way.

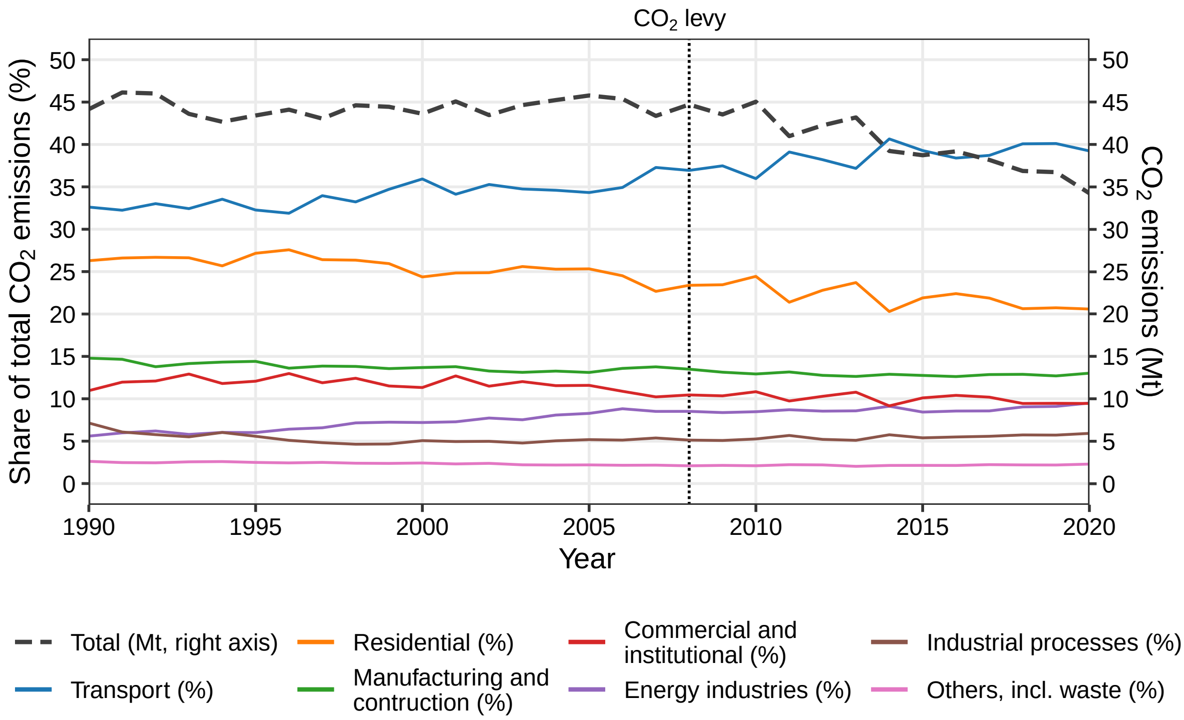
On top of measures from the $CO_2$ Act, other instruments not specifically designed to be part of Switzerland's climate policy also passively play a role in it. Three of them should be mentioned here. The first one is the mineral oil tax, which is a tax levied mainly on gasoline and diesel, which are not concerned by the $CO_2$ levy. Its rate on other types of fossil fuels is only 0.3 cents per liter, against more than 75 cents per liter of gasoline or diesel[8]. Even though this tax is primarily designed to collect revenue to finance road transport infrastructures and the government's general budget, it implicitly acts like a carbon tax that incites consumers to adapt their fossil fuel consumption to its rate.

The second instrument that acts like a climate policy tool is the performance-related heavy vehicles charge. It is a user charge levied on trucks when they drive on Swiss roads. Its rate is currently comprised between 2.28 and 3.10 cents per tonne-kilometer, depending on the European emission standard of the truck[9]—that is, how polluting it is. The performance-related heavy vehicle charge acts therefore like an indirect emissions tax, although the amount to pay is not directly computed on the basis of the volume of fuel consumed and subsequent $CO_2$ emissions. This system is nevertheless adapted to the nature of road freight, because the country where emissions are caused is not necessarily the same as the one where fuel is purchased. Levying a charge on road use and truck weight is hence a good proxy from an environmental perspective. Nevertheless, this charge is not designed as a pure environmental policy tool, in that its proceeds must mainly be used to maintain the quality of road infrastructures: it is a compensation for road wear and tear caused by foreign trucks. Part of the revenue is however also allocated to financing rail infrastructure projects, which supports a transition from road to rail freight.

The last policy worth mentioning is the need to sort waste and reduce its generation, as stated

[8]See `https://www.bazg.admin.ch/bazg/en/home/information-companies/taxes-and-duties/importation-into-switzerland/petroleum-tax.html` [accessed October 22, 2022].

[9]See `https://www.bazg.admin.ch/bazg/fr/home/infos-pour-entreprises/transport--document-de-voyage--redevances-routieres/redevances-sur-le-trafic-des-poids-lourds--rplp-et-rplf-/rplp---generalites---tarifs.html` [accessed October 24, 2022].




Source: UNFCCC.

Figure 0.4: Sectorial $CO_2$ emissions in Switzerland, 1990-2020

in the *Federal Act on the Protection of the Environment*[10]. More specifically, the Federal Court has ruled in 2011 that waste treatment should be financed by taxes directly linked to the amount of waste generated and not by general taxes[11]. It is possible not to do so only if a sufficient level of waste reduction and recycling is achieved by other means. Waste taxes and other measures meant to lower waste generation have as positive side-effects that $CO_2$ emissions from their incineration decrease. These instruments therefore complete those explicitly designed as part of Switzerland's climate policy.

The joint impact of all these instruments cannot easily be assessed without a deep analysis of each sector. It is nevertheless interesting to look at the evolution of total $CO_2$ emissions in Switzerland over time, as well as the relative shares of the main polluting sectors, which are displayed in Figure 0.4. An interesting observation is that total $CO_2$ emissions (right axis) remain at around 45 Mt between 1990 and 2010, and start to fall afterwards. This decline begins more or less at the time the $CO_2$ levy was introduced, but also at the time of the Great Recession that hit Europe and the rest of the world. The exact cause of this decrease (climate policy and/or a decline in economic activity) therefore cannot be so easily determined.

The composition of total $CO_2$ emissions (left axis) shows that transport was and remains the

[10]The full text is available at `https://www.fedlex.admin.ch/eli/cc/1984/1122_1122_1122/en` [accessed October 22, 2022].

[11]The full judgment is available at `https://www.bger.ch/ext/eurospider/live/fr/php/clir/http/index.php?highlight_docid=atf%3A%2F%2F137-I-257%3Afr&lang=fr&zoom=&type=show_document` [accessed October 22, 2022].

main source of $CO_2$ in the country, followed by the residential sector—i.e., heating homes and tap water. It can be observed that the share of the residential sector decreases over time since the mid-2000s, probably thanks to the better energy efficiency of new buildings and the refurbishment of existing ones. This is also the likely reason for the decrease of the share of the commercial and institutional sector—i.e., more energy-efficient commercial buildings. On the other hand, the share of the transport sector increases since the mid-1990s. The Swiss Federal Office for the Environment (2018) attributes the relatively bad performances of that sector to the fact that private cars have become heavier and technologically more complex over time, and thus consume more energy, and to the 30% increase in the total distance driven in Switzerland between 1990 and 2016. This sector is thus likely to stay the largest contributor to Switzerland's $CO_2$ emissions without major changes like the adoption of electric vehicles, lighter cars, or improved public transports to lower the total distance driven by polluting private vehicles.

The role played by the $CO_2$ levy in the decrease in total $CO_2$ emissions and the lowering of the residential and commercial buildings' share of emissions is hard to disentangle from that of other policies. External factors are also likely to influence Switzerland's $CO_2$ emissions, like the availability of new technologies, political pressure, and changes in global fossil fuel prices. A deeper analysis of the $CO_2$ levy is therefore necessary. The next section thus presents this instrument in more details.

## 0.3 The Swiss $CO_2$ levy

Switzerland is among the growing number of jurisdictions that implemented a carbon tax to lower its $CO_2$ emissions: the *$CO_2$ levy*. Switzerland introduced it on January 1, 2008, as a means to reduce its carbon dioxide emissions, following a decision the Swiss Federal Council took in March 2005 to fulfill the abatement goals it set in the 1999 $CO_2$ Act[12]. The first version of the $CO_2$ Act came into force in 2000 and an entirely revised version of it came into force in 2013. The first $CO_2$ Act was accompanied in 2007 by the *Ordinance on the $CO_2$ levy* that contained rules on the application of the tax. The revised version of the $CO_2$ Act is accompanied by the *Ordinance on the Reduction of $CO_2$ Emissions* ($CO_2$ Ordinance)[13] which encompasses different points covered by the $CO_2$ Act, including the carbon tax. An ETS was also created in parallel.

The carbon tax is levied on fossil fuels when they are used to produce heat, light or electricity, or to operate heat-power cogeneration plants. It does not affect motor fuels, which are primarily taxed through the mineral oil tax—this point is one of its most interesting characteristics, as it means a large share of Switzerland's $CO_2$ emissions, that is, those from transport, are not taxed by the carbon tax but by an energy tax whose purpose is to collect revenue for the general budget. The $CO_2$ levy is collected by the Swiss Federal Customs Administration when imported fuel crosses the border or when it leaves a registered tax-exempted warehouse to be commercialized. The amount to pay depends on the the approximate $CO_2$ content of each fuel, which is determined using a standardized table with information on each fossil fuel category.

The rate of the $CO_2$ levy increased by a factor of 10 between its introduction and its current rate: it started at CHF 12 per tonne of $CO_2$ in 2008 and was increased to CHF 36 in 2010,

[12]The $CO_2$ levy is presented in Chapter 5 of the Act.

[13]The $CO_2$ Ordinance is available at `https://www.fedlex.admin.ch/eli/cc/2012/856/en` [accessed May 10, 2022].

CHF 60 in 2014, CHF 84 in 2016, CHF 96 in 2018, and CHF 120 in 2022, which is its maximum potential rate allowed by the law. It is currently world second regarding the height of its rate, behind Sweden's carbon tax. The rate increased at different moments in time because emissions abatement targets set in the law were not reached.

The Swiss $CO_2$ levy has been designed as a steering tax. About two-thirds of the revenue it generates are redistributed to individuals and firms, while the remaining part (with a maximum of CHF 450m) is used to finance the Buildings Program of the Swiss government, which is a subsidy program for energy-efficient renovations of buildings in Switzerland, and a technology fund (with a fixed amount of CHF 25m). The tax amount paid by individuals is redistributed to all Swiss residents at a flat rate through their health insurance bills, while the amount paid by businesses is redistributed to employers proportionally to the annual payroll they declare to their old-age and survivors' insurance compensation office. In that regard, the design of the $CO_2$ levy partly follows the recommendations of the DD literature, which suggests to lower labor taxes with the proceeds of carbon taxation.

Whereas the taxation of individuals is straightforward to understand—they buy taxed fuels, they pay the levy—, that of companies is more complex, in that exemption possibilities exist in the law. Exemption conditions significantly changed between before and after the 2012 revision of the $CO_2$ Act. Between 2008 and 2012, businesses could apply for a carbon tax exemption by reaching an agreement with the Swiss authorities to limit their $CO_2$ emissions by setting an abatement target and presenting concrete measures to reach it. Eligible firms were large companies, fuel consuming companies getting together in groups, and companies for which the total carbon tax amount paid exceeded 1% of their gross production's value. No specific participation threshold was legally specified. Exempted firms would receive emission permits according to their target. They had to submit monitoring reports to the Federal Office for the Environment on a regular basis. They could also join the Swiss ETS on a voluntary basis to trade their emission permits.

Between 2013 and 2021, the exemption system became more formal and structured, with strict eligibility conditions and thresholds. The system became more complex, as companies could fall into three categories: energy-intensive (more than 20MW) firms emitting a lot of $CO_2$ (more than 25,000 tonnes per year) would be exempted but must take part to the Swiss ETS. Firms in specific production sectors with a high energy intensity but which emitted relatively low amounts of $CO_2$ or with a medium energy intensity (10–20MW) could choose between joining the ETS or reaching an emissions abatement agreement with the authorities to be exempted. Finally, firms with a low energy intensity (less than 10MW) in specific production sectors could decide to reach an emissions abatement agreement with the authorities to be exempted from the $CO_2$ levy, but they could not join the ETS. Sectors concerned by exemption possibilities were generally polluting, like the production of chemicals, plastics, glass, metals, machines, and so on. All other firms must pay the tax. This exemption system was clearly meant to prevent big emitters from being affected by an increase in their production costs while at the same time requiring from them measures to decrease their emissions to obtain the same environmental effect as if they would have had by paying the $CO_2$ levy.

However, on June 13, 2021, a short majority of citizens (51.6%) rejected the proposed reform of the $CO_2$ Act, which proposed to increase the maximum potential rate of the $CO_2$ levy to CHF 210, in addition to other measures to fight climate change such as a tax on flight tickets of CHF 30 to 120, and an increase in the mineral oil tax levied on motor fuels by a maximum of 12 cents per liter. The Federal Assembly promptly voted an extention of the current $CO_2$ Act until 2024 to maintain its measures until a new reform is adopted. The ETS entered in a new trading period in 2021 that should last until 2030. It was also coupled with the ETS of the European Union, so that Swiss emission permits can be traded with European ones, creating a bigger market.

The current reform project scraps most of the planned toughening of the $CO_2$ levy. It leaves the $CO_2$ levy rate at CHF 120, and no other tax should be introduced, favoring non-tax measures like subsidies. Economic lobbies and right-wing parties are generally satisfied with the less "punitive" approach, whereas the left and ecologist associations are more skeptical regarding the effectiveness of these measures to reach zero net carbon emissions by 2050 (Swiss Federal Office for the Environment, 2022; Swiss Federal Council, 2022).

The failure of the 2021 reform of the $CO_2$ Act and current political debates on the new reform illustrate the political complexity surrounding carbon taxation. The 2021 reform was backed by all mainstream parties, except the Swiss People's Party, a populist right-to-extreme-right-wing party. It was the result of long negotiations between the left and ecologist parties on one side and center-right parties on the other, so that a large majority of the Federal Assembly would support it. In the end, it nevertheless failed to convince a majority of voters. The main line of arguments against the reform concerned its economic costs for individuals as well as small and medium enterprises, and a minority of environmental activists also rejected it because of its lack of ambition *vis-à-vis* the urgency of climate change (GFS.Bern, 2021). It is therefore crucial to design a carbon tax that is both environmentally effective and economically efficient to obtain the support of a majority—the DD hypothesis has some relevance here. A better understanding of the whereabouts of carbon taxation is hence needed for it to become an effective tool of climate policy.

## 0.4 Thesis content and structure

The purpose of this doctoral thesis is to investigate deeper some of the issues raised by the idea of designing and implementing a tax on $CO_2$ emissions as a means to tackle anthropogenic climate change. Many questions emerge from the large body of literature on that topic, both from theoretical and empirical perspectives, and the contribution of this thesis is to bring new elements of answer to them while at the same time opening new discussions on our understanding of these issues. Among all the questions that can arise from carbon taxation, three of them are treated here.

The first question is the viability of carbon taxation as a means to raise fiscal revenue to finance an ambitious ETR, given that the base of a $CO_2$ tax erodes as the rate increases, which is the first purpose of such a climate policy instrument. This issue relates to the theoretical grounds of carbon taxation and considerations that need to be accounted for in the design of ETR projects beforehand. Once a carbon tax is designed and implemented, even if it is based on sound theoretical grounds, a simple question arises: its effectiveness—that is, the extent of the first dividend, which is the second issue considered in this thesis. Even though the numerous *ex-ante* simulations that exist are usually affirmative in that regard, the *ex-post* empirical literature is scarcer, so that a general conclusion on the effectiveness of $CO_2$ taxes cannot easily be drawn without a deeper investigation of the issue. A third and last question is the acceptance of carbon taxes by the general public. For such an instrument not only to be implemented, but also to develop and survive through time, it must be backed by a significant share of the population, in a democratic context. Several factors can influence acceptance, and their impacts need to be analyzed further to better understand what shapes preferences regarding carbon taxes.

This thesis is thus divided in three chapters, each of them corresponding to an essay on one of the aforementioned questions relative to carbon taxation. Together, they answer to these three interrelated problems, each of which concerns one aspect of $CO_2$ taxes. Empirical studies focus on Switzerland, as it is an interesting case that did not receive much attention from scholars until now in comparison to Nordic countries that have had carbon taxes for a longer time. In particular, the political context of Switzerland and its reliance on direct democracy tools such as popular referenda make it a good candidate for analyses related to the acceptance of carbon taxation. There are not many jurisdictions in the world where public opinion matters as much for the success of a policy than Switzerland, making it a very interesting case to study from a political perspective. Besides, as the University of Neuchâtel is a Swiss institution, doing research on Switzerland makes a lot of sense given the intended audience of the research contributions presented in this thesis.

Chapter 1 is hence concerned with the first question, i.e., the theoretical foundations of $CO_2$ taxation from a public finance point of view and the viability of such policy to raise fiscal revenue. Literature on the double dividend hypothesis does not pay much attention to the capacity of carbon taxes to raise fiscal revenue and the necessity to do substantially so in order to get a second dividend by sufficiently lowering existing distortionary taxes. However, by nature, such instruments have a negative impact on the size of their tax base, i.e., $CO_2$ emissions, and therefore the use of fossil fuels. In the long term, distortionary taxes might need to be reimplemented to maintain fiscal revenue at a sufficient level, meaning that carbon taxation does not seem to be a viable source of income for governments in the medium to long term. ETR as a project to shift the burden of taxation from factors of production—in particular labor—to negative environmental externalities is thus limited as a model of conduct for public finance.

Nevertheless, although fossil fuels as energy sources are doomed to progressively disappear, they are being replaced by cleaner, renewable sources (hydropower, wind power, solar panels, etc.). As renewable energy sources develop to replace fossil fuels, new opportunities to raise fiscal revenue emerge while the use of the latter shrinks. Energy production as well as an inefficient use of energy cause negative externalities by themselves, even if produced without emitting $CO_2$, as they usually imply an increase in land use, landscape deterioration, pressure on wildlife, and also require many materials whose extraction and transformation generate local pollution and the destruction of previously untouched natural environments. Taxing energy from renewable sources can thus be justified in order to encourage less environmentally detrimental options and to push for improvements in energy efficiency to lower overall energy use. At the same time, as energy is a necessary input to any production process, it represents a relatively reliable tax base over time because it cannot be replaced. Taxing renewables could therefore solve the issue that carbon taxation cannot represent a stable source of fiscal revenue, so that ETR and its potential benefits in terms of DD can be sustained in the long term.

The first chapter of this thesis therefore focuses on these issues and proposals. It provides an in-depth review of the debate surrounding the DD hypothesis and analyzes its implications from a public finance perspective. Then, it proposes a new partial equilibrium model constructed on an energy-based production function which treats energy as a necessary input to factors of production instead of a separate one, on the basis of Keen et al.'s (2019) proposition. Energy is modeled as being produced from both fossil and renewable sources, with different cost functions. This model allows to look further at the interactions between taxes on fossil and renewable energy sources and taxes on consumption and factors of production, both through its formal presentation and some numeric illustrations. The conclusion is that taxing renewables along with fossil fuels, although at different rates so that the transition of energy sources away from carbon is still encouraged, can be a solution to the issue of the lack of sustainability of fiscal revenue from $CO_2$ taxation.

Once initial design considerations have been solved so that a carbon tax is implemented, the second question presented above becomes relevant: is it effective from an environmental point of view? Chapter 2 tries to answer that question by empirically analyzing the effectiveness of the Swiss $CO_2$ levy, with a focus on its capacity to push households to lower fossil energy demand for heating and warm water. If discussions on the economic impacts of carbon taxes fuel debates on their design, the question of their effectiveness regarding their primary goal, that is, lowering $CO_2$ emissions, remains surprisingly little investigated in the *ex-post* empirical literature. Evaluations of existing carbon taxes are fundamental to assess the capacity of these policies to generate a first dividend, as they are supposed to do. Sound climate policy requires effective tools, hence the need to bridge the gap between theoretical design considerations and practical applications.

This second chapter focuses on Swiss households' responses to the 2016 and 2018 $CO_2$ levy rate increases, which provide interesting natural experimental conditions for an analysis of the short-term impact of a higher carbon price. The study of the short-term effectiveness of carbon taxation is important because Switzerland increased the rate of its tax progressively and linked it to yearly targets in $CO_2$ emissions abatement. An increase in the rate automatically followed a missed emissions target: implicitly, Swiss authorities assumed there would be a short-term effect of carbon taxation—otherwise, the policy design would have probably been different, with longer-term targets for instance. The short-term aspect of the question is also crucial to assess the potential of carbon taxation as a tool to lower $CO_2$ emissions quickly enough to be in line with internationally agreed targets, such as carbon neutrality by 2050 in Switzerland or the European Union. If taxing emissions is not effective in the short term, climate change mitigation policies might turn instead to non-market measures like regulation or subsidies, which can be more costly and administratively heavy to implement. There are thus good reasons to hope for the short-term effectiveness of the $CO_2$ levy.

Another important point is that the analysis presented in Chapter 2 concerns households, not firms. Because of the complexity of the $CO_2$ levy design regarding exemptions presented in Section 0.3, isolating the effect of carbon taxation as a price mechanism from other measures is hard to achieve in the case of private companies. On the other hand, all households must pay the tax on their non-motor fossil fuel consumption: they cannot avoid it. In addition, the use of fossil heating fuels (heating oil and natural gas) in the residential sector is one of the main sources of $CO_2$ emissions in Switzerland. The reaction of households to the tax is therefore important to analyze, as it determines a large part of the overall impact, and thus the effectiveness, of the $CO_2$ levy.

The empirical analysis carried out is based on household-level data from the Swiss Household Energy Demand Survey collected between 2016 and 2020. A difference-in-differences regression model is used to compare the evolution of heating consumption between households who use heating oil or gas as fuel for heating and those who produce heat through other means such as heat pumps, wood, or electric heaters. The former are thus affected by the increases in the $CO_2$ levy rate and compose the treatment group, whereas the latter remain unaffected and thus form the control group. As the composition of the two groups does not perfectly overlap, so that comparisons of the two groups might not be meaningful, inverse probability of treatment weights are used to balance the distribution of certain characteristics between the treatment and control groups by giving more weight to units in the control group who are the most likely to belong to the treatment group.

Results from the regression analysis show that although heating consumption decreases between the first and the last period for the two groups, no clear short-term effect of the increase in the $CO_2$ levy rate could be detected on the treatment group in comparison to the control group. This finding questions the relevance of the design of the $CO_2$ levy with respect to households, as they do not seem to have either the time, the willingness, or the ability to lower their fossil heating fuel demand in line with emissions abatement targets.

This apparent lack of effectiveness, at least in the short term, raises the question of the acceptance of the $CO_2$ levy by the Swiss population: who would be in favor of a policy that costs money without bringing substantial environmental benefits? This last issue is at the core of Chapter 3. Implementing a carbon tax usually provokes negative reactions from part of society. Any change in the tax, especially its rate, can also be met with little enthusiasm by the people, so that the survival of the policy, or its consolidation to toughen the policy response to climate change, can be under threat in a democratic context. Better understanding the determinants of the acceptance of carbon taxes, both in terms of design choices and individual characteristics of supporters and opponents, would help policy-makers overcome resistance to them by finding an optimal balance between citizens' heterogeneous preferences and interests.

To investigate this question, a discrete choice experiment has been run in 2019 by using the then under discussion revision of the Swiss $CO_2$ levy. This situation provided a realistic framework to elicit the preferences of Swiss residents regarding potential changes in the attributes of this policy: the tax rate and the use of generated revenue. In addition, data on the respondents have been collected, so that the influence of individual-level characteristics can be interacted with policy attributes. The experiment is composed of two parts: a first one, in which respondents are asked to select their preferred $CO_2$ levy reform among three options, and a voting experiment, where they are asked to vote on some of their preferred reform proposals.

Two latent class and a random coefficient models are used to analyze these data and the sources of heterogeneity among respondents. Latent classes are particularly meaningful, in that they show that Switzerland's population seems to be split into two distinct but relatively homogenous preference profiles: Pro-tax reform and Anti-tax reform. Respondents belonging to the first group tend to favor higher $CO_2$ levy rates and a redistribution of revenue benefiting low-income individuals, whereas those in the second group prefer lower rates and a uniform redistribution of collected revenue across all taxpayers. Results from the voting experiment point to a general support among the Pro-reform, but an uncertain approval from the Anti-reform group. Whether a reform of the $CO_2$ Act would be accepted in a popular referendum was uncertain according to the experiment's data. The 2021 referendum eventually answered this question, although the reform that has been voted differed from the situations used of the experiment, in that it included supplementary measures regarding a tax on flight tickets and an increase in the mineral oil tax levied on transport fuels, not only the $CO_2$ levy.

This thesis is thus composed of the three aforementioned chapters, which are finally followed by a general conclusion that summarizes their content and opens questions on further directions to follow for future research on the broad topic that is carbon taxation.

# Chapter 1

# The viability of raising fiscal revenue from carbon taxation

*This chapter is an original work of the author and has never been published before.*

**Abstract** This chapter investigates the issue of the viability of raising fiscal revenue from carbon taxes. A carbon tax can be used to lower preexisting distortionary taxes such as labor taxes, so that the society gets both environmental and economic benefits (the double dividend hypothesis). However, by nature, such an instrument has a negative impact on the size of its tax base, i.e., fossil fuels. In the long term, distortionary taxes might need to be reimplemented to maintain fiscal revenue at a sufficiently high level, so that carbon taxation seems not to be a viable source of income for governments. Nevertheless, as renewable energy sources develop to replace fossil fuels, new opportunities to raise fiscal revenue emerge while the use of fossil fuel shrinks. This chapter thus discusses the literature on carbon taxation and its whereabouts from a public finance perspective, with a focus on the double dividend hypothesis. It then presents a partial equilibrium model aiming to analyze the interactions between a carbon tax, a tax on renewables, and a consumption tax. It suggests that taxing energy from both fossil and renewable sources might provide sufficient fiscal revenue to avoid reestablishing other distortionary taxes in the long term.

**Keywords:** Carbon tax, energy tax, environmental tax reform, double dividend, public finance.

**JEL classification:** H21, H23, Q43, Q58.

## 1.1 Introduction

Since the 2015 United Nations Climate Change Conference took place in Paris, the implementation of carbon taxes has gained some momentum. Between 2015 and 2021, their number increased from 20 to 35 regional, national, and subnational instruments effectively in place, according to the World Bank's Carbon Pricing Dashboard[1].

Many economists have long advocated carbon taxation as a cost-efficient way to fight anthropogenic climate change caused by greenhouse gas emissions, with an explicit focus on carbon dioxide emitted by the combustion of fossil fuels. A central argument for carbon taxes proposed in the literature is that such policies might actually improve economic efficiency while at the same time delivering environmental benefits: the *double dividend* hypothesis (see, e.g., Pearce, 1991; Goulder, 1995, 2013). Put simply, the idea behind this concept is that environmental taxes correcting a negative externality, like a carbon tax on $CO_2$ emissions, could be a substitute for preexisting distortionary taxes such as labor or consumption taxes. The final goal is to both benefit from a better environment—the first dividend—and reduce existing distortions affecting production and consumption—the second dividend. Although the actual potential for a double dividend in reality is not clear (see for instance Goulder, 2013), this idea is appealing from a policy-making perspective, as it opens the door to joint economic and environmental enhancements, which are desirable from a societal point of view. Obstacles might nonetheless need to be overcome in order to see both dividends materialize.

From a public finance point of view, carbon taxes can thus be appealing means to raise fiscal revenue from new sources. Such taxes nevertheless face the inherent drawback of being implemented with the eventual goal of reaching carbon neutrality in the future, as stated in the 2015 Paris Agreement. This implies that their tax bases are set to shrink, because of carbon taxation itself, and because of other environmental policies such as emissions limits on new cars. Distortionary taxes might thus need to be reimplemented at some point to compensate, so that the second dividend cannot be securely sustained. At the same time, renewable energy sources are developed to generate the energy that used to be produced with the help of fossil fuels, so that renewables should eventually replace coal, oil, and gas. Relying on $CO_2$ taxes as sources of fiscal revenue might thus not be sustainable in the long term. However, renewables might become interesting sources of revenue for governments in the future, as their development parallels the fall in the use of fossil fuels.

The nature of carbon taxation thus raises the issue of its long-term viability as a source of fiscal revenue for governments. Under which conditions can they rely on such a policy to collect revenue and benefit from a double dividend in the long term? This chapter investigates this question in two steps. First, it reviews the literature on environmental taxes and their implications from a public finance perspective by discussing the main findings on the double dividend hypothesis and their whereabouts. Second, it proposes a simple model which allows to analyze some of the implications of carbon taxes for fiscal revenue raising and illustrates its predictions through different simulation scenarii. This chapter suggests to start taxing renewable energy sources as the use of fossil fuels decreases because of their market prices. As the price elasticity of energy is generally low, fiscal revenue can be secured in the long term by taxing all energy sources—although at different rates to encourage transition toward renewables. The viability

[1]`https://carbonpricingdashboard.worldbank.org/` [accessed January 31, 2022].

of substituting taxes on $CO_2$ emissions or renewables to preexisting taxes however relies on the assumption that energy is necessary to "activate" other factors of production such as labor and capital—that is, energy is an input to them. It nevertheless implies that taxing energy has an impact on the marginal cost of factors of production, which means it acts as an indirect tax on them. This assumption can be justified by the fact that humans and machines require energy to work; otherwise, they are inert. There is therefore a strong complementarity between energy and other factors of production, as none of them can be used in isolation to produce.

The chapter is structured as follows. Section 1.2 reviews existing theoretical and empirical findings related to how environmental taxes interact with the fiscal system and the economy. Section 1.3 discusses the relevance of carbon taxes from a public finance perspective. Section 1.4 presents and discusses a partial equilibrium model to analyze how the taxation of fossil fuels and renewables can be substituted to a preexisting tax levied on consumption[2]. Section 1.5 presents the results of simulation scenarii to illustrates some of the predictions of the model. Finally, Section 1.6 wraps up the chapter by discussing some policy implications and ideas for further research.

## 1.2 Interactions between environmental taxes and the economy

### 1.2.1 Taxing negative externalities

The taxation of $CO_2$ emissions is based on the concept of Pigovian taxes to correct negative externalities (Pigou, 1920). The initial purpose of such taxes is hence only to equate the private and social marginal costs of externality-generating activities, so that economic agents fully internalize all external (usually negative) impacts their decisions have on others. Social welfare is thus maximized. A carbon tax allows to lower $CO_2$ emissions to their theoretical socially optimal level—which is not necessarily zero. This policy instrument's basic feature is often referred to as its *first dividend*, that is, its first beneficial consequence for society: environmental protection.

In theory, the environmental effectiveness of a carbon tax raises little doubt: its rate must simply be adapted to reach its optimum from a Pigovian perspective, as agents are supposed to react accordingly. If a strong reaction is desired, then the price of carbon might simply need to be high. In practice, many difficulties can arise, though. An important one is that it is difficult, if not impossible, to determine the optimal rate of a carbon tax, as marginal social cost of $CO_2$ emissions is not directly observable. There exists however an extensive literature on methodologies to estimate externalities.

Tol (2013) analyzes 588 marginal social cost of carbon estimates from the literature and finds that they vary a lot, with an estimated mean of $196 per ton of $CO_2$ and a standard deviation of 322. He also underlines the crucial role of time preferences, in that a high rate of discounting regarding future impacts of climate change leads to significantly smaller values than a low discounting rate. Uncertainties are therefore high in this domain, meaning that setting a carbon tax at its socially optimal rate is no trivial task. Heterogeneity among economic sectors and countries also toughens the estimation of the Pigovian rate, because marginal social costs can vary a lot depending on each situation.

In the absence of clear guidelines regarding the carbon tax rate that would lead to a desired

[2]An extension to a tax levied on income is presented in Appendix 1.A.

level of emission abatement, policy-makers can choose to follow an incremental approach, where the tax rate is increased over time. An argument in favor of that approach is that it smoothens the impacts on economic agents *vis-à-vis* increasing fossil fuel prices (Marron and Toder, 2014). By looking at the trajectory of $CO_2$ emissions in parallel to their price, it is theoretically possible to manage the rate in order to achieve a pre-specified abatement path. The optimal tax rate at each moment in time could hence be approximated and adjusted if necessary.

### 1.2.2 Evidence on the environmental dividend

In the real world, the environmental effects of carbon taxation are not clear-cut. In the computable general equilibrium (CGE) and related simulation literature, carbon taxes are generally found to have a negative impact on $CO_2$ emissions, as expected (Freire-González, 2018; Maxim et al., 2019). Strong modeling assumptions regarding the reactions of economic agents to carbon taxes might however play a role here, so that this *ex-ante* result should be compared to *ex-post* empirical findings before drawing any general conclusion.

In her review, Green (2021) considers 37 ex-post studies and concludes that the impact of carbon pricing (taxes or tradable emission permits) on $CO_2$ emissions is generally present, but varying in magnitude, with many studies reporting no effect. Depending on the estimation method, results can diverge. For instance, with a time series regression model, Shmelev and Speck (2018) find no specific impact of Sweden's carbon tax on its emissions, although taxes on coal, petrol, and gas, are found to have expected negative impacts. Lin and Li (2011) find a negative, although statistically insignificant, impact of carbon taxation in Sweden, but with a difference-in-differences model this time. On the other hand, Andersson (2019), using a synthetic control model, estimates an average 6.3% annual decrease in emissions from Sweden following the introduction of a carbon tax in 1991. Results thus seem to differ across studies depending on the methodology followed.

There is therefore some uncertainty surrounding estimates of carbon taxes' first dividend, with potential doubts on its actual achievement by existing carbon taxes. This might partly be caused by the relatively low level of the effective price of carbon emissions, which lacks incentivizing power to induce massive emissions abatement such as those needed to reach the target of the Paris Agreement (see OECD, 2021). Moreover, existing research generally analyzes the impact of the *existence* of a carbon tax on emissions or fossil fuels' use, not of the rate itself, so that estimates in the literature cannot directly be understood as marginal effects of tax rate changes on $CO_2$ emissions. In this context, determining whether applied rates are optimal from a Pigovian point of view is a complicated task to undertake.

The fact that fossil fuels have relatively low price elasticities of use indicates that the extent of the first dividend depends on carbon taxes' rates. Labandeira et al. (2017) reports estimates from the literature ranging from $-0.157$ to $-0.568$, depending on the fossil fuel considered and the time horizon (less than one year or more). Caldara et al. (2019) estimate the price elasticities of supply and demand for crude oil to range from 0.021 to 0.081 for its supply and $-0.017$ to $-0.080$ for its demand—although their estimates for the elasticity of demand lack precision due to relatively high variances. These rather small values suggest carbon taxes should be high to have a substantial impact on carbon emissions[3]. Taxes nevertheless tend to have larger impacts

[3]Estimates of elasticites are usually implicitly assumed to be constant—that is, they are treated as if they do not depend on initial quantities and prices.

on demand for fossil fuels than equivalent price changes, as found by, e.g., Rivers and Schaufele (2015), Li et al. (2014), or Baranzini and Weber (2013) in the case of taxes levied on gasoline.

A few studies estimating the tax semi-elasticity of carbon taxes exist, such as Hájek et al. (2019). Studying a sample of European countries (Denmark, Finland, Ireland, Slovenia and Sweden), they estimate that an increase by €1 per tonne of $CO_2$ in the carbon tax rate can lead to a drop of 11.58 kg of annual $CO_2$ emissions per capita. Extrapolated to, e.g., Sweden in 2015, this amounts to a drop of approximately 0.28% in its total $CO_2$ emissions[4]. Using OECD data on the effective price of carbon emissions (see OECD, 2016, 2018, 2021)[5], Sen and Vollebergh (2018) find that a €1 per tonne increase in the price of $CO_2$ emissions leads to a 0.73% drop in long-term emissions for a sample of OECD countries. These estimates show that carbon emissions react to higher prices, so that a first dividend can be achieved, but the magnitude of the reaction is uncertain and could be too limited, especially in comparison to the ambitious targets set in the Paris Agreement.

### 1.2.3 Recycling environmental tax revenue

The concept of a *second dividend* of environmental taxes has been proposed by researchers such as Pearce (1991) and Goulder (1995), and further discussed by, e.g., Goulder (2013) or Zhou and Segerson (2012). It resides in the possibility of substituting environmental taxes to preexisting distortionary taxes such as labor or consumption taxes to raise revenue and lower potential deadweight losses. Labor taxes such as payroll taxes are a good example: they increase the cost of hiring workers, so that labor demand decreases, and they decrease workers' net income, which causes a drop in the equilibrium level of labor supplied, if assuming a positively sloped labor supply function. Reducing the level—and thus the impact, which depends on the incidence—of such taxes is beneficial to society, and using a carbon tax to raise new revenue instead also increases social welfare as it corrects a negative externality. The coexistence of the first and second dividends is the *double dividend* (DD) hypothesis.

On paper, this situation can benefit households, firms, and governments, at an aggregate level—there would of course be winners and losers depending on their fossil energy intensity. Based on this logic, an environmental tax reform (ETR)—the substitution of environmental taxes to those levied on, e.g., labor, capital, or consumption—appears to be a promising solution to both reduce the impact of human activities on the environment and boost economic activity. It has indeed been described as "kill[ing] two birds with one stone" (Jaeger, 2012, p. 213). In practice, the design of some existing carbon taxes include a revenue-recycling mechanism inspired by the DD hypothesis: cuts in taxes on labor and income in jurisdictions like British Columbia, Denmark, and France, or reductions in social security contributions in Finland and Switzerland (Partnership for Market Readiness, 2017). The idea of benefiting from a second dividend is thus important, because it influences design considerations for carbon taxes beyond

[4]Own computations based on Eurostat's data on Sweden's $CO_2$ emissions (40,384,962 tonnes) and population (9,747,355) in 2015.

[5]Rafaty et al. (2020) use a methodology—similar to the OECD's—developed by Dolphin et al. (2020) to construct an emission-weighted carbon price, which corresponds to the average effective market price of $CO_2$ emissions in a jurisdiction in a year. They then investigate its impact on carbon dioxide emissions growth. While they find a small negative impact of the introduction of a carbon tax on $CO_2$ emissions, their estimations do not yield any significant result regarding the semi-elasticity of a $1 change in the existing carbon price, but it should be noted that this article is only at its working paper stage of the publication process as of summer 2022.

purely environmental aspects. It is better that it relies on sound economic theory and evidence, then.

Goulder (1995) describes three forms of the DD hypothesis: the weak, the intermediate and the strong. The weak form simply posits that using proceeds from environmental taxes to lower other distortionary taxes' marginal rates lowers the overall economic cost of the tax system—without considering any environmental benefit—in comparison to a situation where the revenue they generate is redistributed in a lump-sum fashion to taxpayers. This claim is reasonable, as the two situations that are compared involve the existence of at least a distortionary tax and an environmental tax. The question is only on the way proceeds from the environmental tax are used: lump-sum transfers to taxpayers or cuts in the marginal rate of a preexisting distortionary tax. Lump-sum transfers do not affect the overall efficiency of the tax system, while cuts in the rate of a distortionary tax is welfare-improving. There is therefore little doubt that a weak DD can be achieved from a theoretical point of view as it does not require strict or restrictive assumptions to apply[6], although its magnitude remains an open question.

The intermediate form states that there exists a distortionary tax such that the substitution an environmental tax to this tax involves a neutral or even negative gross economic cost. The strong form goes a step further by saying that this benefit from tax substitution applies to any typical distortionary tax[7]. If the weak form seems plausible, the stronger forms imply that existing distortions are so large and an environmental tax lowers them so much that it becomes beneficial to substitute environmental taxes to existing distortionary taxes without even looking at environmental benefits. The stronger forms of the DD hypothesis thus look less likely to be achievable from a theoretical or practical perspective, as they usually require that the tax system is initially inefficient (Goulder, 1995). The question of whether a strong DD can be obtained is thus subject to discussion and therefore occupies a central place in the literature on the topic.

### 1.2.4 Missing the second bird

Bovenberg and de Mooij (1994) is a seminal paper regarding the limits of the strong DD argument, as it serves as benchmark for much of subsequent literature. The authors use a simple model with only one factor of production (labor) which is used to produce a clean good and a dirty good. They conclude that in a second-best economy, that is, an economy where distortionary taxes are levied due to fiscal revenue requirements[8]—in this case, a labor income tax—a strong DD cannot be achieved. More precisely, their model shows that an increase in the environmental tax rate on the dirty good generates two effects. The first one is an income effect, because of the dirty good's price increase it causes, so that real income decreases. The second is a substitution effect in consumption decisions, because consumers start to consume more clean good and less dirty good, so that the tax base of the environmental tax erodes. Due to fiscal revenue requirements, the government is unable to lower the labor income tax sufficiently to compensate: real after-tax income hence falls, as environmental taxes act as implicit taxes on dirty goods and services. The *tax interaction* effect—the creation of distortions due to interactions between the preexisting distortionary tax and the environmental tax—is larger than the

[6] This result can nevertheless depend on model assumptions, like how the labor supply would react to an increase in income thanks to the transfers in comparison to a cut in the labor tax rate, for instance.

[7] The intermediate form is generally considered as being part of the strong form, so that most literature only distinguishes between the weak and strong forms of DD.

[8] A first-best setting would be an economy where only a lump-sum tax is levied.

*revenue recycling* effect—the lowering of the marginal rate of the preexisting distortionary tax. They conclude that, overall, increasing the environmental tax rate to reduce the labor income tax rate introduces more distortions in the model than it removes. A strong DD hence cannot be achieved in these circumstances[9]. The authors nevertheless note that a weak DD can be achieved, as returning environmental tax revenue in a lump-sum fashion to the public is less efficient than lowering existing distortionary tax rates, because the first option would lead to even larger distortions in the labor market due to a larger tax base erosion (i.e., lower labor supply).

Bovenberg and de Mooij (1994) also argue, on the basis of their theoretical model, that the typical environmental tax rate is lower than the Pigovian rate in a second-best setting. They also argue that, when fiscal revenue requirements increase, the environmental tax rate should be increased at a slower pace than the rate of the tax levied on the clean good due to the distortions caused by the environmental tax, so that the differential between the two tax rates decreases. This logically means that a DD cannot be achieved in this case, as otherwise the tax rate differential would widen, as the environmental tax would generate additional benefits that the other tax would not. Fullerton and Metcalf (1997) discusses this finding by underlining this result only holds if indirect taxes on non-polluting goods lie below a certain threshold; otherwise, the inverse is correct, based on their model. However, the general message of Bovenberg and de Mooij's (1994) paper remains unchanged: environmental taxes tend to add more distortions in the market than they remove, so that a strong DD cannot be expected to materialize (Bovenberg and de Mooij, 1997). Bovenberg (1999) shows that, although it is theoretically possible to achieve a second dividend if the initial tax system is not optimal, no strong second dividend can be obtained if it is at its optimum, which is in line with the conclusions presented in Goulder (1995).

Zhou and Segerson (2012) summarize the debate on the conditions that could lead to a DD and argue, with the help of a simple static model based on Bovenberg and de Mooij (1994), that the conditions under which a second dividend can be obtained are less likely to hold when the tax revenue raised by an environmental tax is small compared to the amount generated by other taxes. The narrowness of the tax base of environmental taxes such as carbon taxes is one of the fundamental reasons why swapping environmental taxes for other distortionary taxes might not suffice to raise sufficient tax revenue to substantially benefit from a second dividend or to significantly lower public deficits, because the potential to collect fiscal proceeds is limited.

The DD argument might thus be less attractive than it initially appears: the conditions under which a strong second dividend can be obtained seem indeed rather limited from a theoretical perspective, and the prospects for a successful large-scale ETR hindered. Bovenberg and Goulder (2002) and Goulder (2013) present several issues related to how environmental taxes interact with the fiscal system[10] and conclude that there is little scope for a strong DD, except when the existing tax system is significantly suboptimal. With the help of a simple theoretical model and a CGE simulation, Babiker et al. (2003) also argue that the weak DD hypothesis might actually not hold.

If the second dividend is uncertain, the overall impact on social welfare thus heavily depends

[9]Parry (1995) reaches the same conclusion with a different model but for similar reasons.

[10]For another review of several theoretical and practical issues related to designing and implementing environmental taxes, see Parry et al. (2012).

on the first (environmental) dividend. This means that it might nevertheless be socially optimal to introduce an environmental tax for environmental reasons (Goulder, 2013): a strong DD would be a free lunch, but it can nonetheless be worth paying for it to enhance overall social welfare. Lai (2018) however warns about implementation issues for carbon taxes in a democratic context, as policies that lower labor taxes to appear more acceptable to the public might be less effective (or even detrimental) from an environmental point of view, so that the first and second dividends compete with each other, nullifying the DD hypothesis in practice. The stone might thus only be able to kill one bird at a time.

### 1.2.5 Critiques and further developments on the economic dividend

Jaeger (2011, 2012) provides a critique of these negative conclusions on the strong DD hypothesis. In these two papers, Jaeger demonstrates some of the flaws in existing literature such as Bovenberg and de Mooij (1994) to argue against the position that a strong DD is very unlikely to materialize, even in a second-best setting where distortionary taxes are in place due to tax revenue requirements. He identifies two sources of confusion that question previous arguments against the strong DD. The first one contradicts the conclusion that the environmental tax rate in a second-best setting is generally lower than the Pigovian rate set in a first-best world, which is used to argue that a strong DD is not achievable. The logic is that if there are additional benefits from environmental taxation in a second-best setting in comparison to a first-best situation, then the point at which the marginal social damage (MSD) and the marginal benefit curves intersect should be higher in a second-best world than in a first-best one—the intersection in a first-best setting determining the Pigovian rate.

The issue here is that other authors (e.g., Bovenberg and de Mooij (1994) or Fullerton and Metcalf (1997)) take MSD—which is the ratio between the marginal social disutility of environmental damages and the marginal utility of income—as an algebraic proxy for the Pigovian rate and fail to consider that MSD is not necessarily the same in first-best and in second-best settings due to differences in the marginal utility of income. An environmental tax can thus have a higher rate in a second-best setting than in a first-best one, but MSD can also be much higher, so that the finding that the second-best environmental tax rate is generally lower than the Pigovian rate is not always true. Kampas and Horan (2016) also argue that environmental tax rates in first-best and second-best settings cannot easily be compared as MSDs differ between the two and because, depending on the weights given by the regulator to environmental protection in comparison to production, the environmental tax rate can either be below, equal to, or above MSD. The argument against the DD hypothesis regarding the relative values of the environmental tax rate and the Pigovian rate therefore lacks general validity.

Jaeger's second point against the conclusion that the environmental tax rate is lower than the Pigovian rate in a second-best world relates to the type of tax base (nominal labor income or consumption/expenditures in the literature) used to raise government revenue. Jaeger (2011) demonstrates that the optimal nominal environmental tax rate will be smaller if fiscal revenue is raised through an income tax than when it is through a uniform tax on expenditures to obtain the same amount of tax revenue. The argument is simply that there is a double taxation phenomenon between the income tax and the environmental tax, the latter being an implicit tax on consumption and therefore an indirect income tax, because it impacts the level of real income. Starting from a first-best setting with an environmental tax at its Pigovian rate and introducing a labor income tax to raise fiscal revenue, the rate of the environmental tax will need to be adjusted to reach its second-best optimal value. This new value lies below the Pigovian rate, which could lead to the conclusion that there is no second dividend, because the optimal environmental tax rate is lower in a second-best world than in a first-best one. However, this argument fails to consider the double taxation of income in this situation: it is directly taxed a first time by the labor tax, and indirectly a second time by the environmental tax, whereas if a tax on expenditures is used instead of the labor tax, income is only (indirectly) taxed once.

The point is that to obtain the same incentives to reduce pollution—i.e., the consumption of the dirty good—and still collect the same amount of tax revenue, the nominal environmental tax rate will be lower when a labor tax is present than when a consumption tax is used to raise fiscal revenue[11]. Indeed, when revenue requirements increase, the optimal nominal environmental tax rate decreases in presence of a labor income tax, while it increases when a consumption tax is levied (see Bovenberg and Goulder, 1996). Nevertheless, Jaeger (2011) shows that the *effective* environmental tax rate—i.e., related to the real after-tax income level—actually rises with revenue requirements in presence of a labor income tax. The explanation is that due to the environmental tax, a consumer would need to work more and earn more to pay for it. If an income tax is present, this means that more tax revenue is collected from the labor income tax, whereas this is not the case if tax revenue is collected from a consumption tax. The optimal nominal environmental tax rates thus differ between these two situations; however, the effective rates are the same. Therefore, when revenue requirements increase, the optimal effective environmental tax rate increases, which supports the strong DD hypothesis rather than dismissing it, as environmental taxes can (and should) effectively be used to collect revenue instead of labor or consumption taxes.

Conclusions against the strong DD from the literature on the tax interaction effect thus need to be considered with caution, as their case is not that robust in the end. Moreover, modeling assumptions are critical to the validity of aforementioned theoretical predictions against the strong DD, which implies that changing some parameters, like introducing capital as production factor (see Goulder, 1995) or considering the potential impact of environmental quality on labor productivity (see Williams, 2002), can open an additional window for a strong second dividend.

Fernández et al. (2011), on the basis of the model developed by Fernández et al. (2010), discuss how to reach a DD in a dynamic equilibrium model. With the help of their model, they show that a strong DD can be obtained in a dynamic setting where government can issue debt in addition to levying taxes to finance its expenditures. The core idea is that a DD can be achieved thanks to a tax reform combining the introduction of an environmental tax—in their case, an emissions tax—with a cut in the rate of the household income tax, in addition to public debt issuing at the beginning of the time sequence. The reason is that issuing debt today to cut distortionary taxes is growth-enhancing, so that the tax base of the income tax will increase in the future, leading to more fiscal revenue to pay back the debt at a later stage. The authors argue that such a reform can be justified by the fact that present generations pay for environmental measures that will benefit future generations, so that intertemporally sharing the burden of paying for the green transition seems acceptable from a societal perspective. Debt issuing thus compensates for the tax interaction effect, in this setting. One could argue against this idea on the ground that past and present generations have already benefited a lot, if not too much, at the expense of future generations. The cost-benefit analysis should therefore include utility gains

[11]See Jaeger (2011) for an algebraic proof.

made in the past and all the costs already induced for future generations from an environmental perspective.

### 1.2.6 Evidence on the economic dividend

Existing evidence, which largely consists in CGE models, generally backs the argument that the revenue recycling effect is not necessarily sufficient to compensate for the tax interaction effect. Freire-González (2018) analyzes 69 CGE simulations from 40 studies and report varying results regarding the existence of a second dividend. He finds that only 55% of simulations achieve a strong DD, implying some economic benefit from environmental taxes' revenue recycling in some cases, but none in about half of them. The authors also highlight the heterogeneity between the studies they consider: the variables capturing the second dividend differ from one to another, as is the revenue recycling strategy. According to Patuelli et al. (2005), who did a similar analysis in the mid-2000s, whether a DD is observed or not in a study depends on modeling strategies and the operationalization of the concept of second dividend, which can take different forms: reduction in unemployment, increase in production, consumption, or consumers' utility, and so on. Zhou and Segerson (2012) reach the same conclusions in that regard.

Some observations can be made on studies considered by Freire-González (2018). The first one is that a strong DD is obtained in 9 out of 10 simulations where fiscal revenue is recycled as cuts in social security contributions. On the other hand, recycling revenue as lump-sum transfers is barely linked to a strong DD, as only 1 out of 10 studies achieves one. Results concerning other types of revenue recycling mechanisms (mainly cuts in labor income taxes and taxes on capital) are more mixed. Second, a strong DD is more often achieved in simulations of European economies than Asian and North American ones. Zhou and Segerson (2012) also report this trend in empirical studies, and suggest that this might be partly caused by lower unemployment rates and labor taxes in the United States in comparison to European countries (see also Elkins and Baker, 2001). Studies on Africa, South America, and Oceania, are still scarce, but the few existing ones tend to find a strong DD. Finally, Freire-González (2018) reports that simulations using production and employment as measures of a second dividend tend on average to find an increase, whereas those considering investment see a decrease. Those using utility or consumption do not find any change, on average.

Maxim et al. (2019) conduct a meta-regression analysis on the employment effect found in some ETR simulations. They run a regression model to investigate the factors that make this effect deviate from the mean of all considered studies. They find that recycling revenue as cuts in social security contributions is connected to a higher-than-average employment effect. Lowering the value-added tax (VAT) is also linked to a higher positive effect, but only in simulations focusing on European countries.

The general take from this literature is that the strong DD hypothesis can neither be completely rejected nor unconditionally accepted. The first dividend is likely to materialize, albeit not necessarily with a large magnitude. However, achieving a second dividend depends on many factors that make it more hazardous. The numerous ways of recycling revenue from environmental taxes, coupled with the different indicators of a second dividend, give a nuanced picture of the interactions between environmental taxes and the economy rather than a clear-cut answer, so that the question of the actual existence of a DD remains open.

## 1.3 Carbon taxation as source of fiscal revenue

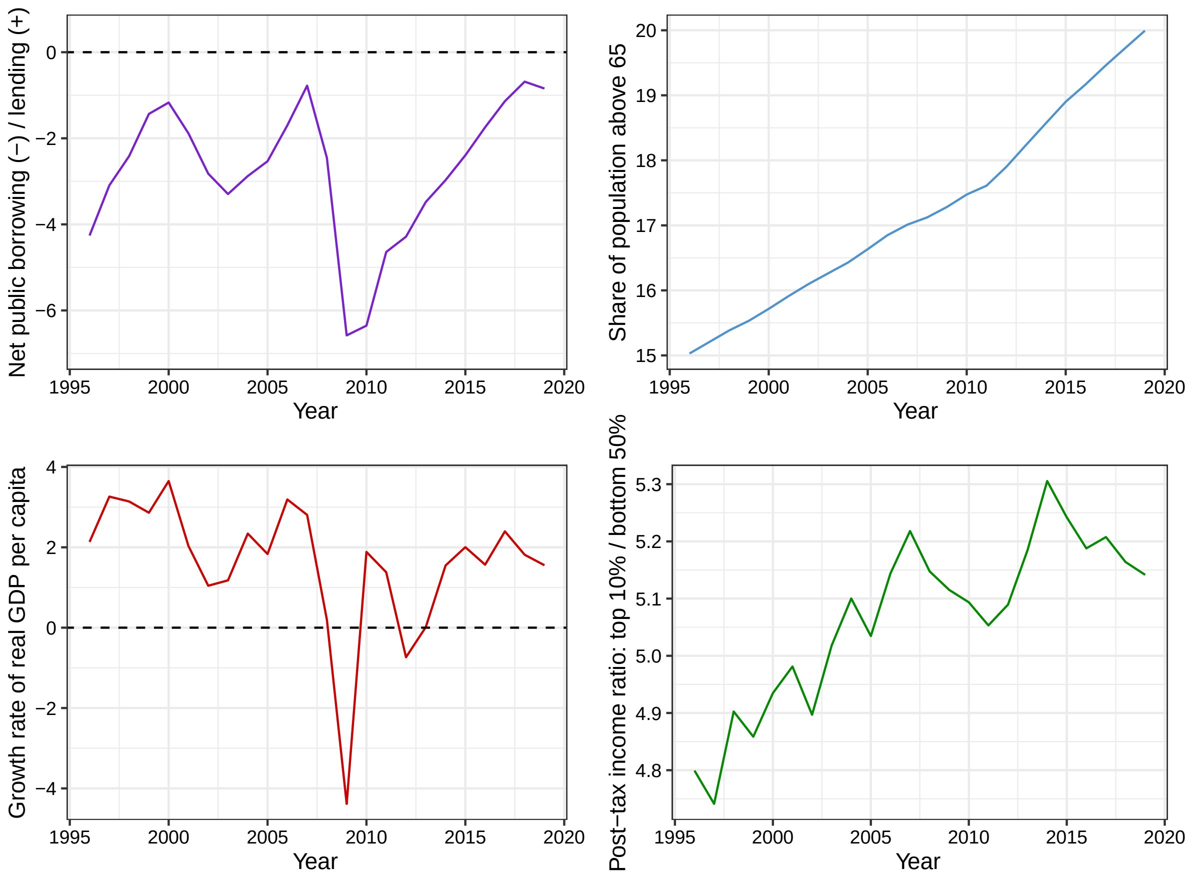
### 1.3.1 Securing the fiscal space

Besides discussions focusing on the existence of a second, non-environmental dividend, environmental taxes can be considered as instruments to raise new tax revenue independently from issues related to economic efficiency. The variety of environmental taxes that can be levied creates some opportunities for new sources of income: tax on waste production, on the use of polluting products, on road use, and, of course, $CO_2$ emissions. This new revenue can be welcome when governments run budget deficits in the long term due to a lack of revenue.

The concept of *fiscal space* is useful to consider in this context. It has been defined by Heller (2005) as "[...]the availability of budgetary room that allows a government to provide resources for a desired purpose without any prejudice to the sustainability of a government's financial position" (Heller, 2005, p. 3). Fiscal space therefore relates to the idea that governments have a limited financial capacity to provide common goods and thus need to manage their revenue and expenses properly to keep on doing so in the long term. Governments must choose over time how to spend their resources so as to reach socially desired goals: long-term economic growth, reducing inequalities, providing education, healthcare, environmental protection, and so on. At the same time, they have to decide on how to raise the funds necessary to finance their expenditures using taxes, income from publicly-owned assets and the sale of publicly-produced goods and services, and debt issuance.

Debt starts to accumulate when spending is higher than revenue over the medium term. The payment of interests then constrains governments' fiscal space in the longer term, so that socially desired goals might not be attainable anymore in the future as the burden of debt increases. There is an important intertemporal aspect in fiscal space, because spending decisions have implications over time and can influence future tax revenue, and the burden of debt or the lack of reliable sources of revenue can affect future spending possibilities. The Ricardian equivalence hypothesis, if it holds, also implies that today's public deficit is fully made at the expenses of future generations, which will have to pay it back with no economic benefit from debt issuance in the long term. Financial resources and expenditures are therefore interconnected over time. Securing the fiscal space is thus of major importance for society as a whole.

Kose et al. (2017) present a new dataset containing several indicators of fiscal space and its development over time. Although they show that fiscal space tends to improve in advanced economies during the 2010s after the 2008 Great Recession, they also document that the fiscal balance of these countries has been negative for a long time, as can be seen for European countries on the top left graph of Figure 1.1. This negative gap between revenue and expenditures raises concerns regarding the sustainability of the current level of provision of common goods in Europe: in times of aging population, moderate economic growth and high inequalities (see Figure 1.1), securing fiscal revenue to ensure that socially desired goals can still be reached in the long term is of fundamental importance. Otherwise, cuts in public spending can have detrimental impacts on equity and welfare, as underlined in Bloch et al. (2016) in the context of fiscal consolidation after the 2008 Great Recession. Keeping on financing deficits by issuing debt might also not be sustainable due to interest payments. Raising revenue through carbon taxation might thus provide more fiscal space to governments, which is also an argument in its favor, on top of the DD hypothesis. Both can be blended, as not all revenue from carbon taxes




Sources: Eurostat, World Inequality Database.

Figure 1.1: Trends of public borrowing, population aging, growth of real GDP p.c., and income inequality in Europe (population-weighted average of 25 European countries), 1996–2019

needs to be recycled through cuts in preexisting taxes: revenue neutrality is not a necessity of such policies.

### 1.3.2 Raising revenue from $CO_2$ emissions

One of the main issues regarding carbon taxation, as coined by Goulder (2013) in line with Zhou and Segerson (2012), is particularly interesting from a public finance point of view: the *breadth of the tax base*. Environmental taxes in general have relatively narrow tax bases: greenhouse gas emissions, local pollution, waste disposal, and so on—arguably, exceptions are energy and (road) transport taxes (Smith, 1998). In comparison, the taxes they can replace to benefit from a second dividend have comparatively broad bases: labor income, sales turnover, consumption. A narrow tax might be easier to avoid than a broad one. It is even one of the primary goals of carbon taxes, as discussed in Section 1.2.1: reducing its tax base, that is, $CO_2$ emissions from fossil fuels, by finding alternative ways to produce and consume that do not contribute to global climate change.

The eventual target of $CO_2$ taxes as an instrument of today's climate policy is to eventually reach carbon neutrality with the help of complementary measures (subsidies for energy-efficient renovations of building, support for research in carbon-free technologies, legal standards on maximum emissions, etc.). This goal is specified in the Paris Agreement negotiated at the 2015 United Nations Climate Change Conference: "[...]Parties aim to reach global peaking of greenhouse gas emissions as soon as possible [...]and to undertake rapid reductions thereafter in accordance with best available science, so as to achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century[...]"(UNFCCC, 2015, art. 4, § 1). Jurisdictions such as the European Union and Switzerland already stated their commitment to reach this goal by 2050.

Even though global $CO_2$ emissions are growing today, it should not be the case anymore in the foreseeable future. Raising revenue from carbon taxes might thus only be transitory, so that the second dividend vanishes in the long term for such policy instruments. Fiscal distortions might need to be reintroduced in the economy at some point, as governments still need to find reliable sources of tax proceeds. The move away from environmental taxation might be needed even sooner than one could expect, as such taxes can have two impacts: lowering the breadth of the tax base, but also increasing its erosion rate (see reviewed articles in Green, 2021). A higher $CO_2$ tax rate might thus have a double impact on its base: decreasing its size (i.e., an impact on its value) and speeding up its narrowing (i.e., an impact on its decrease rate)[12]. Complementary policies aiming at lowering $CO_2$ emissions also strengthen these effects. Prospects for higher carbon tax revenue are thus hindered in the long term. It might thus not be possible to benefit from a stable DD, with the risk that undertaken tax cuts need to be reversed in the future, which might be politically difficult to justify. Substituting a carbon tax to other distortionary taxes might hence become a threat to the stability of public finances in the long term, with a risk of seeing the existing fiscal space shrinking and socially desired collective goods not being provided.

Regarding short-term tax revenue, the net effect of carbon taxation is less clear. Siegmeier et al. (2018) present a review of previous theoretical and empirical findings related to carbon taxes and the fiscal system. They argue that environmental taxes' impact on investments can favor the accumulation of producible capital to compensate for the reduction in rents from fossil fuels. They also argue that land prices and rents are likely to increase as demand grows for different reasons (urban consolidation, use of available land to set up renewable power plants and carbon capture systems, etc.). The net effect on fiscal revenue from capital and land rents could therefore increase with carbon taxation. The integration of environmental taxation within broader fiscal considerations and adjustments is thus advisable, as synergies between environmental and non-environmental taxes can thus better be exploited (Siegmeier et al., 2018).

### 1.3.3 Taxing all energy sources

To consolidate the fiscal space and benefit from lower distortionary taxes in the long term, this chapter proposes a new policy approach, which consists in progressively taxing carbon-free energy sources as the tax base of carbon taxes erodes. Taxes on $CO_2$ emissions act as implicit fossil energy taxes: each type of fossil fuel has a fixed carbon content, so that carbon taxes are equivalent to excise taxes with different rates on each type of fossil fuel. Increasing the price of $CO_2$ emissions therefore increases the unit price of fossil fuels, and thus of the energy produced with their help. As the cost of fossil energy increases, it becomes more and more beneficial to use renewable energy from, e.g., wind turbines, solar panels, or hydropower, which do not generate $CO_2$ emissions—not taking gray energy into account. Renewable energy can thus act as a new

[12]It should be noted that the erosion rate of $CO_2$ emissions is likely to decrease at some point, when available abatement possibilities become relatively too costly to apply.

tax base to raise fiscal revenue, as the use of fossil energy decreases with time because of carbon taxes and other measures aiming at reaching carbon neutrality.

Taxing renewable energy sources can also be justified from a Pigovian perspective: producing energy from renewable sources can cause negative externalities not related to $CO_2$ emissions, such as negative visual impacts on landscapes (Wolsink, 2007), increased land prices (Myrna et al., 2019) and conflicts for land use (Huber et al., 2017), threats to biodiversity (Serrano et al., 2020), alteration of protected built heritage (Broström and Svanström, 2011; Stanojević et al., 2021), and so on. Although the Pigovian framework does not apply to all renewable energy production methods and contexts (for instance, solar panels on a building of no significant cultural or historical value), some social groups might be negatively affected by local disturbances such as those caused by wind turbines. Costs and benefits from renewable energy might thus be unevenly distributed, which could cause welfare losses if energy generation decisions do not fully include side-effects on local communities.

In addition, it is socially optimal to increase energy efficiency, and not only to encourage switching of energy sources. Producing high amounts of energy has a huge cost, and using renewables might not be sufficient to cover all future energy needs. Targeting a lower energy consumption per capita is therefore fundamental—see, e.g., the 2,000-watt society proposal (Stulz et al., 2011). Taxes on renewable energy, along with carbon taxation, can help reaching this goal by giving economic agents incentives to reduce their energy use. Overall, the fiscal system would shift from distortionary taxes on capital, labor, or consumption, to energy taxes.

Newbery (2005) argues in favor of excise taxes on energy with four arguments. First, such taxes can help solve negative externality issues caused by pollution, as already discussed above. Second, they can serve as indirect charges on transport infrastructure and finance their maintenance. Third, they can be used to improve the tax structure of the economy, both regarding the efficiency and redistributive properties of other taxes. Finally, they can serve as substitute to oil (and other transportable fuels) import tariffs without breaking international trade laws. It must be noted that Newbery focuses on fossil fuels in his recommendations; nevertheless, these principles can also apply to other types of energy sources. As mentioned above, renewables also cause negative externalities. Transport is moving away from gasoline and diesel, with the advent of electric vehicles: if road maintenance is financed mainly by fossil fuel taxes, there is a risk of lacking resources to do so in the future. Taxing electricity generated from renewable sources can help compensate these losses, for example.

This line of argument is particularly valid for Switzerland. At the federal level, road infrastructures are indeed mainly financed by the proceeds of the mineral oil tax levied on gasoline and diesel consumption. Although fossil fuel consumption for transport has increased over the past decades (see Swiss Federal Office for the Environment, 2018), the foreseen replacement of internal combustion engine vehicles by electric and hydrogen ones will significantly challenge the financial equilibrium of road maintenance and development in the country. The same applies to the financing of some climate policies: for instance, public subsidies from the Buildings Program (the federal fund set up to support energy-efficient renovations) are financed with proceeds from the $CO_2$ levy—i.e., Switzerland's carbon tax. As the use of fossil fuel decreases, less funds are available. On the other hand, investment costs to decarbonize the economy might not decrease at the same pace as $CO_2$ emissions. There is thus a risk of insufficient funding for this type of program, which would hinder the country's climate policy. Raising revenue from all energy sources could be a solution to these issues, when fossil fuel use will have significantly declined.

A last argument for overall energy taxation is tax avoidance and the *rebound effect*. If only fossil energy is taxed, it is possible to progressively switch to tax-free energy sources to avoid being taxed. Without sufficient taxes on alternatives to oil, gas, and coal, energy use can face a rebound effect during the transition. The direct rebound effect is defined as the percentage of potential energy saving that is not conserved, following an improvement in energy efficiency (Berkhout et al., 2000). The idea is that an improvement in the energy efficiency of a system means that less energy is needed to provide the same service, *ceteris paribus*. If less energy is needed, the cost of providing the service, and thus its price, diminishes, so that it becomes cheaper to consume it. A drop in the price of the service leads to an increase in consumption. It can be understood as an efficiency elasticity of demand (Sorrell and Dimitropoulos, 2008). A second, indirect, rebound effect can also happen if the money saved through lower energy spending is used to purchase other systems' energy services, which also causes an increase in energy demand (see Hediger et al., 2018).

In the case of a switch from fossil to renewable energy, if the latter is cheaper than the former, it is likely that consumers increase their overall energy demand by purchasing more energy-intensive goods and services. The fact that this energy is carbon-free can also increase its use. Sorrell et al. (2009) review empirical evidence on the rebound effect in the case of household energy services (heating, transport, and so on). They find that estimates vary a lot, but in general the direct rebound effect could be as high as 30% for households, which should not be overlooked. If using renewables instead of fossil fuels leads to higher energy consumption, the environmental issues caused by overall energy use would not be solved: for instance, Deng and Newton (2017) find an average rebound effect in electricity use of about 20% following the installation of solar panels in a sample of Australian households. Taxing renewables could help countering this effect by keeping pressure on prices and overall energy use. There are hence strong arguments in favor of general energy taxes, and not only on fossil fuels.

One should nevertheless not think that renewables should be taxed straight away at a high rate to bring extra fiscal revenue. The whole idea of taxing all energy sources, even clean ones, is a long term perspective on the question of energy taxation. As of 2022, the development of renewables is not strong enough to justify levying significant taxes on their use. However, in the near future, this option should be considered to achieve a clean and sustainable energy transition without impairing the stability of fiscal revenue.

### 1.3.4 Evidence on the fiscal potential of energy taxes

In an OECD report, Akgun et al. (2017) present the basic framework within which the relation between tax rates and fiscal revenue can be analyzed. The capacity to raise fiscal revenue from different tax bases depends on the latter's reaction to an increase in the marginal tax rate. Depending on how easy and costly it is to avoid being taxed by changing behaviors and decisions or moving to another fiscal jurisdiction, increasing marginal tax rates can have impacts of varying sizes on their bases. The final effect on tax revenue—i.e., an increase or a decrease—is thus determined by the sensitivity of the tax base to changes in the marginal tax rate, which determines the location of "tax rate-tax revenue" pairs on the Laffer curve. Tax avoidance opportunities influence the shape of the Laffer curve, and therefore the potential to raise more revenue by increasing the marginal tax rate[13].

The question of whether increasing the marginal tax rate increases fiscal revenue or not depends on the price (or tax) elasticity of the tax base. An elasticity close to 0 suggests that significantly more revenue could be raised, following an increase in the tax rate. An interesting feature of energy as tax base is that is has a low price elasticity of use, which implies a limited erosion of the tax base even at high marginal tax rates. Labandeira et al. (2017) review estimates of price elasticities of overall energy demand from the literature and report them to generally be on average between $-0.15$ and $-0.20$ in the short term (up to one year) and between $-0.37$ and $-0.57$ in the long term (more than one year), depending on the energy source considered.

Nevertheless, one must pay attention to the fact that taxes might cause larger behavioral reactions than equivalent price increases. Sussman and Olivola (2011) show with a set of experiments that tax aversion makes people dislike taxes beyond their impact on costs. They find that people tend to avoid taxes more than equivalent or larger costs. Regarding consumption taxes, Chetty et al. (2009) find that showing tax-inclusive prices on price tags has a stronger negative effect on consumption than displaying tax-exclusive prices and applying the tax only at the moment of purchase. The salience of a tax thus matters regarding its impact on its base. A highly salient tax might therefore raise less revenue than a less salient one due to the larger impact of the former on the tax base. Rivers and Schaufele (2015) find, for instance, that British Columbia's carbon tax on gasoline has an impact 4.1 times larger than an equivalent price change, leading them to conclude that it quite salient to consumers. Li et al. (2014) argue that gasoline price increases receive more media coverage than equivalent non-tax price increase in the US, so that publicity regarding carbon taxes might play a role in their salience and their impact on gasoline demand.

In Table 1.1, I provide a rough estimate of the 1-year elasticity of final energy use with respect to the implicit tax rate of energy using a linear regression model with country and year fixed effects. Data come from Eurostat, the World Bank, OECD, and the Swiss Federal Statistical Office, and cover a panel of 28 European countries between 1996 and 2019[14]. The implicit tax rate of energy is computed by Eurostat as the ratio between total energy tax revenue and final energy use for non-energy purpose. It is expressed in 2010 Euros per GJ of energy, whereas energy use is expressed in thousands of GJ. All other monetary variables are expressed in constant 2010 Euros. I use the first lag of the implicit tax rate to avoid the issue of endogeneity caused by the fact that the dependent variable is the denominator of the main independent variable[15]. Covariates include time-varying factors that can impact energy use per capita: public environmental expenditures as percentage of GDP; GDP per capita; human development; importance of the industrial sector in the economy; road freight; cooling and heating degree days. The dependent variable is the natural logarithm of energy use per capita.

[13]Akgun et al. (2017) estimate the elasticity of tax revenue to effective marginal tax rates in a sample of OECD countries for three broad tax categories: personal income taxes, corporate income taxes and consumption taxes. They find that, if most countries in their dataset already have effective consumption tax rates close to their revenue-maximizing levels, many of them have some leeway to raise more revenue from corporate taxes by increasing tax rates. Open economies however have less room to raise more revenue from corporate income taxes than others. Regarding personal income taxes, the authors find that marginal returns decrease more quickly in low and high income brackets than in average ones. A progressive taxation of personal income is also found to increase fiscal revenue up to a certain point, after which the effect reverses.

[14]One observation has been dropped due to missing values

[15]Data from 1995 has been used to construct the lagged independent variable.

| | (1) | (2) | (3) |
|---|---|---|---|
| log(Implicit tax rate) (lagged) | −0.104*** | | −0.086*** |
| | (0.010) | | (0.015) |
| log²(Implicit tax rate) (lagged) | | | −0.011 |
| | | | (0.007) |
| Implicit tax rate (lagged) | | −0.047*** | |
| | | (0.008) | |
| Implicit tax rate² (lagged) | | 0.002*** | |
| | | (0.001) | |
| Environmental expenditures (% of GDP) | 0.012 | 0.015 | 0.014 |
| | (0.009) | (0.010) | (0.009) |
| log(GDP per capita) | 0.264*** | 0.222*** | 0.251*** |
| | (0.030) | (0.032) | (0.031) |
| Human development index | 1.378*** | 1.372*** | 1.392*** |
| | (0.251) | (0.254) | (0.251) |
| Share of industry in total employment | 0.007*** | 0.007*** | 0.007*** |
| | (0.001) | (0.001) | (0.001) |
| Freight in kg-kms per capita | 0.021*** | 0.022*** | 0.021*** |
| | (0.002) | (0.002) | (0.002) |
| Cooling degree days | 0.018*** | 0.017*** | 0.017*** |
| | (0.006) | (0.007) | (0.006) |
| Heating degree days | 0.009*** | 0.009*** | 0.009*** |
| | (0.001) | (0.001) | (0.001) |
| Obs. | 671 | 671 | 671 |
| Adj. $R^2$ | 0.641 | 0.638 | 0.642 |

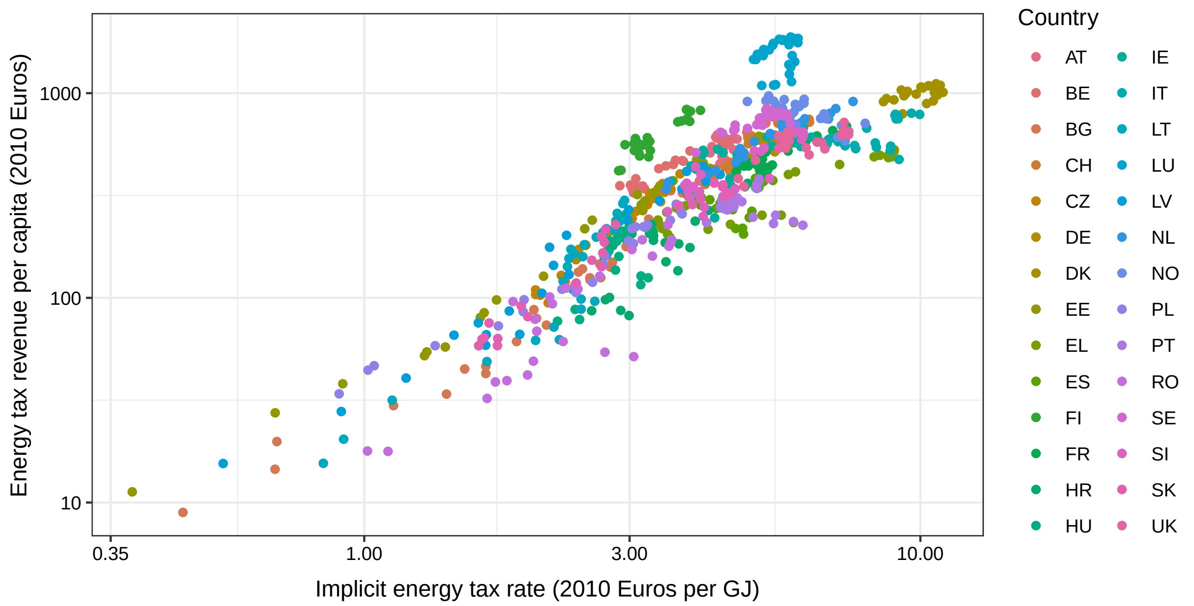
Notes: ****p*-value < 0.01; ***p*-value < 0.05; **p*-value < 0.1. The dependent variable is the natural logarithm of energy use per capita. Cooling and heating degree days have been multiplied by 100. Two-way fixed effects are included in the regression model

Table 1.1: Regression analysis of energy use per capita in Europe, 1996-2019

The estimated one-year tax elasticity of energy use from the first column, which is around −0.1, supports the idea that energy use has a low tax elasticity at current rates. The results presented in the third column show that the tax elasticity of energy use does not seem to be dependent on the level of the implicit energy tax rate, as the coefficient of the latter's squared logarithmic transformation is close to 0 and not statistically significant. If a quadratic relation between the value of the implicit tax rate and the dependent variable is used (second column), it can be seen that the impact of the tax rate on energy use slows down as the former increases. The estimated turning point would be around €12 per GJ, which is above the maximum value in the sample (€11 per GJ), so that no conclusion can be drawn on any hypothetical inversion of the negative relation between the implicit energy tax rate and energy use.

These results suggest that fiscal revenue is likely to strongly increase with higher energy tax rates, as can be seen in Figure 1.2, which shows that countries in the sample that apply on average higher energy tax rates also raise higher revenue per capita from energy taxes. This correlation is consistent with the low price elasticity of energy use found in the literature, and with the estimates displayed in Table 1.1.

From a public finance perspective, it must be noted that energy use represents a broad tax base, especially in advanced economies. In Switzerland, for instance, final energy consumption for non-energy use amounted to 831,420 TJ in 2018, or 97.65 GJ per inhabitant. The current rate of the Swiss $CO_2$ levy is CHF 120 per tonne of $CO_2$, or CHF 8.85 per GJ generated when




Sources: Eurostat, Swiss Federal Statistical Office.

Figure 1.2: Relation between the implicit tax rate of energy and energy tax revenue in Europe, 1995–2019

burning heating oil. A general energy tax equivalent to the $CO_2$ levy rate (in terms of CHF/GJ) could thus be enough to compensate for about a third of VAT proceeds in Switzerland (CHF 22.62 billion at a 7.7% rate)[16]—if there is of course no behavioral reaction to the introduction of the energy tax regarding consumption.

At a global level, there might also be room for more fossil energy taxation: in 2015, fossil fuel subsidies—which are equivalent to a loss of tax revenue from a budgetary perspective, acting like negative taxes—accounted for 6.5% of the world's GDP (Coady et al., 2017). Scaling such subsidies down could save some fiscal revenue to benefit from a DD.

In the next section, I propose a simple partial equilibrium model of energy taxation that solves the issue of tax base erosion while preventing fiscal revenue from falling. The eventual goal is to benefit from lower distortionary tax rates on consumption or income—the second dividend of environmental taxes. In order to encourage fuel substitution toward renewable energy sources, governments impose taxes on $CO_2$ emissions—which are equivalent to fossil fuel taxes—so that the relative price of polluting and non-polluting fuels progressively weighs in favor of the latter. However, as substitution occurs, the base of taxes on $CO_2$ emissions shrinks, leading to a risk of progressive drop in revenue as the tax base becomes closer to zero. The idea is thus to progressively tax renewable energy sources as their use increases, but to still keep the relative price of polluting and renewable fuels imbalanced in favor of the latter. Overall energy use, including from renewable sources, will diminish as tax rates increase, depending on its price-elasticity. In the end, as overall energy use will always need to be positive for the economy to function, the base of energy taxes will not disappear in the long term, so that fiscal revenue can stabilize. This

[16]In comparison, revenue from the two main Swiss energy taxes, the mineral oil tax and the $CO_2$ levy, amounted to CHF 4.58 billion and CHF 1.08 billion in 2018, respectively. The $CO_2$ levy rate was CHF 96 per tonne of $CO_2$. Sources: Federal Office for Customs and Border Security, Federal Office for the Environment.

tax will simply act as a production tax on energy use, which will replace part of other taxes in the long term to avoid a return of the distortions they cause in the economy—although in reality other distortions might appear due to changes in the relative prices of goods depending on their energy intensities (see Bovenberg and de Mooij, 1994).

## 1.4 A model of energy taxation

### 1.4.1 The role of energy in production

Energy plays a central role in production, and the positive correlation between energy use and economic growth is quite stable over time and across countries[17] (Csereklyei et al., 2016). Kümmel (2011) argues in favor of including energy alongside labor and capital in production functions due to the necessity of energy to activate physical capital. He proposes a capital-labor-energy-creativity model, where capital is activated by energy and managed by labor. Labor performs two types of work: routine work, and creative work. If the former can be replaced by a combination of capital and energy, the latter represents the human factor in production for which there is currently no substitute: inventions, ideas, and interactive decisions that are dependent on human characteristics and reactions. The standard neoclassical technological progress consists in energy and creativity, in this model.

Kümmel (2011) then proposes two distinct ways of integrating energy in a production function. First, he presents what he calls the "energy-dependent Cobb-Douglas production function", where labor, capital, and energy are substitutes to each other. The author points to the fact that this assumption is problematic if one attempts to forecast future production, but he finds that past production can be fairly well be approximated by such a function. The second approach he presents is the so-called LinEx production function, where production depends linearly on energy and exponentially on output elasticities of labor, capital, and energy. When trying to forecast past production in Germany, Japan, and the US, with the LinEx function, Kümmel obtains predictions close to real values. Interestingly, he finds that energy accounts for most of the contribution to economic growth of the neoclassical technological factor (the so-called Solow residual). This result is in line with what Stern (2019) describes as the "ecological economics" view on the link between energy and economic growth, which is that growth is primarily fueled by energy use.

Kümmel's model does not account for the role of *energy sources* and their link to production. On the other hand, Barreto (2018), drawing on Tsur and Zemel (2011), proposes an endogenous growth model where energy is generated from fossil fuels and alternative, renewable, sources. The latter is assumed to need capital to be generated, as well as to be costlier than fossil fuels. The author models the stock of fossil fuels as depleting over time, while at the same time renewable energy becomes of better quality and replaces them. Barreto uses a Cobb-Douglas production function with capital, effective labor, and an energy flow consisting in fossil fuels and renewables. The two are modeled either as perfect or imperfect substitutes. Transition toward a carbon-free economy happens because of the progressive depletion of fossil fuels and improvements in the productivity of renewables. These two parameters are evolving according to exogenous, pre-specified rules. Consumption follows a saddle growth path due to the assumed productivity gap between fossil fuels and renewables, the former being considered as more productive than the

[17]It should be noted that energy use is likely to increase production, but production is also likely to lead to higher energy use, so that no causality link can be drawn between the two from this stylized fact alone.

latter. The post-transition steady-state level of consumption can be either higher or lower than the initial level, depending on whether the productivity of renewable energy exceeds that of fossil energy at some point or not. If it never does, then the post-transition steady-state level of consumption would always be lower than the peak level of consumption in times when fossil fuels were abundant and cheap—assuming that the renewable energy generation technology is not evolving.

Environmental externalities and carbon taxes can be introduced in growth models. For instance, Acemoglu et al. (2012) present a growth model where production is made with inputs from two sectors: the first uses carbon-emitting machines, and the other a carbon-free technology. Production is made by labor and a continuum of sector-specific machines, as well as an exhaustible natural resource for the polluting sector. This sector also causes a negative environmental externality, i.e., $CO_2$ emissions. Innovation in the two sectors is endogenous to the model. A carbon tax and an innovation subsidy for the clean sector are introduced to direct technological change toward a carbon-free economy. The authors find that, if the elasticity of substitution between the two sectors is high enough, a transition toward carbon-free economic growth is possible with a temporary policy combining innovation subsidies directed to the clean sector and a moderate carbon tax. Any delay in intervention is costly in terms of economic growth: a swift and strong policy response is found to decrease the length of the slow growth transition phase. This policy recommendation has important implications, given the relatively slow pace at which climate policies have been implemented in many countries since the signature of the UNFCCC.

Eriksson (2018) reconsiders Acemoglu et al.'s conclusion that the policy intervention for a transition to clean technology only has to be temporary. With a similar model, but with a low elasticity of substitution between the clean and polluting sectors, he concludes that the tax-and-subsidize policy from Acemoglu et al. (2012) needs to be permanent to prevent a return to pollution. Some of the subsidy needs to be directed toward making the polluting input more effective, and therefore easier to phase out because of its lower necessity to produce the same amount of goods and services. This paper shows the importance of modeling assumptions regarding the model's conclusions: depending on the construction of the relation between inputs, the influence of external interventions can have significantly different impacts on outcomes. The way energy is included in production functions thus matters, both on the conceptual and the practical sides of the problem.

Keen et al. (2019) discusses epistemological issues on the inclusion of energy in production functions that are used in economics. Like Kümmel (2011), they criticize standard Cobb-Douglas production functions that assume energy as a mere third factor of production (FOP) alongside labor and capital, in that energy is needed by them to work, and not a simple substitute. They therefore suggest to treat energy as a necessary input to labor and capital, and to consider the *exergy*, or *useful work*, performed by labor and capital once activated by energy in the production process. They then derive a simple alternative *energy-based Cobb-Douglas production function* where labor and capital's exergies are the main production inputs instead of labor, capital, and energy side-by-side.

This function departs from the classical way of including additional FOPs in a Cobb-Douglas production function, in that energy cannot directly be substituted to other FOPs but is a necessary input whose level depends on the ratios of energy needed per unit of each other FOPs.

Considering energy more as a complement to other FOPs than a substitute is justified by the intuitive assumption that energy is needed to action FOPs, but faces significant limits as to be substituted to them. The energy-based Cobb-Douglas production function hence models this complementarity between energy and other FOPs, which allows for a better inclusion of the role of energy in production.

The other peculiarity of this production function is that it expresses output in units of exergy. The intuition behind it is that FOPs such as labor and capital are activated with the help of energy, so that they are able to generate useful work whose combination would result in the production of goods and services. In the end, FOPs are not so much labor and capital than the exergy generated by them, which allows to produce. In short, energy is turned into exergy through the fact it is fueling usual FOPs. For any FOP $M$, the exergy it generates from the energy it receives can be written as $M \cdot E_M \cdot e_x^M$, where $E_M$ is the energy needed to activate a unit of $M$, and $e_x^M$ is the exergy generated by $M$ per unit of energy it uses—i.e., its energy efficiency. The exergy generated by a unit of $M$ can be written as $E_x^M \equiv E_M \cdot e_x^M$.

It is on the basis of this function that the model presented in Section 1.4.2 is constructed, because of its logic regarding the treatment of energy in production, and its flexibility *vis-à-vis* the present model's needs. It also allows to manipulate the energy intensity of FOPs ($E_M$), as well as their energy efficiency ($e_x^M$), to investigate their impacts on the outcomes. Finally, its relative simplicity eases the model's tracking and its interpretation.

A point should nonetheless be made on the weaknesses of this function. Its most obvious source of issues is that it remains a Cobb-Douglas production function at its core, with all its problematic underlying assumptions that have extensively been discussed in the literature. Some of them include the fact that it stems from an accounting identity, from which the constant returns to scale assumption, as well as the algebraic equivalence between output elasticities and FOP cost shares, can be derived (see, e.g., Simon, 1979; Sylos Labini, 1995; Felipe and Adams, 2005; Carter, 2011).

Beyond these critiques, Kümmel (2011) underlines that the fact that it assumes complete substituability of FOPs can be a problem to model future production scenarii. One could also add that its simplistic assumption of constant output elasticities does not necessarily represent reality in an accurate fashion. Moreover, its "black box" modeling of exogenous factors other than aggregate FOPs, like the so-called Solow residual (also sometimes referred to as "multifactor productivity"), does not inform at all on its nature. Finally, the proper definition and empirical measurement of FOPs can be a problem, as is their aggregate nature: accurately accounting for existing heterogeneity can prove challenging.

It should nonetheless be noted that these issues do not make Cobb-Douglas-type production functions completely useless, especially to develop a model whose final goal is not to be fitted on actual data as such. Measurement questions, for instance, would only be a problem in a second stage, if the theoretical model seems relevant enough to be tested with real-world data. The constant output elasticities assumption is however a relevant drawback to acknowledge. The vague nature of multifactor productivity also limits the extent of the analysis of how changes in FOPs translate in changes in production. One should keep these limits in mind while reading the remainder of this chapter.

### 1.4.2 Model presentation

The model developed below presents a simplified economy with a representative firm that produces a single aggregate good with two FOPs, labor and capital, and energy as necessary input to capital, like in Kümmel (2011). The firm is assumed to choose its production level so as to maximize its profit. Energy is modeled as being generated from two sources: fossil fuels and renewables, which have distinct U-shaped unit cost functions. The firm is indifferent between the two energy sources: it relies on both and seeks to minimize its total cost of generating energy. Labor is assumed to be inelastically supplied for simplicity. Capital is supplied through savings on income from labor, capital, and profit (i.e., dividends). Taxes are levied on both energy sources, as well as on consumption, which amounts to the part of income that is not saved to supply capital.

The goal of this model is to analyze the impacts of substituting taxes on energy to the consumption tax, and to illustrate the role played by structural factors such as energy efficiency on the outcomes. It is a partial equilibrium model, as it suffices for what it intends to present and because such a model has the advantage of being easy to track and understand in terms of both its development and its predictions. A general equilibrium model would of course be more detailed and complete, but the fundamental points it aims to show would probably become less visible, which would go against its very purpose.

The setup of the model relies on Keen et al.'s (2019) premise that energy in needed by other FOPs to produce output. Energy is not a FOP itself: it is a necessary—but not sufficient—input whose use is conditioned on the use of FOPs that necessitate energy to function. In particular, energy is needed to help physical capital produce: without energy, capital cannot produce much by itself in terms of goods and services, as it only consists in inert machinery. These considerations are used to construct the production function of the present model:

$$Y = A(NE_x^N)^{\beta}(KE_K e_x^K)^{1-\beta} \tag{1.1}$$

where $Y$ is the output; $N$ represents labor and $K$ (physical) capital; $E_K$ is the energy needed per unit of capital, i.e., its energy intensity; $e_x^K$ is capital's energy efficiency coefficient, that is, exergy (i.e., useful work) per unit of energy; $E_x^N$ is the exergy generated per unit of labor; $\beta$ represents the output elasticity of labor's useful work, and $1-\beta$ that of capital's useful work. $\beta$ is a constant, and the production function displays constant returns to scale. These assumptions are strong, but given that the model is static and is not meant to forecast future production, their influence on outcomes is limited.

Four points should be noted at this stage. First, the maximum theoretical value $e_x^K$ can take is 1: all energy is turned into exergy, which means perfect energy efficiency—which is actually unattainable in reality. Maximum total useful work is thus limited by available energy, labor, and capital. Growth in production thus cannot only be obtained thanks to better energy-to-exergy transformation technologies: the quantities of inputs matter.

Second, the reason why labor's exergy is expressed as $NE_x^N$ and not $NE_N e_x^N$ is that the model presented here is meant to deal with energy generated from sources only relevant to capital: oil, gas, wind power, hydropower, and so on. Energy sources relevant to labor, on the other hand, consist in the food absorbed by humans to activate their muscles and brain, which are not directly at stake in the context of energy taxation as it is commonly understood. Total energy use in this context amounts to $E = KE_K$, and not $NE_N + KE_K$. It is hence not meaningful to separate labor exergy into three components, unlike capital exergy: a simpler formulation can be used instead.

Third, as total energy use is equal to $KE_K$, it directly depends on the quantity of capital present in the economy, as well as on its energy intensity. The same quantity of energy can be used either from a lot of capital with a small energy intensity, or from a little quantity of energy-intensive capital. The same quantity of useful work can hence be obtained from different settings regarding the quantity of capital used and its type. Substitution of energy and capital is therefore possible at that level, but is not endogenous in this model because $E_K$ is assumed to be set exogenously.

Finally, although Keen et al. (2019) suggest to express output directly in terms of useful work, for the purpose of this model, an additional factor $A$ is added to capture how exergy is turned into goods and services, i.e., real value. $A$ is thus not so much a technological development factor as a way to express combined exergies from labor and capital, which are difficult to relate, in usual production units, which are more widely understood. This parameter nevertheless has the disadvantage not to be easily definable in more concrete terms than is multifactor productivity in a more standard Cobb-Douglas production function.

One should note that capital is here modeled as homogeneous, which it is not in reality. Distinctions could be made between information and communication technology (ICT) and non-ICT capital, for instance, with different energy intensities and energy efficiency ratios. The choice not to distinguish between different types of capital is to keep the model as clear as possible at this stage of development. Extensions such as including different types of capital could come at a later stage.

In the present model, it is here assumed that each unit of energy costs $z(E)$ to generate. Two energy generation technologies (or energy sources) are available: fossil fuels $f$ and renewables $r$, with $E_f + E_r = E$. They are assumed to be perfect substitutes to each other. Their unit cost functions, $z_f(E_f)$ and $z_r(E_r)$, are modeled as:

$$z_i = \rho_i E_i^{-1} + \phi_i E_i + \theta_i \qquad i \in \{f, r\} \tag{1.2}$$

where $\rho_i$ is energy source $i$'s fixed cost of production and $\phi_i E_i$ represents the linearly-increasing variable unit cost of $E_i$'s generation. $\phi_i$ is a coefficient representing exogenous factors that can influence the marginal cost of using more $E_i$, like regulations or available technology. $\theta_i$ is a unit tax on energy source $i$, which captures all implicit or explicit unit taxes on $i$—any existing carbon tax is thus included in $\theta_f$. A negative value of $\theta_i$ would mean that $E_i$'s generation is subsidized. $z_f$ and $z_r$ are U-shaped, which mirrors the idea that energy generation implies fixed costs that weigh heavily on the price per unit of energy when energy generation is low, and that each additional unit of energy produced has a higher marginal cost than the preceding one. To model the fact that energy from fossil fuels is generally cheaper to generate than energy from renewables, it can be said that $z_r(E_r = Q) > z_f(E_f = Q)\ \forall Q$ when $\theta_f = \theta_r = 0$. However, as $z_f$ and $z_r$ are both U-shaped, it is usually optimal to diversify between $E_f$ and $E_r$, which reflects the fact that both types of energy sources are used in reality—if $z_f$ and $z_r$ were only decreasing or constant, it would always be optimal to use either only fossil fuels or only renewables. The assumption regarding the shape of the unit cost functions is strong, but it is here necessary to ensure that both energy sources are used: if marginal costs were assumed to be decreasing or constant, it would be optimal to use only the cheapest source. No substitution between fossil and renewable energy sources would happen then, which is also unrealistic.

Total energy use $E$, which is determined by $K$ and $E_K$, is assumed to be produced at the lowest possible cost, so that the values of $E_f$ and $E_r$ depend on $z_f$ and $z_r$. The economy thus faces the following cost-minimization problem:

$$\min_{E_f,E_r} Z(E_f,E_r) = z_f E_f + z_r E_r \quad \text{s.t.} \quad E_f + E_r = E \tag{1.3}$$

which can thus be reformulated as

$$\min_{E_f} Z(E_f) = \rho_f + \phi_f E_f^2 + \theta_f E_f + \rho_r + \phi_r (E - E_f)^2 + \theta_r (E - E_f) \tag{1.4}$$

The first order condition of (1.4) gives the following results:

$$E_f = \frac{\phi_r}{\phi_f + \phi_r} E - 0.5 \frac{\theta_f - \theta_r}{\phi_f + \phi_r} \tag{1.5}$$

$$E_r = \frac{\phi_f}{\phi_f + \phi_r} E + 0.5 \frac{\theta_f - \theta_r}{\phi_f + \phi_r} \tag{1.5a}$$

From the perspective of the representative producer, the source of energy does not matter: $E_f$ and $E_r$ are perfect substitutes. It therefore uses $E = KE_K$ and pays a weighted average cost per unit of $E$ amounting to $z = \nu z_f + (1-\nu) z_r$, where $\nu = E_f/E$ represents the share of total energy produced with fossil fuels. $z$ depends on $E_f$ and $E_r$, which themselves depend on $K$, so that $z = z(K)$. If the producer faces a unit cost of labor noted by $w$ and a unit cost of capital noted by $R$, its total cost function can be written as:

$$C(N,K) = wN + RK + z(K)(KE_K) \tag{1.6}$$

The profit maximization problem of the producer with respect to $N$ and $K$ is the following:

$$\max_{N,K} \pi(N,K) = A(NE_x^N)^\beta (KE_K e_x^K)^{1-\beta} - wN - RK - z(K)(KE_K) \tag{1.7}$$

where $\pi(N,K)$ is the profit function.

The first order conditions of (1.7) are:

$$\beta N^{-1} A(NE_x^N)^\beta (KE_K e_x^K)^{1-\beta} = w \tag{1.8}$$

$$(1-\beta) K^{-1} A(NE_x^N)^\beta (KE_K e_x^K)^{1-\beta} = R + \frac{\partial z(K)}{\partial K} KE_K + z(K) E_K \tag{1.8a}$$

where (1.8) and (1.8a) are the implicit labor and capital demand functions. The marginal products of labor ($MPN$) and capital ($MPK$) are equal to:

$$MPN = \beta N^{-1} A(NE_x^N)^\beta (KE_K e_x^K)^{1-\beta} \tag{1.9}$$

$$MPK = (1-\beta) K^{-1} A(NE_x^N)^\beta (KE_K e_x^K)^{1-\beta} \tag{1.9a}$$

By substituting (1.5) and (1.5a) into:

$$z(E) = \frac{E_f}{E}(\rho_f E_f^{-1} + \phi_f E_f + \theta_f) + \frac{E_r}{E}(\rho_r E_r^{-1} + \phi_r E_r + \theta_r) \tag{1.10}$$

it can be deduced that:

$$z(K) = \frac{\rho_f + \rho_r}{KE_K} + \frac{\phi_f \phi_r (KE_K) + \theta_f \phi_r + \theta_r \phi_f}{\phi_f + \phi_r} - 0.25 \frac{(\theta_f - \theta_r)^2}{(\phi_f + \phi_r) KE_K} \tag{1.11}$$

$$\frac{\partial z(K)}{\partial K} = \left( \frac{\phi_f \phi_r}{\phi_f + \phi_r} - \frac{\rho_f + \rho_r}{(KE_K)^2} + 0.25 \frac{(\theta_f - \theta_r)^2}{(\phi_f + \phi_r)(KE_K)^2} \right) E_K \tag{1.11a}$$

For simplicity, labor supply is modeled as inelastic: $N = \overline{N}$. Adjustments in the quantities of FOPs thus concern capital only. Regarding the supply of capital, at the steady-state equilibrium, it is assumed that savings on income from labor, capital, and profit (dividends) cover the depreciation of capital, i.e., $\delta K$. It means that $\delta K = s(wN + RK + \pi)$, where $s$ is the (exogenous) marginal propensity to save and $wN + RK + \pi$ is the income available for consumption and saving. By rewriting this equation, we obtain the long-term equilibrium supply of capital:

$$K = \frac{s(wN + \pi)}{\delta - sR} \Leftrightarrow R = \frac{\delta}{s} - \frac{wN + \pi}{K} \tag{1.12}$$

Consumption is equal to the share of income that is not saved. It is taxed at rate $\tau$, so that actual consumption $x$ is:

$$x = (1 - \tau)(1 - s)(wN + RK + \pi) \tag{1.13}$$

Finally, the government raises fiscal revenue from consumption and energy amounting to:

$$G = \tau(1 - s)(wN + RK + \pi) + \theta_f E_f + \theta_r E_r \tag{1.14}$$

Production $Y$, which represents the total value of economic activity, is thus composed of six elements:

1) Labor income $wN$;
2) Capital income $RK$;
3) Profit/dividends $\pi$;
4) Government's fiscal revenue $G$;
5) Energy generation costs net of taxes $z(E)E - (\theta_f E_f + \theta_r E_r)$;
6) Capital depreciation $\delta K$.

It can therefore be seen that two components of total economic activity are not welfare-enhancing: replacing depreciated capital and generating energy. While the first is standard in the economic literature, leading for instance to the distinction between gross and net domestic products in national accounting, the second is worth mentioning here as it is also a justification for the present model. Even though generating energy is necessary to economic activity, it does not bring any welfare on its own: it is its use by capital jointly with labor that allows to generate useful work, which will in the end produce goods and services. An economy whose industries are very energy-intensive might thus allocate a large share of its production capacity to generating required energy, which is not directly welfare-improving. Energy generation is thus a "necessary evil" in this model.

The equilibrium of this static partial equilibrium model is characterized by the following expressions:

$$w = MPN \tag{1.15}$$

$$R = MPK - \frac{\partial z(K)}{\partial K} KE_K - z(K)E_K \tag{1.15a}$$

$$R = \frac{\delta}{s} - \frac{wN + \pi}{K} \tag{1.15b}$$

$$E_f = \frac{\phi_r}{\phi_f + \phi_r}(KE_K) - 0.5\frac{\theta_f - \theta_r}{\phi_f + \phi_r} \tag{1.15c}$$

$$E_r = \frac{\phi_f}{\phi_f + \phi_r}(KE_K) + 0.5\frac{\theta_f - \theta_r}{\phi_f + \phi_r} \tag{1.15d}$$

$$x = (1-\tau)(1-s)(wN + RK + \pi) \tag{1.15e}$$

$$G = \tau(1-s)(wN + RK + \pi) + \theta_f E_f + \theta_r E_r \tag{1.15f}$$

The key endogenous parameter of the model is hence $K$, which is determined by finding the implicit solution to (1.15a) and (1.15b). Once $K$ is known, all other endogenous parameters whose values are determined by it can be computed: $Y$, $w$, $R$, $E_f$, $E_r$, $x$, and $G$. The rest of the parameters (labor supply $N$, plus structural parameters $A$, $s$, $\beta$, $\delta$, $\rho_f$, $\rho_r$, $\phi_f$, $\phi_r$, $E_K$, $e_x^K$, and $E_x^N$, as well as tax rates $\tau$, $\theta_f$, and $\theta_r$) must be set exogenously and can therefore be manipulated to see their impact on the equilibrium.

A variation of this model where a tax is levied on total income instead of only consumption is presented in Appendix 1.A.

### 1.4.3 Model discussion

The model presented above can be used to analyze the potential for the DD hypothesis to hold, given its assumptions and its structure. To do so, energy tax rates $\theta_f$ and $\theta_r$ can be exogenously set at different rates, while at the same time the consumption tax rate $\tau$ can be adapted to benefit from the recycling of revenue from the two energy taxes. From an initial situation, it is therefore possible to increase $\theta_f$ and $\theta_r$ and reduce $\tau$ while keeping $G$ constant: all new revenue from energy taxes is recycled to lower the consumption tax. In this context, the first dividend is represented by a lowering in $E_f$, or even in $E$ as a whole, as overall energy use has detrimental impacts on the environment, whatever the energy source (see Section 1.3.3). The second dividend can be represented by $x$, as it is a measure of consumers' economic welfare that is affected by all taxes levied in the economy. $Y$ should also be considered regarding the second dividend, in that production is also an indicator of economic welfare beyond consumption. It should nevertheless be noted that no metric of market distortions caused by taxes is present in the model, although it would be useful for a more complete assessment of the DD hypothesis.

An important characteristic of this model is the presence of a double taxation phenomenon: energy taxes affect the equilibrium level of capital, which in turn affects labor and capital incomes, as well as profit, and hence the share of income used for consumption. This reflects the fact that consumption taxes such as VAT are generally applied to goods and services whose pre-tax prices include all energy taxes paid during the production process. Energy taxes thus increase retail prices and hence consumption tax proceeds. It means that cutting consumption taxes as recycling method for energy tax revenue is interesting, in that part of the negative impact on fiscal revenue from the cut is compensated by an increase in pre-consumption tax prices.

As a result of changes in the tax rates applied to $E_f$ and $E_r$, their relative use can be modified through changes in $z_f$ relative to $z_r$, so that overall energy use consists in more renewables and less fossil fuels. As the overall cost of energy would then increase, a lowering of capital should follow to lower total energy use, leading to a drop in production, *ceteris paribus*. Nevertheless, consumption might still increase as a result, thanks to the lowering of the consumption tax and to a potential decrease in the share of economic activity devoted to energy generation and depreciated capital replacement. More of $Y$ could then be used for consumption, even if $Y$ is lower than before: the ratio $x/Y$ can *a priori* either increase or decrease. The two dividends nevertheless compete against each other: less energy means less production, everything else being constant. The reaction of $x$ to a lowering of $\tau$ and increases in $\theta_f$ and $\theta_r$ will thus determine the final outcome in that regard.

In addition to energy tax rates, it is possible to control $\phi_f$ and $\phi_r$ to reflect changes in the unit cost of using fossil fuels and renewables caused by new regulatory standards, technological improvements, or variations in international prices. The relative costs of $E_f$ and $E_r$ can therefore also be affected by such changes, not only by energy tax rates. If a government aims at reducing $E_f$ to 0 at some point, it might want to increase $\phi_f$ along with $\theta_f$ so that using fossil fuels becomes prohibitively expensive. At the same time, investing to lower $\phi_r$ would help make renewables more attractive substitutes for fossil fuels.

In this model, lowering energy use amounts to lowering production because of fixed needs in energy per unit of capital ($E_K$) and a fixed exergy per unit of energy coefficient ($e_x^K$). It is nevertheless possible to achieve both lower energy use and higher production if $E_K$ were to decrease while $e_x^K$ would increase. This situation would correspond to a drop in the energy intensity of capital coupled with improvements in energy efficiency: for a given quantity of capital, using less energy generates more useful work. It should nonetheless be noted that $e_x^K$ is bounded between 0 and 1, as it is physically impossible to obtain more exergy from a system than the energy input it receives—otherwise, it would be possible to generate an infinite amount of energy from a finite energy input. Improvements in energy efficiency are therefore limited.

Keen et al. (2019) suggest that the exergy performed by a unit of labor $E_x^N$ is constant through time because it is used to perform tasks on machines or, one could add, provide services such as teaching or counseling, but physiological human limits do not allow much more in terms of generating additional useful work. Increasing human capacities beyond a certain threshold would require transhumanistic transformations that are irrelevant in the present context. On the other hand, the useful work generated by capital has increased a lot during the past centuries, so that today's machines and computers can perform tasks more efficiently than before when used in conjunction to one unit of labor's exergy. In short, human capacities to perform tasks such as reading, speaking, thinking or moving have not progressed a lot, whereas the productivity of their combination with capital expanded tremendously with time: computers are always more efficient, machines are becoming more sophisticated, quick, and precise in the execution of their tasks, transportation time improved thanks to new technologies, and so on. Such changes can be reflected in the values of $E_K$ and $e_x^K$.

Overall energy use has increased with production during the past decades (see, e.g., Csereklyei et al., 2016; Stern, 2019). As a consequence, pressure on the environment also increased over time due to the heavy use of fossil fuels and subsequent $CO_2$ emissions. If output is assumed to be produced through an energy-based production function, either Cobb-Douglas or another, total production is linked to total energy use, which implies that lowering total energy use while maintaining a certain level of output and/or economic growth would require massive improvements in energy efficiency.

From a public finance perspective, the fact that energy is so crucial to production means that it forms a reliable tax base, as the risk of erosion and evasion is limited by the energy intensity of capital, which cannot be null. It nevertheless means that taxing energy acts as an implicit unit tax on capital: as capital needs energy to work, its use is indirectly taxed by an amount that depends on its energy intensity. Energy taxes thus favor capital with a low energy intensity, which can also be a desirable policy goal from an energy conservationist perspective, but which implies a partial erosion of the tax base, and therefore a potential reduction of fiscal space. As previously said, improvements in energy efficiency can help counter negative impacts on production, with positive effects on revenue from other taxes than energy ones—in this model, the consumption tax.

## 1.5 Numerical simulations

### 1.5.1 Simulation set-up

The model presented in Section 1.4.2 can be used to look at the impacts of changes in the taxation of fossil and renewable energy sources, as well as to see to what extent it is possible to lower the consumption tax to benefit from a second dividend. As the model is static, the simulation consists in finding a succession of equilibria corresponding to changes in some exogenous parameters. The main changes of interest here are increases in fossil and renewable energy sources' tax rates ($\theta_f$ and $\theta_r$), but also changes in the slope of their unit cost ($\phi_f$ and $\phi_r$) provoked by external changes in the marginal cost of each source of energy. These variations mimic the potential evolution of some key parameters in real-world economies and show some of the possible uses and predictions of the model presented above. The purpose of simulations presented below is not to analyze the precise situation of a country like in a CGE model, but to highlight some of the features of the model and illustrate how it works in different settings.

The base setting for the simulation is that the economy is at its steady-state level of production, with a tax levied on consumption. There are also taxes on both $E_f$ and $E_r$, but with $\theta_r < \theta_f$. Any new fiscal revenue collected from increases in energy taxes is used to lower $\tau$ while keeping $G$ constant at its initial level, if feasible. Then, 20 rounds of simulation with varying parameter values are run, with $t \in \{0, 1, ..., 20\}$ indicating the simulation number—0 is the initial situation.

Six scenarii are considered:

1) $\theta_f$ is increased to collect additional tax revenue from fossil energy sources and accelerate the transition from relying on $E_f$ to using more $E_r$. Any new revenue is recycled by lowering $\tau$. This scenario is the benchmark, in that it presents the outcomes of the model with a higher tax on fossil fuels in comparison to the initial situation.

2) In addition to $\theta_f$, $\theta_r$ is also raised, although by a smaller amount to still encourage a transition from fossil fuels to renewables. Increasing $\theta_r$ means that additional tax revenue

| Parameter | Scenario (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| $A$ | 1 | 1 | 1 | 1 | 1 | 1 |
| $N$ | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| $s$ | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 |
| $\delta$ | 0.025 | 0.025 | 0.025 | 0.025 | 0.025 | 0.025 |
| $\beta$ | 1/3 | 1/3 | 1/3 | 1/3 | 1/3 | 1/3 |
| $E_x^N$ | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |
| $\rho_f$ | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 |
| $\rho_r$ | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 |
| $\phi_f$ | 0.1 | 0.1 | $0.1(1.02)^t$ | $0.1(1.02)^t$ | $0.1(1.02)^t$ | $0.1(1.02)^t$ |
| $\phi_r$ | 0.5 | 0.5 | 0.5 | $0.5(0.98)^t$ | $0.5(0.98)^t$ | $0.5(0.98)^t$ |
| $E_K$ | 0.85 | 0.85 | 0.85 | 0.85 | $0.85(0.99)^t$ | $0.85(0.99)^t$ |
| $e_x^K$ | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | $0.3(0.99^{-1})^t$ |
| $\theta_f$ | 0.01 | 0.01 | $0.01+0.0005t$ | $0.01+0.0005t$ | $0.01+0.0005t$ | $0.01+0.0005t$ |
| $\theta_r$ | 0.001 | 0.001 | 0.001 | $0.001+0.00025t$ | $0.001+0.00025t$ | $0.001+0.00025t$ |
| $\tau$ | $\leq 0.25$ | $\leq 0.25$ | $\leq 0.25$ | $\leq 0.25$ | $\leq 0.25$ | $\leq 0.25$ |

Starting values: $\tau = 0.25$, $\theta_f = 0.01$, $\theta_r = 0.001$, $\phi_f = 0.1$, $\phi_r = 0.5$, $E_K = 0.85$, and $e_x^K = 0.3$.

Table 1.2: Simulation settings

is collected, which can be recycled by lowering $\tau$ by a potentially larger amount than in Scenario 1.

3) On top of raises in $\theta_f$ and $\theta_r$, $\phi_f$ is modeled as increasing at the same time. This scenario is meant to reflect the decarbonization of the economy through the implementation of restrictions on the use of $E_f$ while at the same time taxing energy use.

4) The previous scenario is applied, but $\phi_r$ is decreased in parallel to $\phi_f$'s increases. This scenario is meant to represent what happens when the marginal cost of using renewables diminishes thanks to technological improvements and regulatory easing happening simultaneously to tighter regulation of fossil fuels.

5) Scenario 4 is applied again, but in a context where $E_K$ decreases. This scenario reflects the lowering in energy intensity that could follow increases in the cost of using energy to produce. The purpose of this scenario is look at the impact of a transition to low energy intensity capital.

6) Scenario 5 is applied again, but with increases in $e_x^K$ that compensate the effect on exergy per unit of capital of the lowering in $E_K$. The goal is to see what could happen when less energy is necessary to generate the same amount of exergy for a given level of capital.

The settings of the different scenarii are displayed in Table 1.2, whereas the outcomes of the simulations are presented in Section 1.5.2. Values displayed are fictional and cannot be interpreted in terms of classical units such as money, hours worked, or joules. They are used only to illustrate how the model works and show some possible outcomes.

Outcomes from the model with an income tax instead of a consumption tax presented in Appendix 1.A are available in Appendix 1.B.

### 1.5.2 Simulation results

The results of the six simulation scenarii are provided below. For each scenario, four graphs are provided to present the evolutions of key variables:

1) $Y$, $K$, and $x$;

2) $E$, $E_f$, and $E_r$;

3) $w$, $R$, $z$, and $\pi$;

4) $G$, $G_x = \tau(1-s)(wN + RK + \pi)$, $G_f = \theta_f E_f$, and $G_r = \theta_r E_r$;

All graphs show indices taking the value 100 for the start period, so that evolutions can be understood in percentages with respect to the initial situation, and thus compared across variables when relevant. In addition, as numbers used for the simulations are fictional, their absolute values are not meaningful by themselves. The horizontal axis always shows the value of $\theta_f$, the main exogenous parameter manipulated, expressed as an index.

The outcomes of Scenario 1 are displayed in Figure 1.3. In this scenario, only $\theta_f$ is raised by an amount equivalent to 5% of its initial value in each simulation. Additional fiscal revenue is used to lower $\tau$. As can be seen, in this situation, both the use of capital and the level of production decrease as $\theta_f$ increases. This is due to the impact on the cost of energy of a higher tax on fossil fuels, so that less $K$ is used in order to lower $z(K) \cdot E(K)$, which results in a decrease in $E$. However, consumption $x$ is seen to be positively impacted by the revenue recycling strategy: although there is a drop in production, as the use of energy decreases, so does its cost, which means a larger share of $Y$ can be allocated to consumption. *Ceteris paribus*, in this model, consumers seem to be better off when a tax is levied on fossil energy instead of consumption.

Figure 1.4 presents the outcomes of Scenario 2, in which both $\theta_f$ and $\theta_r$ are increased, although by smaller values for $\theta_r$. Evolutions of all variables are similar to those of Scenario 2, but slightly amplified. This indicates that taxing renewables has the same public finance virtues as taxing fossil fuels: increased revenue. In addition, the substitution of $E_r$ to $E_f$ cannot be used to avoid being taxed anymore. This situation can be exploited to encourage the transition toward an economy based on renewables, but without sacrificing valuable fiscal revenue.

In both Scenario 1 and 2, the double dividend hypothesis is found to be relatively valid, in that a first and a (strong version of the) second dividend are achieved. The first stems from the lowering in energy use, especially from fossil fuels. The second comes from the fact that $x$ is seen to increase with $\theta_f$: the more fiscal revenue can be used to lower $\tau$, the better for consumer welfare. Nevertheless, production decreases, which weakens the extent of the second dividend beyond consumer welfare. In the real world, increasing $\theta_f$ (and $\theta_r$) to a high level might not be politically feasible (see Carattini et al., 2018), so that it is unsure whether sufficient tax revenue would be collected to benefit from a substantial second dividend.

Scenario 3 introduces the fact that many jurisdictions, especially in the economically developed world, tend to progressively put more restrictions on the use of fossil fuels through non-tax measure such as $CO_2$ emission limits or fuel quality restrictions. The impact of these measures can be represented by an increase in $\phi_f$, that is, the parameter capturing the marginal change in the unit cost of using fossil fuels when $E_f$ increases. The slope of $z_f(E_f)$ hence becomes steeper, which amplifies the impact of higher values of $\theta_f$ in comparison to the initial situation.

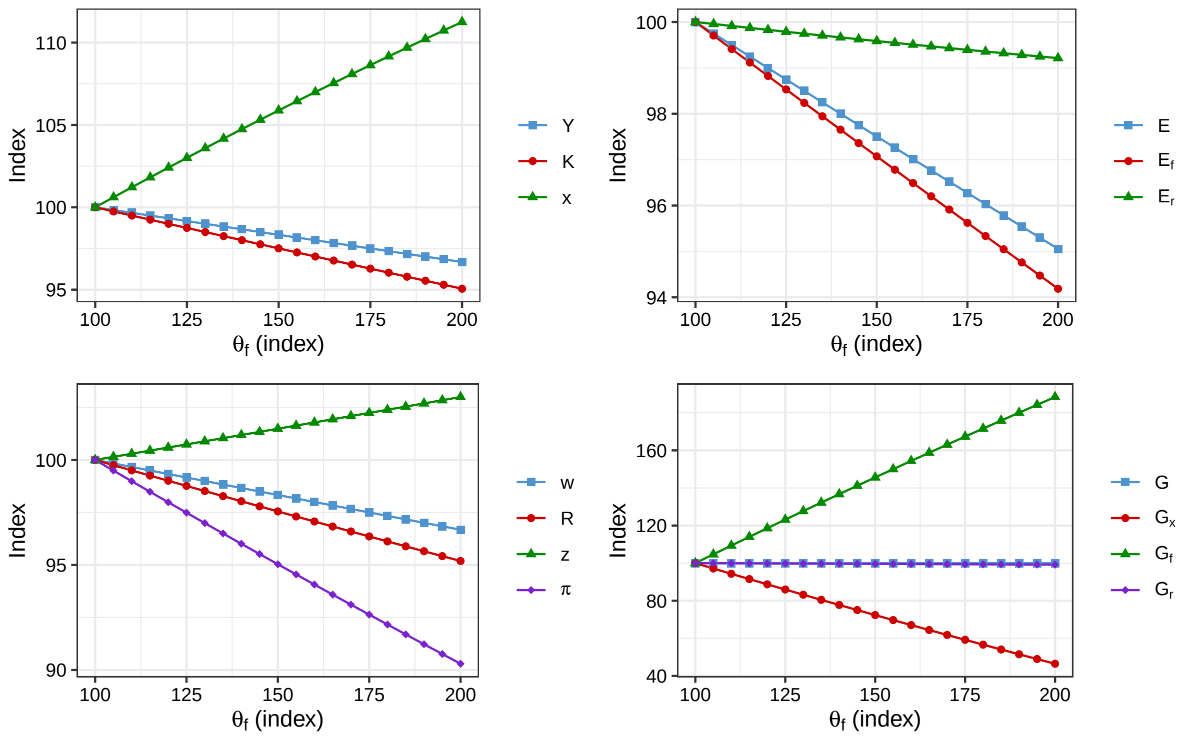


Figure 1.3: Scenario 1

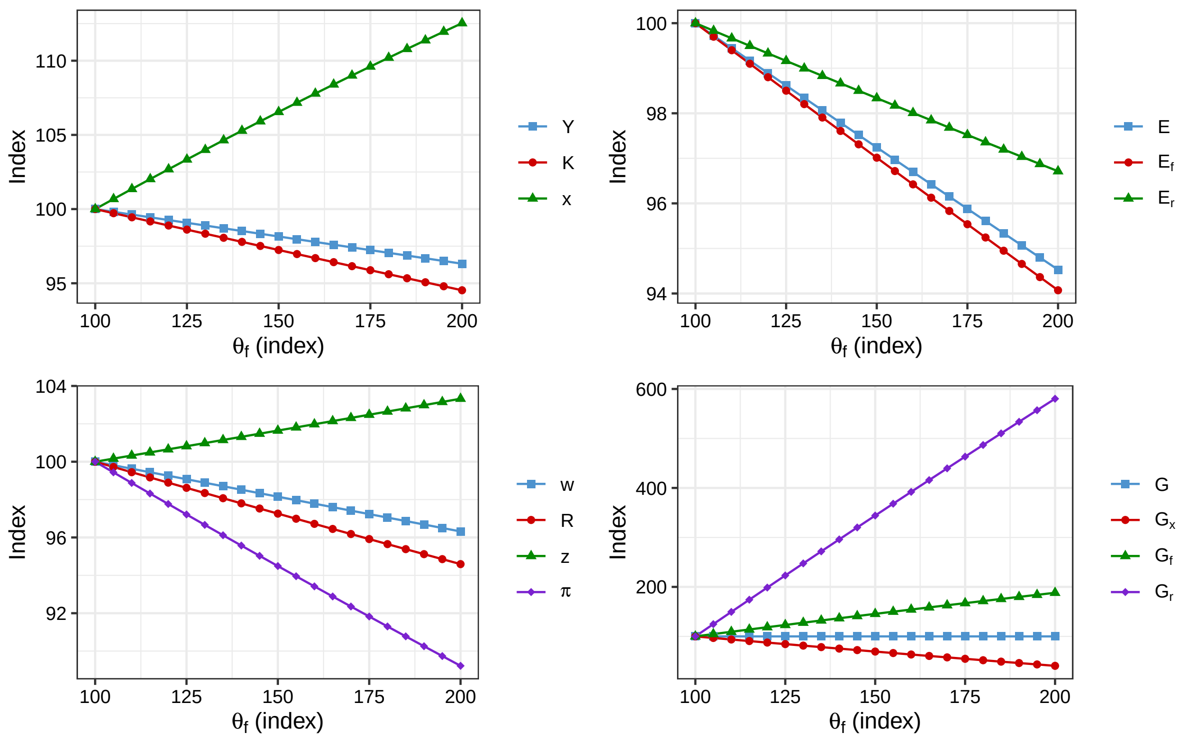


Figure 1.4: Scenario 2

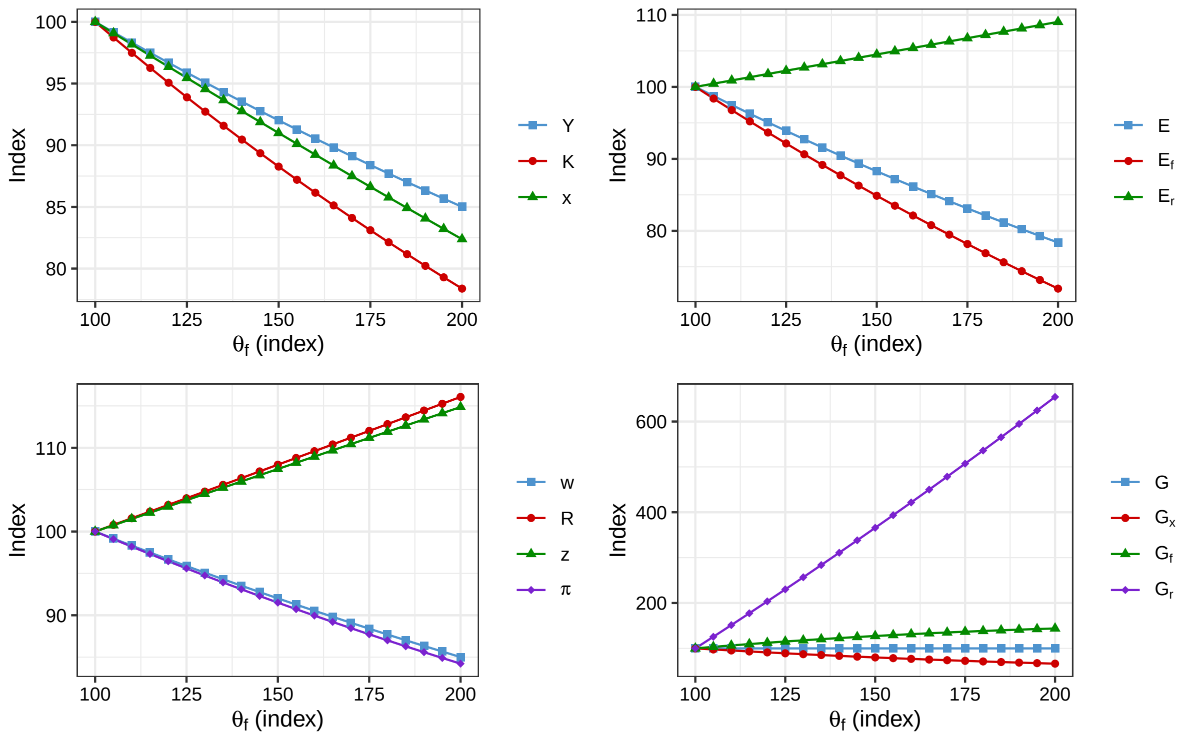



Figure 1.5: Scenario 3

Outcomes of this scenario, which are displayed in Figure 1.5, differ from the two previous ones in two regards. First, they show that given the steep increase in the unit cost of fossil fuels, the use of renewables increases in comparison to the initial situation instead of simply decreasing at a slower rate than overall energy use. Second, consumption drops, which cancels any hope for a second dividend here. This latter result comes from the fact that $z_f$ is also increased because of $\phi_f$, not only $\theta_f$, and no additional fiscal revenue can be obtained from that increase. This shows the issue, from a public finance perspective, of the erosion of carbon taxes' tax base: if the narrowing of the latter is not linked to any fiscal gain, fiscal space from carbon taxation shrinks. Taxing alternatives to fossil fuels thus becomes advisable to maintain a certain level of revenue for the government.

Nevertheless, some policies can help countering the narrowing of the tax base of $\theta_f$ by increasing that of $\theta_r$, which is the situation presented in Scenario 4 (Figure 1.6). Indeed, in this scenario, $\phi_r$ is decreased as $\phi_f$ increases, which can correspond to technological improvements in renewable energy generation processes that decrease the unit cost of $E_r$. Public policies supporting transition to a carbon-free economy by making renewables less costly are mirrored in a lower value of $\phi_r$ in comparison to the initial situation.

The main differences with Scenario 3 are that the increase in $E_r$ is stronger, so that overall energy use decreases by less than before, and the drop in $x$ is lower because the increase in $z$ is smaller than before, which supports production. This scenario illustrates how the transition from a carbon-intensive economy to a renewable-intensive one can impact the economy: increases in the cost of using fossil fuels can have detrimental effects on production and consumption, but new opportunities can arise from a bettering of new energy generation technologies.

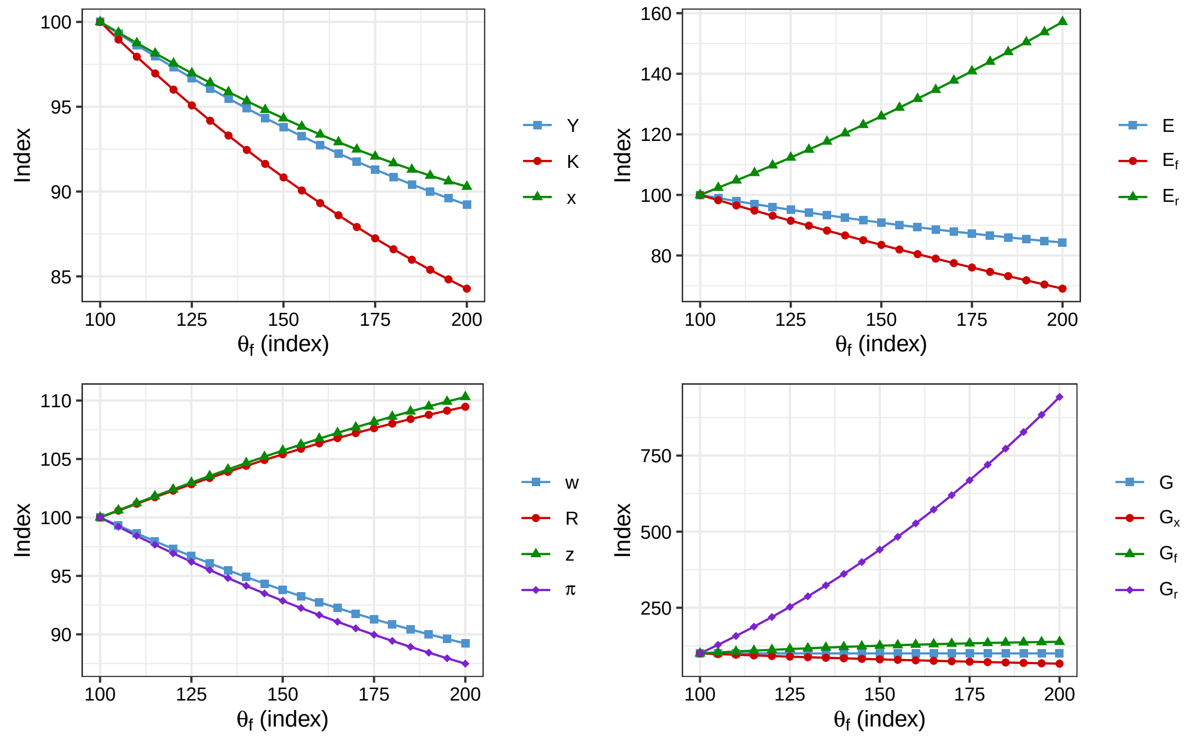



Figure 1.6: Scenario 4

The goal of Scenario 5 (Figure 1.7) is to see if the outcomes of Scenario 4 hold in the presence of the adoption of low energy intensity capital, that is, a lowering of $E_K$. In this model, if $e_x^K$ stays constant, a lower value of $E_K$ can result in the same amount of capital exergy only if more capital is used—i.e., $K$ increases. The idea here is to look at what happens if less energy is required to activate $K$, while other parameters behave like in Scenario 4. The main difference with the previous scenario is that whereas production decreases by more than before, as overall energy use diminishes significantly, total energy costs also decrease, so that the share of $Y$ allocated to energy generation is lower than in Scenario 4. As a result, more of $Y$ can be allocated to consumption, so that the drop in $x$ is way less noticeable. Although no second dividend is achieved in this scenario either, the situation is less negative than in the previous one.

Scenario 6 applies the same logic as Scenario 5, but coupled with an increase in the amount of exergy generated by a unit of capital energy, i.e., $e_x^K$. In this model, improvements in energy efficiency mean that more output can be obtained from the same production inputs, or that it is possible to attain the same level of production with less energy. It implies that there might be a rebound effect: as less energy is necessary to produce, there is an incentive to use this opportunity to increase production instead of only decreasing overall energy use. From an environmental perspective, part of the benefit is sacrificed to get a higher production level.

Figure 1.8 shows that this scenario indeed results in a decrease in overall energy use in comparison to the initial situation, but also in increases in $K$, $Y$ and $x$. This means that improvements in energy efficiency did not only lead to a reduction in energy use, but also in a higher level of production, which implies that there is a rebound effect in this case. The rebound effect is smaller than 100%, that is, not all energy saving from the increase in $e_x^K$ results in more production and energy use, but the potential for a lower use of energy is not fully achieved either. Here, there is

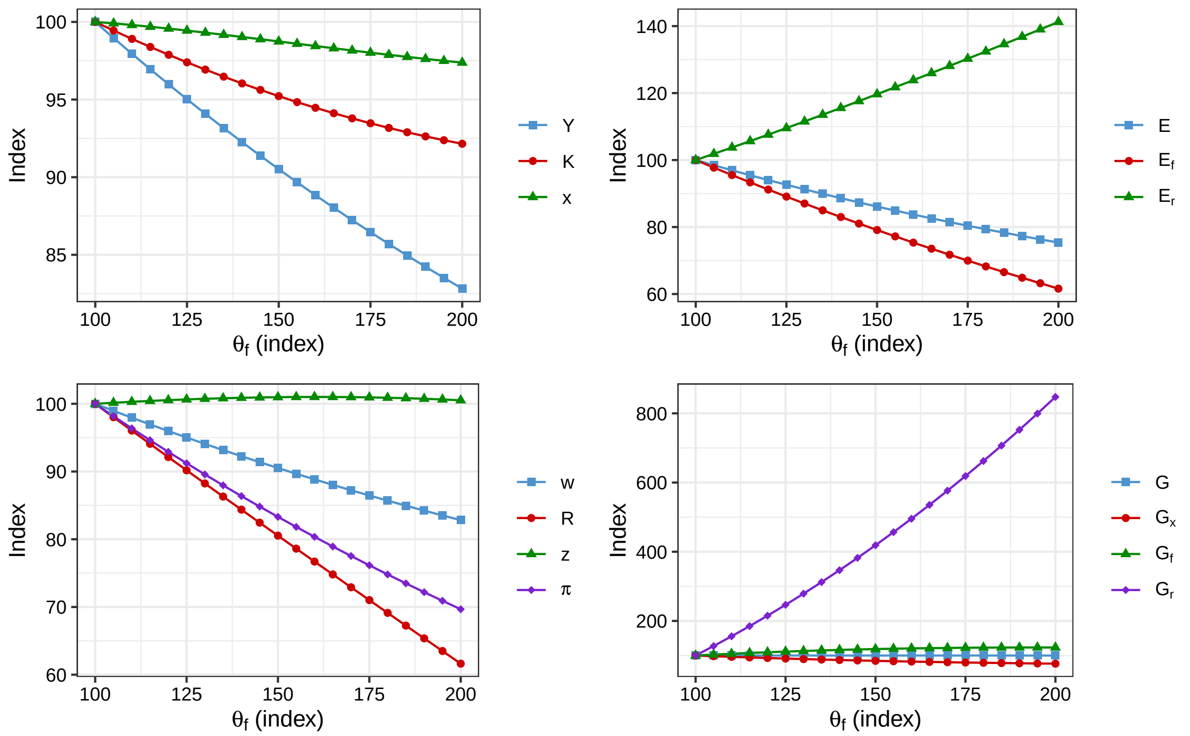



Figure 1.7: Scenario 5

a trade-off between the first and the second dividends: the first one requires mainly a lowering in $E$ (little to no rebound effect), whereas the second one is fueled by an increase in $Y$ and therefore $x$ (large rebound effect). A balance between environmental protection and economic welfare must hence be sought, which will depend on social preferences.

The overall take from these scenarii is that the DD hypothesis is linked to the potential for fiscal revenue within a transition from fossil to renewable energy sources. If changes are caused by non-tax measures that do not bring any new revenue to the government, there is no opportunity to lower preexisting distortionary taxes to improve economic welfare. The concept of fiscal space should therefore be included in considerations regarding carbon taxation: ensuring long-term benefits from it depends on the stability of fiscal revenue that can be recycled. This is where taxing energy from non-fossil fuels becomes interesting: the fiscal space is broadened, which is economically positive. Environmental benefits would also arise in that case.

Technologies that lower the energy intensity of capital and that allow to generate more exergy from energy inputs are also desirable, in that they can help achieve a low carbon economy while maintaining a certain level of economic welfare. An economically and environmentally successful energy transition would thus benefit from such changes.

## 1.6 Conclusion and policy implications

The goals of this chapter are to review the whereabouts of carbon taxation from a public finance perspective, as well as to provide a new perspective on the topic with the help of a partial equilibrium model where energy is included as fully depending on the level of capital and its energy intensity. Existing literature heavily discusses the double dividend hypothesis and provides ar-

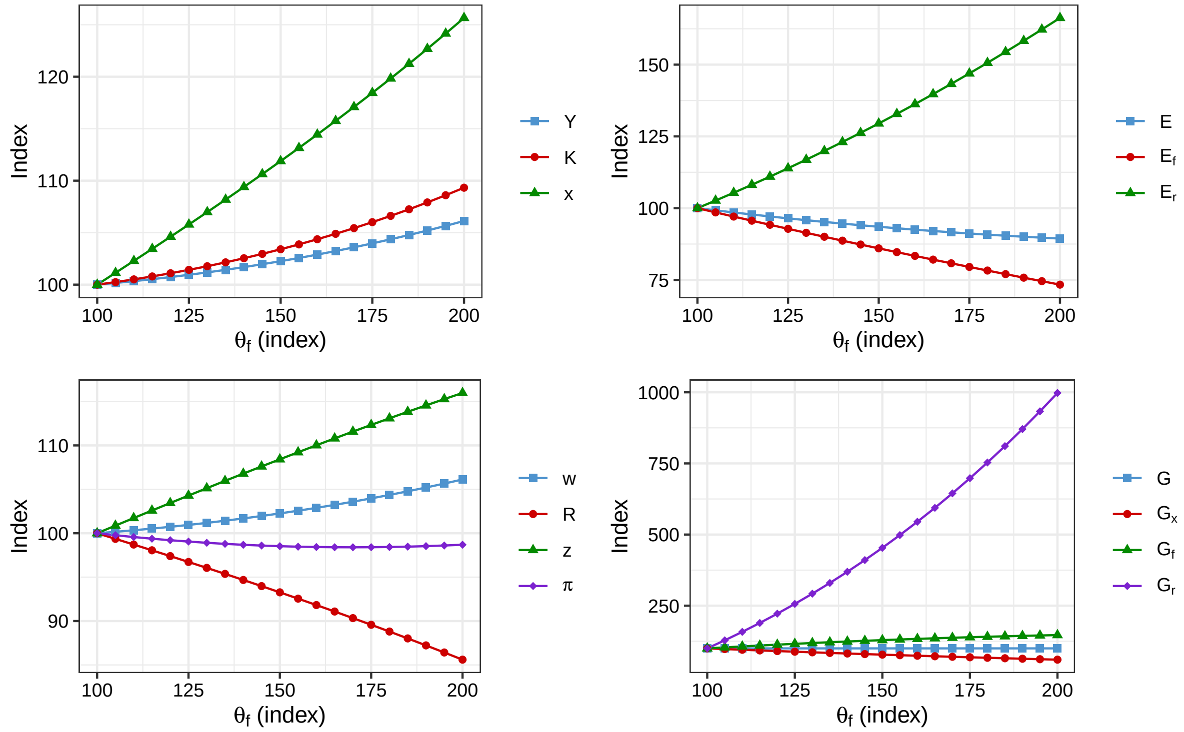



Figure 1.8: Scenario 6

guments both in favor and against its (theoretical) existence. The central argument against it is that levying an environmental tax causes a drop in real income due to its effect on prices, coupled with a tax base erosion effect which negatively impacts the potential to raise fiscal revenue from such a tax. Overall, proceeds from an environmental tax are unlikely to suffice to compensate its negative economic effect by being recycled through a drop in other preexisting distortionary taxes on factors of production.

The issue of the erosion of the tax base of carbon taxes is crucial to its potential role as tool to collect fiscal revenue. The principle of Pigovian taxes on negative externalities is to reach a socially optimal level of externality, but the current political debate on $CO_2$ emissions aims at eventually reaching carbon neutrality in the foreseeable future. Carbon taxation is one policy among others that are used to reach this goal. This expected long-term trend regarding $CO_2$ emissions implies that emissions are not a stable tax base from which fiscal revenue can be collected. A solution would be to start levying a tax on renewable energy sources. Indeed, a carbon tax is a unit tax on energy from fossil fuels, with different rates depending on the fuel considered and is carbon content. As renewable energy is used instead of fossil energy, taxing both types of energy would stabilize the tax base, which would be overall energy use instead of only fossil energy use.

One of the interesting characteristics of energy is that it is necessary to production and will always be. Keen et al. (2019) provide crucial insights on that regard: they model energy as being a necessary input to other factors of production instead of being another one that can be substituted to them. This epistemological take on the subject can intuitively be explained by the following quote: “[..]labour without energy is a corpse, while capital without energy is a sculpture” (Keen et al., 2019, p. 41). As energy is fundamentally required to generate useful work to produce goods and services, it represents a reliable tax base from which to raise revenue. This is the reason why the present chapter suggests to tax energy from renewable sources along with fossil energy, so that although fossil energy is set to disappear at some point, energy as such is still taxed. The point is to carefully choose tax rates to make sure that switching to renewable energy sources remains more profitable in the long term than sticking to fossil fuels. Complementary measures affecting the marginal costs of using fossil and renewable energy sources are also likely to be needed to encourage the transition.

The model presented in this chapter aims at including these considerations into a single framework to derive some analytical predictions and numeric illustrations on the issue. An important takeout from it is that a strong second dividend in terms of both production and consumption is unlikely to be achievable without improvements in energy efficiency and a lowering of the energy intensity of production inputs. As energy taxes indirectly increase the cost of other factors of production, there is little room for benefiting from a second dividend if energy requirements and energy efficiency do not improve. Nevertheless, taxes on fossil and renewable energy sources can be jointly used to raise sufficient fiscal revenue to lower other distortionary taxes while keeping total tax revenue at a steady level, with the desirable consequence of supporting a substitution of renewable energy to fossil energy.

From a policy perspective, two advices can be provided. The first one is to carefully consider the whole tax system before introducing a carbon tax with the goal of raising revenue from it, as interactions between taxes can cause undesirable side-effects on the economy. The double dividend hypothesis is not based on rock-solid grounds, and taxing $CO_2$ emissions can have detrimental economic effects if not taken in a broader picture that includes price levels, the marginal costs of production inputs, and the strength of the link between overall energy use and other factors of production. The second advice is that taxing renewables can be needed at some point during the transition towards carbon-free energy, so that energy stays a reliable source of fiscal revenue. Otherwise, distortionary taxes might need to be reintroduced in the economy, with the consequence that the marginal costs of production inputs would rise.

Further research is needed on the link between energy intensity and other factors of production. A transition to an environmentally sustainable future requires that overall energy use becomes green and sustainable in terms of volume. This means that the scope for lowering energy needs while keeping production at a high level is narrow and involves improvements in energy efficiency. From a public finance perspective, the potential of energy as tax base instead of consumption or income should be investigated further, and direct and indirect incentives from taxes on energy with respect to other factors of production requires more attention to inform on how to best design an energy taxation policy.

## 1.A Appendix A: Model with an income tax

It is possible to use the model presented in Section 1.4.2 to investigate the impact of levying a tax not only on consumption, but on income, be it saved to replace depreciated capital or not. The tax base hence becomes $wN + RK + \pi$, so that $\delta K = (1-\tau)s(wN + RK + \pi)$. Equations (1.15b) and (1.15f) are thus replaced by:

$$R = \frac{\delta}{(1-\tau)s} - \frac{wN+\pi}{K} \tag{1.16}$$

$$G = \tau(wN + RK + \pi) + \theta_f E_f + \theta_r E_r \tag{1.16a}$$

This apparently small modification has an important impact on the model's behavior because $\tau$ now affects the determination of the equilibrium level of capital through the expression (1.16). A decrease in the income tax rate $\tau$ would increase $K$ as savings are less heavily taxed, but at the same time it would imply a larger quantity of depreciated capital to replace and a higher use of energy, which would push fossil and renewable energy unit cost functions up. The outcomes of Scenarii 1 to 6 are thus likely to differ from the situation where the tax would only be levied on the share of income used for consumption, and not the share saved to replace depreciated capital (see Appendix 1.B).

An interesting result is that consumption and capital react in the same proportion to exogenous changes. To see why it is the case, it must be noted that $wN + RK + \pi = Y - zE$. Expressions (1.15e) and (1.16) can thus be rewritten as:

$$x = (1-\tau)(1-s)(Y - zE) \tag{1.17}$$

$$K = (1-\tau)\frac{s}{\delta}(Y - zE) \tag{1.17a}$$

It can easily be seen that both expressions vary proportionally to each other to changes in $\tau$ and $Y - zE$, as long as $\delta$ and $s$ remain constant. Consumption and capital therefore vary proportionally when $\theta_f$ and other parameters determining $Y$, $z$, $E$, and $\tau$, are manipulated. In this version of the model, consumption hence follows capital, as it determines the level of production and total energy costs, which capture a share of $Y$ that cannot be used either for consumption or for replacing depreciated capital.

## 1.B Appendix B: Simulations with an income tax

The outcomes of the six scenarii when a tax is levied on income instead of consumption are displayed below.

In the first scenario (Figure 1.B.1), where only $\theta_f$ is increased, the effects on the economy diverge from the model with a consumption tax in that the lowering of $\tau$ has a positive impact on $K$, so that energy use, production, and consumption remain fairly stable. Renewables replace part of fossil fuels. Overall, if the first dividend is partly achieved in that fossil energy use decreases, the second one is not, as consumption remains stable. Economic welfare therefore does not improve like in the case with a consumption tax, but it does not really deteriorate either, given the magnitude of changes in $Y$ and $x$.

Interestingly, in Scenario 2 (Figure 1.B.2), both $Y$ and $x$ become higher as the income tax is lowered thanks to proceeds from increases in fossil and renewable energy taxes' rates. The increase in $K$ provoked by the lowering in $\tau$ compensates the increase in energy use and the unit cost of energy, so that there is more income available for consumption and to supply capital. As both $E_f$ and $E$ increase, the first dividend is not achieved here: the lowering of $\tau$ has too strong a positive effect on production and energy use. The second dividend is nevertheless achieved, as $x$ increases with $\theta_f$ and $\theta_r$ and the recycling of the newly collected fiscal revenue. This situation illustrates a case where the two dividends oppose each other: it would be possible not to recycle the new energy tax revenue to lower $\tau$, so that production and energy use do not increase. However, consumption would probably drop by doing so.

The outcomes of Scenarii 3 and 4 (Figures 1.B.3 and 1.B.4) are however very similar between the models with consumption and income taxes. Only the magnitudes of variations change; otherwise, their directions stay the same. This shows the important impacts of non-tax changes in the cost of using fossil and renewable energy sources. The fact that no extra fiscal revenue is collected from these changes does not open much room for cuts in other distortionary taxes, be they levied on consumption or income.

Scenario 5 (Figure 1.B.5) displays similar outcomes in the two versions of the models. However, Scenario 6 (Figure 1.B.6) differs from the model with a consumption tax in two respects. First, the magnitude of the decrease in energy use is lower when the tax is levied on income, which is linked to the larger increase in production in this version of the model. The first dividend is therefore smaller here. Second, both $R$ and $\pi$ increase here, whereas they were decreasing, or decreasing then increasing, in the model with a consumption tax. Although these differences do not have strong implications regarding the main outcomes of the models, it means that relative remunerations of FOPs are not similarly impacted depending on how taxes are levied in the present model.

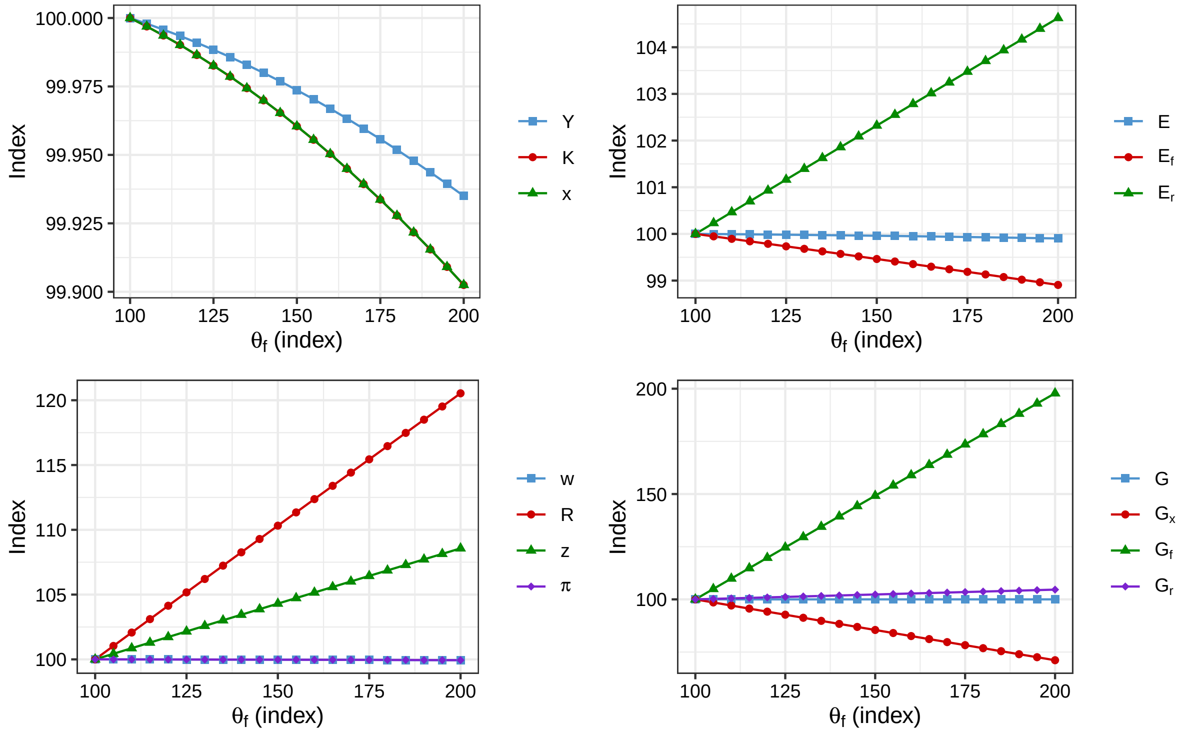



Figure 1.B.1: Scenario 1 (income tax)

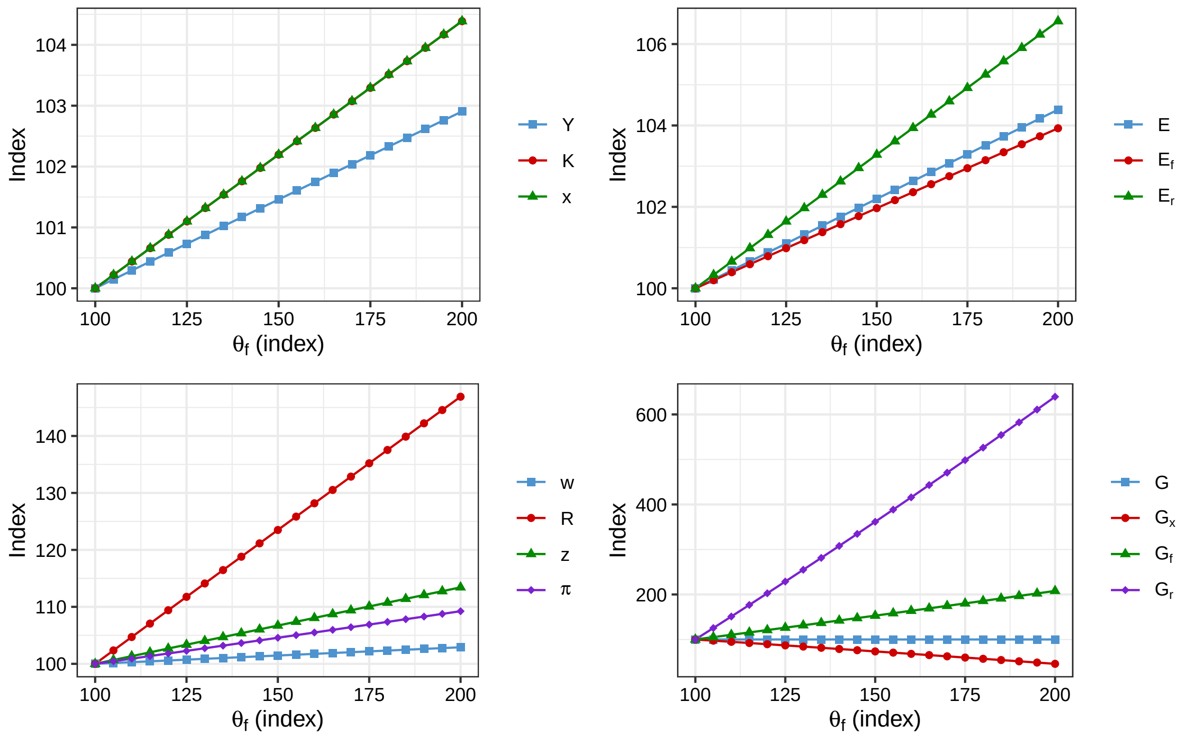



Figure 1.B.2: Scenario 2 (income tax)

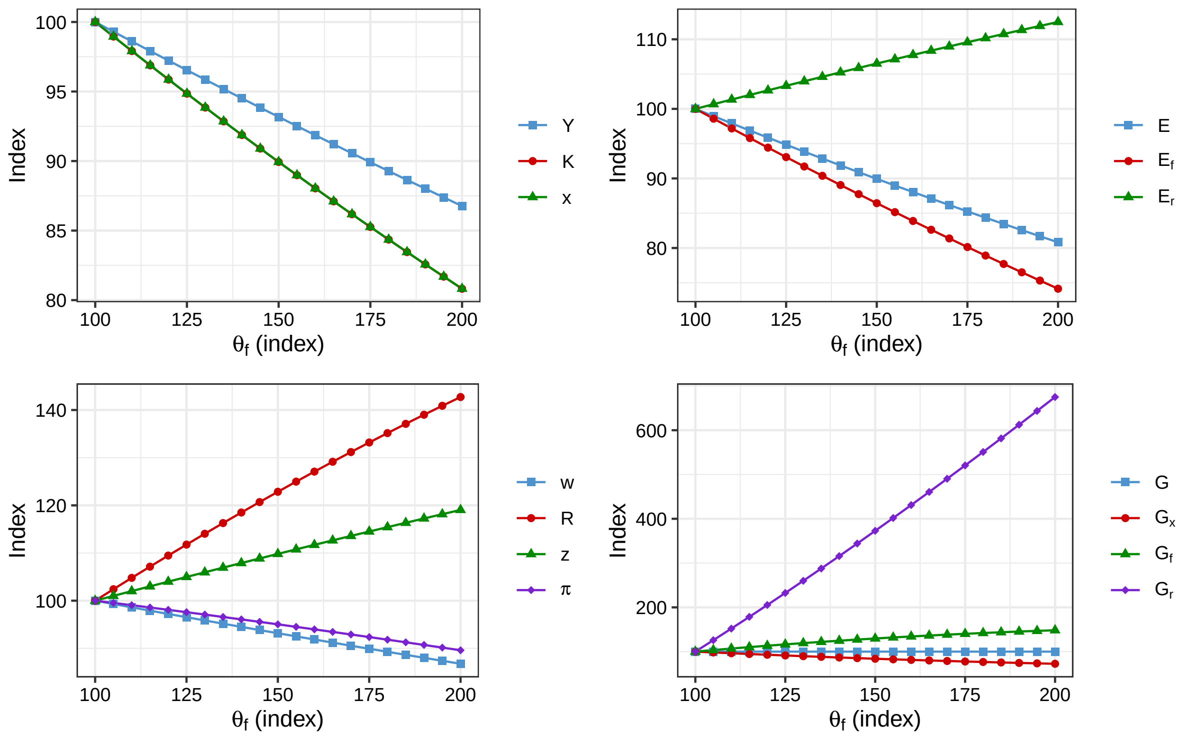



Figure 1.B.3: Scenario 3 (income tax)

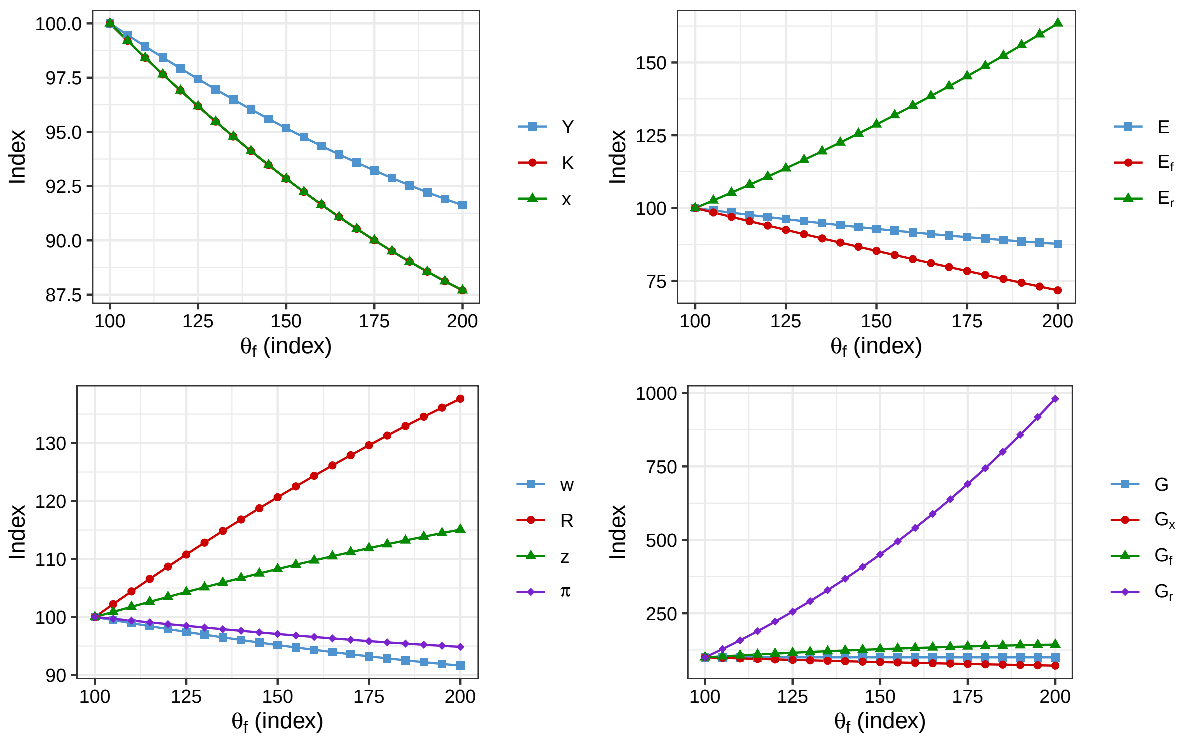



Figure 1.B.4: Scenario 4 (income tax)

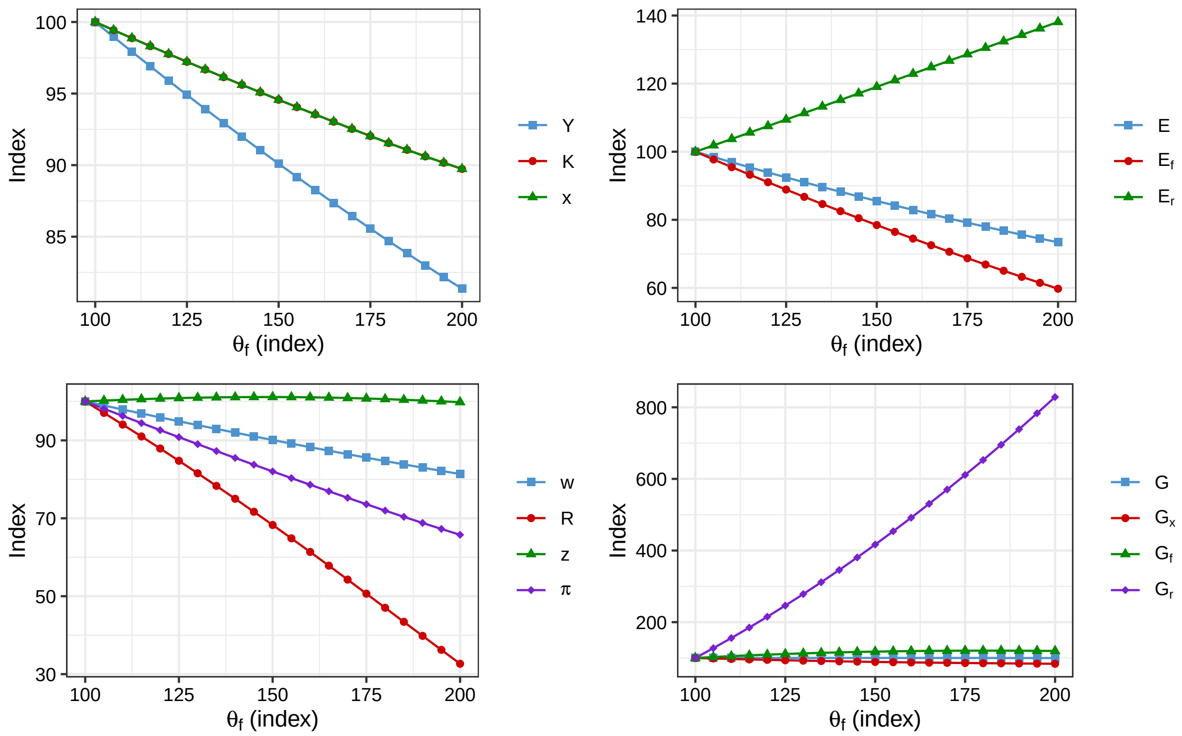



Figure 1.B.5: Scenario 5 (income tax)

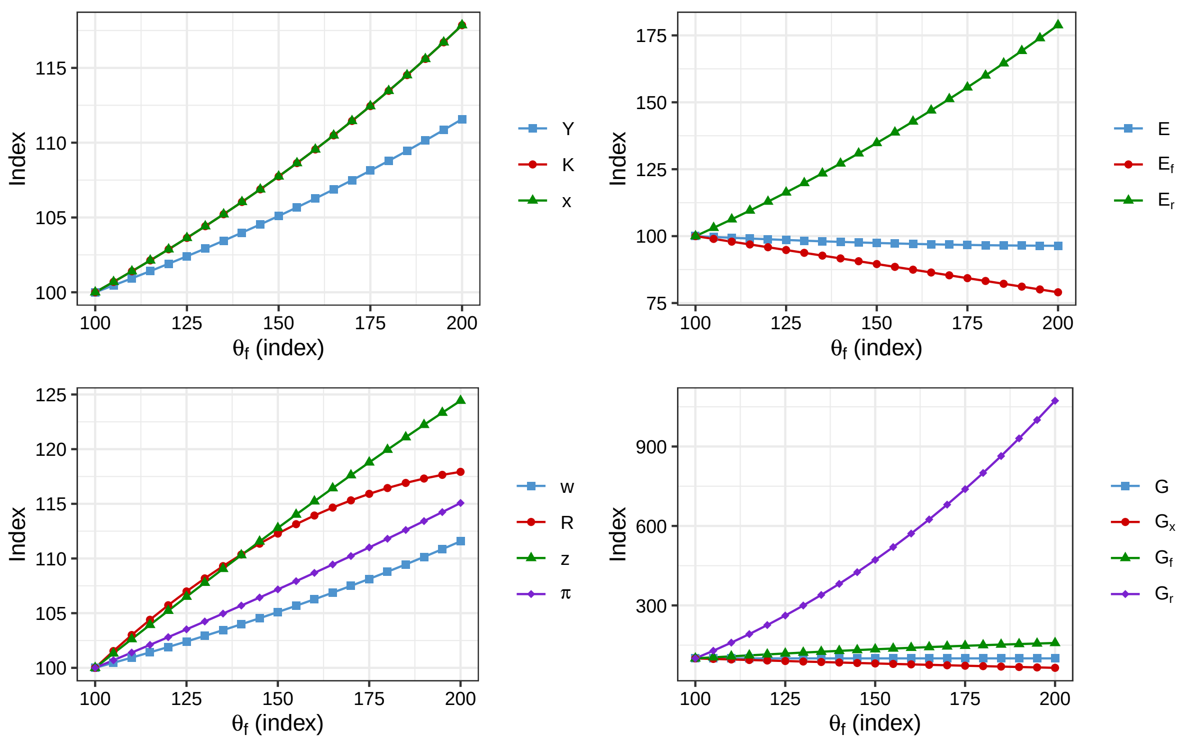



Figure 1.B.6: Scenario 6 (income tax)

# Chapter 2

# The effectiveness of the Swiss $CO_2$ levy on residential heating demand

*This chapter is based on an article co-authored with Prof. Sylvain Weber and has been published as: Ott, L. and Weber, S. (2022). How effective is carbon taxation on residential heating demand? A household-level analysis.* Energy Policy*, 160:112698.*
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**Abstract** This chapter investigates the impact of the Swiss $CO_2$ levy on households' heating demand. Using a difference-in-differences approach combined with inverse probability of treatment weighting, we test whether the 2016 and 2018 carbon tax rate increases had a short-run impact on Swiss households' heating and hot water expenditures—i.e., a proxy for heating consumption. Micro-level data from the Swiss Household Energy Demand Survey are used to estimate the models. Our regression analysis shows that heating consumption decreases with time for all households, but it does not detect any clear short-run impact of the $CO_2$ levy on fossil fuel users in comparison to non-fossil fuel users. We nevertheless find that many factors significantly affect heating consumption, such as setting the thermostat at a lower temperature. Even though further research is needed regarding possible long-run impacts, our findings challenge the relevance of this policy instrument under its current form to lower households' $CO_2$ emissions. Considering that its rate is regularly increased based on short-run emission targets, households may have too little time to adapt. The tax design might thus need to be revised to take into account the slow reaction time.

**Keywords:** Carbon tax, energy consumption, fossil fuel, policy evaluation, inverse probability of treatment weighting, difference-in-differences.

**JEL classification:** C21, C23, H23, Q41, Q58.

## 2.1 Introduction

Given the current state of scientific knowledge concerning the role played by anthropogenic greenhouse gas (GHG) emissions in climate change (Stern, 2007), there is today a clear need for ambitious policy action on purely environmental grounds. The $CO_2$ levy is one of Switzerland's main climate policy instruments in that regard, as its direct impact on fossil fuel prices is supposed to incentivize GHG emitters, be they enterprises or individuals, to take action to become more environmentally friendly. The extent of its impact on $CO_2$ emissions is thus its main *raison d'être*.

Although some firms can be exempted from paying the tax, as described in Section 0.3, households have no alternative but to pay the tax on all their fossil non-motor fuel purchases, i.e., mainly extra-light oil and natural gas used for heating and hot water[1]. To reduce their tax burden, households need to consume less fossil fuels, which can be realized through behavioral changes (set thermostat lower, air less often, etc.), renovations (of windows, heating system, etc.), or—more radically—installation of renewable heating systems such as heat pumps or solar panels. The $CO_2$ levy is precisely intended to lead to such adaptation strategies from households so that their tax burden is minimized: the higher the tax, the stronger the incentives for becoming more energy-sufficient and energy-efficient.

However, the extent and the speed of reactions to a carbon tax are open to debate. The effectiveness of the tax relies on the assumption that individuals are *homines oeconomici*, who correctly interpret the price signal of a Pigovian tax and react by lowering their fossil fuel demand accordingly. Such a situation should however not be taken for granted. Different factors may erode the impact of the carbon tax on households' reaction: imperceptibility of the price signal; lack of knowledge and incorrect understanding of the $CO_2$ levy; bounded rationality. The literature in behavioral economics argues that individuals do not always behave rationally from an economic point of view (Congdon et al., 2009). Moreover, the price-elasticity of demand for fossil fuels is generally estimated as being rather low (see, e.g., Baranzini and Weber, 2013; Labandeira et al., 2017). Hence, the expectation that the $CO_2$ levy pushes people to reduce fossil fuel consumption is far from obvious and deserves *ex-post* empirical investigations.

This chapter evaluates the effectiveness of the Swiss $CO_2$ levy, focusing on the residential sector. It investigates whether households which rely on fossil fuels to heat their homes do adapt their energy demand—relative to households who rely on non-fossil fuels—following an increase of the levy. More precisely, it analyzes the impacts of the tax rate increases that took place in 2016 (from CHF 60 to 84, or +40%) and 2018 (from CHF 84 to 96, or +14%) and tests the hypothesis that the tax increases led households who use oil or gas as main heating fuel to lower their heating consumption in comparison to other households. As the $CO_2$ Act, which sets the $CO_2$ levy, is currently being reformed, an appraisal of the strategy applied between the $CO_2$ levy introduction in 2008 and today is worth considering to inform policy makers on how it effectively worked during that time.

Household-level data collected in five waves (2016-2020) of the Swiss Household Energy Demand Survey (SHEDS) are used. The advantage of using revealed household-level data is

[1]In 2016, heating and hot water account for about 38% of final energy consumption in Switzerland, making it the largest source of end use energy demand. For a complete description and analysis of heating in Switzerland, see Narula et al. (2019).

twofold. First, in the context of energy demand, tax elasticities usually appear different from price elasticities. Studies relying on simulations may therefore use a wrong elasticity to infer about the impact of taxes. Second, observations at the market level result from the combined reaction of various types of actors, not only households but also firms, and it seems likely that the two groups react differently. Investigating households' reaction is only possible with household-level data and is less frequent in the literature than analyses of firms' reaction, probably because few databases provide measurements at this disaggregate level. Considering that households are responsible for the consumption of more than 50% of the petroleum products and natural gas used in the heating sector in Switzerland (Swiss Federal Office of Energy, 2021), a separate analysis for this group of agents seems justified.

Our empirical strategy relies on a difference-in-differences (DID) approach: heating fuel consumption of the treatment group (households with fossil fuel heating systems, i.e., using heating oil or natural gas) is compared to that of the control group (households with non-fossil fuel heating systems, i.e., heat pumps, electricity, solar panels, wood or district heating) throughout the survey period, which includes the 2016 and 2018 $CO_2$ levy rate rises, so that average treatment effects on the treated (ATTs) can be estimated[2]. To correct for imbalances in covariates between the two groups, inverse probability of treatment weighting (IPTW) is used: each treated household receives a weight of 1 while each control household receives a weight that reflects how similar it is to treated ones (see Austin, 2011). This strategy constitutes an improvement over the standard DID approach since it makes the two groups comparable regarding observable characteristics that could affect the outcome of interest.

With our estimation strategy, we intend to look at the short-run behavioral impact of carbon taxation, that is, the adoption of energy-saving behaviors regarding the consumption of fossil heating fuels. The general conclusion of our econometric analysis is that the $CO_2$ levy has no clearly discernible short-run effect on Swiss households' energy consumption of fossil heating fuels. This finding does not imply that the $CO_2$ levy is a bad instrument nor does it exclude possible reactions over the longer run[3], but it does put certain aspects of the design of the Swiss $CO_2$ levy into question. In particular, the pace at which the tax rate was raised between 2008 and 2022 (almost every second year) may have been too hasty to leave households a chance to adjust if the main channel to decrease fuel consumption is not via a decrease in the amount of heating services consumed but indeed by heating systems renovations and/or changes. The announcement effect might not suffice: whether the tax rate will increase or not depends on countrywide $CO_2$ emissions reduction, not only on individual decisions to abate, so that future costs remain uncertain when the decision to renovate or not must be taken. The lack of salience from the tax can be pointed as a further probable cause for households' non-reaction, as tax increases are hardly perceptible because of substantial market price volatility. Limited decision capacity regarding heating consumption and energy-efficient renovations might also play a role, as well as households' limited understanding of the tax mechanism.

The chapter is structured as follows. Section 2.2 provides background knowledge by reviewing relevant literature and contextualizing the Swiss $CO_2$ levy. Section 2.3 presents the analytical framework and the econometric model used to test the research hypothesis. Section 2.4 de-

[2]The treatment group represents approximately 60% of homes in Switzerland (Source: Swiss Federal Statistical Office, *Survey on the energy sources of residential buildings*, 2017).

[3]By definition, switching from a fossil fuel heating system to a renewable heating system is a long-run reaction, and such changes are not considered in our sample.

scribes the data and explains how weights are assigned to each household in order to achieve covariate balance between fossil fuel users and non-fossil fuel users. Section 2.5 presents and discusses the results of our empirical estimations. Section 2.6 provides policy implications and concludes.

## 2.2 Background

As coined by Andersen (2010), research undertaken on carbon taxation moved from *ex-ante* simulation in the 1990s (e.g., Nordhaus, 1993) to *ex-post* analyses using actual data (e.g., Lin and Li, 2011). However, empirical studies relying on micro-econometric methods are still scarce (for a review, see Green, 2021). Martin et al. (2014) assess the impact of the British carbon tax on manufacturing firms and identify a negative effect on energy intensity and electricity use. In their review of British Columbia's (BC) $CO_2$ tax, Murray and Rivers (2015) quote a few studies relying on difference-in-differences approaches to estimate the impact of the tax on GHG emissions and fossil fuel consumption, and they all report negative impacts as could be expected from a theoretical point of view. Andersson (2019) uses a synthetic control method to analyze the impact of carbon taxation on $CO_2$ emissions from the transport sector in Sweden between 1990 and 2005. He finds an average yearly drop of 6% in emissions attributable to the carbon tax over the period. Bernard and Kichian (2019) estimate the short- and long-run impacts of BC's carbon tax on diesel demand using time-series models. They find a combined reduction of 1.24 liter in monthly per capita diesel consumption, which corresponds to a reduction of 1.3% of the related emissions. Xiang and Lawley (2019) investigate the impact of BC's carbon tax on residential natural gas consumption. They compare results from a fixed-effect regression model and a synthetic-control model with state/province-level panel data and find that the consumption of natural gas decreased on average by 6.9 to 10.1% per year over the period considered. None of these papers however considers the effects of carbon taxes on households at a microeconomic level.

Indeed, the literature on the impact of carbon taxes on households in terms of GHG emission reduction is very limited. Most studies on households tend to focus on distributional aspects (see Beck et al., 2015; Brännlund and Nordström, 2004; Callan et al., 2009; Chapa and Ortega, 2017; Renner, 2018; Tiezzi, 2005; Williams et al., 2014), leaving effectiveness aside. Labandeira and Labeaga (1999) provide one of the few attempts to evaluate the potential effect of a $CO_2$ tax on households. They combine an input-output analysis and a simulation with micro-level data to look at the distributional and behavioral effects of an hypothetical carbon tax in 1994 in Spain. They find a small reduction of energy-related carbon dioxide emissions by households, but this result must be considered cautiously since it relies on a simulation rather than on observation of an actual carbon tax. Lawley and Thivierge (2018) analyze the impact of BC's carbon tax on gasoline demand using household-level data. Their results show that a carbon tax of 5 cents per liter reduces gasoline consumption by 5 to 8%. This finding indicates that carbon taxation is effective in inducing individuals to lower their consumption of fossil fuels in the transportation sector. Brülhart et al. (2020) simulate the potential impact of an airline ticket tax in Switzerland with different scenarios. They estimate that a tax ranging from CHF 30 to CHF 120 could reduce $CO_2$ emissions from the airline sector by 5% to 11% thanks to a lowering of the number of passengers and kilometers traveled. Nevertheless, whether Lawley and Thivierge (2018) and Brülhart et al.'s (2020) conclusions extend to thermal fuels remains uncertain.

Tiezzi (2005) briefly discusses effectiveness considerations in her appraisal of the welfare effects of the Italian carbon tax. She computes price-elasticities of demand for domestic (i.e., mainly heating) and transport fuels and finds them to be respectively $-1.057$ and $-1.282$ at the sample mean, which suggests that taxing $CO_2$ may play a significant role in Italy's environmental policy to lower GHG emissions. However, these elasticities only provide *ex-ante* information on potential effects and might not hold in other socioeconomic, geographical and institutional contexts than Italy in the 1980s-90s. Indeed, Labandeira et al. (2017) conduct a meta-analysis on the price elasticities of energy demand and find that these elasticities are rather low, especially in the short run (less than 1 year in their definition). They report that average short-run elasticities from the literature for different fuels range from $-0.149$ to $-0.201$, whereas long-run elasticities range from $-0.372$ to $-0.572$. Focusing on heating oil, average short-run and long-run elasticities take the values $-0.188$ and $-0.535$, respectively[4]. Little reaction to carbon taxes can therefore be expected, especially in the short run. This might be due to the fact that substantial changes in energy consumption for heating require costly adaptation strategies such as renovations, which are only possible in the long run. In the short run, only behavioral adaptation strategies can be expected, such as heating less, airing less often and when heaters are off, starting to heat later in the season, or heating only rooms when they are occupied (see Hediger et al., 2018).

Weber and Gill (2016) estimate price elasticities of heating consumption in Germany using household-level longitudinal data and investigate the puzzling empirical finding reported in the literature that, counter-intuitively, the elasticity of homeowners is often lower than that of tenants in absolute value. They find that the type of building and the level of initial (i.e., in the first period of the panel) heating consumption actually explain the aforementioned result: tenants usually have a higher heating consumption per $m^2$ of floor surface, which, the authors explain, is connected to a higher elasticity because of their greater potential to reduce consumption. Tenants also live on average in larger buildings with lower outside surface to indoor volume ratios, so that heating less or airing less often have a lower impact on indoor temperatures than in smaller building. It is thus easier for tenants than for owners to lower their heating consumption while keeping their level of comfort constant. It should nevertheless be noted that their (short-run) price elasticity estimates are relatively low, ranging from $-0.251$ to $-0.429$, which is similar to those reported by Labandeira et al. (2017).

Although estimated price elasticities of energy demand are generally low, the literature on tax salience (see Fochmann et al., 2010; Chetty et al., 2009) shows that taxes have larger behavioral impacts than equivalent price changes, in contradiction to what is expected under full economic rationality. Andersson (2019) estimates tax-elasticities to be about three times larger than price-elasticities in the case of gasoline in Sweden. Both Rivers and Schaufele (2015) and Bernard and Kichian (2018) find that British Columbia's carbon tax had a larger impact on gasoline demand than an equivalent increase in price. Li et al. (2014) in the USA and Baranzini and Weber (2013) in Switzerland get similar results for gasoline taxes, which suggests taxes on fossil motor fuels are likely to display salience and therefore command larger responses than market price variations of similar magnitudes. Whether this is also the case in the residential sector remains uncertain. Nevertheless, these findings suggest that carbon taxes might have stronger impacts than market price changes not bearing the label "tax".

[4]Estimations can vary quite substantially depending on the statistical method and the nature of the data used.


Note: The intensity of the red shaded background indicates the level of the Swiss $CO_2$ levy. Per $tCO_2$, the rate was CHF 12 in 2008, CHF 36 in 2010, CHF 60 in 2014, CHF 84 in 2016, and CHF 96 in 2018.

Sources: Swiss Federal Statistical Office, Swiss National Bank, U.S. Energy Information Administration.

Figure 2.1: Evolution of the average heating oil price in Switzerland and Europe Brent crude

Beside their effects on prices, taxes can thus have an impact through their mere existence, as consumers seem to dislike the idea of paying them. Such a phenomenon is particularly relevant in the case of the Swiss $CO_2$ levy, because market price fluctuations are so important that they completely mask the tax changes, as illustrated in Figure 2.1. Since its introduction in 2008, the level of the tax has been raised four times in a decade, reaching in 2018 a level eight times higher than ten years earlier. Yet, the price of oil decreased sharply at the end of 2014 and remained at a lower level thereafter. As a consequence, tax increases left heating oil's market price more or less unchanged, thereby possibly leaving consumers without reaction. Nevertheless, if the carbon tax is sufficiently salient and consumers view it differently from market price variability, an effect can be expected even in absence of a visible price increase because of tax aversion. Figure 2.1 shows that average heating oil prices in Switzerland follow those on international markets, but it also shows how the spread between national and international prices widens as the carbon tax rate increases. The effect of the $CO_2$ levy is not directly visible through jumps in prices, but it appears to affect market prices in the longer run. Its actual salience for households is therefore ambiguous.

Most of existing research on the Swiss $CO_2$ levy however does not address this type of concern. It rather focuses on effectiveness by either using simulations (Ecoplan et al., 2015; Ecoplan, 2017) to establish the aggregate counterfactual situation that would prevail in absence of carbon tax, or by surveying firms (TEP Energy, 2016). While Ecoplan et al. (2015) find a negative effect of the tax on $CO_2$ emissions and a positive one on energy substitution away from oil, their results are by nature hypothetical and might therefore differ from those of an observational study. The main advantage of such analyses based on simulations is their ability to provide an anticipated expectation for effects of the tax before it is actually implemented (or increased). In fact, this methodology appears as the only possibility to conduct such an *ex-ante* exercise. However, after the tax is actually implemented, revealed behavior can be observed and should be investigated using *ex-post* analyses. Hence, we argue there is room for further research projects on the topic, especially empirical ones, as a gap remains in the literature on carbon taxation using empirical methods to establish causal effects.

A similar analysis to the one provided in the remainder of this chapter has been conducted by Francescutto and Mathys (2022). The authors analyze the impact of the $CO_2$ levy with household budget data covering the period between 2006 and 2017. They focus on home owners and their fossil heating fuel demand. They find that house owners and, to some extend, flat owners decreased their fossil heating fuel demand in the period 2014-2017, which corresponds to the $CO_2$ levy's second policy period, in comparison to the pre-tax situation of 2006-2007. The absence of a control group to serve as counterfactual nevertheless limits the reach and the robustness of this finding[5]. The analysis carried out in this chapter can therefore either confirm or question this conclusion on the effectiveness of carbon taxation as it is applied in Switzerland.

## 2.3 Analytical framework

We use a difference-in-differences (DID) approach to compare the fuel consumption trajectories followed by fossil fuel users (treatment group) and non-users (control group) over a five-year time period. Our treatment is the exposure to the $CO_2$ levy and its 2016 and 2018 increases, which is expected to have a psychological impact on fossil fuel users through tax aversion—a hypothesis in line with the literature presented in Section 2.2. We thus intend to estimate the effect of subsequent behavioral changes such as shutting off heating at night, airing less often and not heating with windows open, heating only occupied rooms, or starting to heat later in the season.

DID allows to estimate causal effects (Lechner, 2011) under the classical Rubin causal model (see Imbens and Rubin, 2015). The key idea of DID methodology is to establish a counterfactual (unobserved) outcome for the treatment group using the actual (observed) outcome of a control group that is similar enough so that similar outcomes would be expected for both groups in absence of any treatment—the so-called *common trends assumption*. The validity of any finding in a DID model therefore relies on the comparability between the treatment and control groups, as the average treatment effect on the treated (ATT) is defined as the difference between the actual and the counterfactual outcomes for the treated.

Randomized control trial (RCT) is the gold standard in this regard: by randomly sampling observation units from the same population, it ensures that treated and non-treated units do not systematically differ. However, outside the laboratory, it is often impossible to achieve such a high degree of similarity. The $CO_2$ levy constitutes a so-called *natural* experiment, in the sense that observations units are differently affected by the introduction and increases of the tax, but the allocation of treatment (paying the tax) is not exogenously controlled as in an RCT. We thus need to ensure *ex-post* that treatment and control units are indeed comparable.

To do so, we use inverse probability of treatment weighting (IPTW) as covariate-balancing method (see Austin and Stuart, 2015). The idea is to assign larger weights $w_i$ to units most likely to be in the group (treatment or control) they do not actually belong to (Austin, 2011), which helps to estimate the average treatment effect (ATE) on the whole population. When one is interested in estimating the ATT instead, these weights are set equal to 1 for the treated units and to $e_i/(1-e_i)$ for the non-treated, where $e_i$ is unit $i$'s probability of being treated, that is, a propensity score (PS). It is defined as $e_i = Pr(T_i = 1|X_i)$ where $T_i$ is a dummy indicating the

[5]Leu (2018) does a comparable analysis for Swiss firms in the industry and services sectors with company-level data. He finds a negative effect of the $CO_2$ levy on the firms' fossil energy consumption, but also without counterfactual.

treatment ($T_i = 1$) or control ($T_i = 0$) status of $i$ and $X_i$ is a set of covariates used to estimate $e_i$ (Austin and Stuart, 2015). IPTW relies on the covariate balancing properties of propensity scores (Rosenbaum and Rubin, 1983; Li et al., 2016): conditional on the PS, covariates included in $X_i$ should be balanced between treatment and control units. Said otherwise, all units with the same PS should have the same distribution of $X_i$ (Austin, 2011). Confounding caused by observables can thus be mitigated. Because our dataset is composed of repeated cross-sections, we estimate PSs for each time period separately. We thus ensure that treatment and control groups are comparable at each time period[6].

The estimation of $e_i$ is subject to a couple of important decisions. First, one needs to consider carefully the variables to include, as this will determine for which observables balance should be achieved. Brookhart et al. (2006) recommend to include in the estimation procedure not only covariates that are related to the treatment variable, but also those which are related to the outcome variable without necessarily being linked to the treatment. As underlined by Caliendo and Kopeinig (2008), omitting important variables might result in a biased estimation of the treatment effect. The inclusion of squared terms and interactions should also be considered (see Imbens and Rubin, 2015). A thorough consideration of existing theory and a careful examination of available information are therefore advisable to select relevant variables.

The second choice is how to estimate $e_i$. While the traditional approach is to use a logistic regression model, alternative methods have been proposed. For instance, Lee and Lemieux (2010) suggest to use classification and regression trees, and Imai and Ratkovic (2014) propose a generalized method of moments that includes a covariate balancing condition, which they call the covariate balancing propensity score (CBPS). Deciding which estimation method to use is thus far from obvious; it is therefore advisable to run different ones until proper covariate balance is achieved. In this chapter, we use CBPS because the weights $w_i$ obtained with this technique perform best in terms of covariate balance.

A DID regression is then estimated using weighted least squares (see, e.g., Romano and Wolf, 2017), where the dependent variable $y_{it}$ is household $i$ heating fuel consumption during year $t$. We take the natural logarithm of $y_{it}$ and specify the model as follows:

$$\ln y_{it} = \gamma \cdot T_i + \sum_{t=2017}^{2020} \left[\delta_t \cdot \left(T_i \times \mathbb{1}_{\{year=t\}}\right)\right] + x'_{it} \cdot \beta + \tau_t + \varepsilon_{it} \tag{2.1}$$

where $T_i$ is individual treatment status, $\mathbb{1}_{\{\cdot\}}$ is an indicator function taking the value 1 when the condition in braces is true, $x_{it}$ is a vector of independent variables that contains a set of region fixed effects[7] to account for time-invariant (i.e., geographical, institutional, and cultural) specificities, $\tau_t$ are year fixed effects, and $\varepsilon_{it}$ is an error term. $\delta_t$ are coefficients showing the impact on the dependent variable of being in the treatment group in year $t$, that is, the treatment effect for each year.

The $CO_2$ levy has been raised in January 2016 and January 2018. If such increases do have the intended impact, one should expect relative decreases in heating fuel consumption for fossil fuel

[6]Stuart et al. (2014) propose an IPTW method for repeated cross-sectional data with two periods and binary treatment, where the sample is split in four groups, that is, one per period-treatment combination. The probability of belonging to each of these groups is estimated for each individual in the sample using multinomial logistic regression. This method is however not suitable in our case due to the high number of period-treatment combinations (i.e., 5 periods × 2 groups = 10), which strongly increases the risk that weights take extreme values in practice.

[7]In this analysis, regions correspond to Swiss cantons.

users compared to others shortly afterward. Because of data-related reasons (see Section 2.4), our dependent variable measures heating fuel consumption with a one-year lag. The short-run effectiveness of the $CO_2$ levy should therefore be observed in 2017 and 2019 and in our estimations it is captured by coefficients $\delta_{2017}$ and $\delta_{2019}$.

## 2.4 Data

### 2.4.1 Dataset

Data used in this study come from the Swiss Household Energy Demand Survey (SHEDS)[8], which covers a wide range of aspects related to households' energy demand, preferences, behaviors, as well as psychological and socioeconomic characteristics. Between 2016 and 2020, approximately 5,000 households representative of the Swiss population with respect to gender, age, tenancy status and region were surveyed every year between April and June. A substantial share of the respondents answered several waves of the survey, so that the dataset is a combination of longitudinal and repeated cross-sectional data.

For our purpose, we use yearly heating and warm water expenses (HWWE) stated by the respondents in combination with information about fuel prices to construct the dependent variable. To account for the impact of market price fluctuations on HWWE, we deflate them by price indices for each fuel type. By doing so, HWWE are expressed in market prices of a single reference year—in our case 2015—so that remaining variations reflect changes in quantities. The variable obtained thus mirrors heating fuel consumption.

HWWE are obtained directly from the survey respondents, who are requested to state the amount indicated on their most recent heating bill. The expenses measured in year $t$ therefore mostly relate to energy consumed during year $t-1$. Indeed, to heat their home during the winter, households must have purchased fuel in advance, hence during the preceding year[9]. This is especially true in the case of heating systems running on oil (and sometimes on natural gas), whereby a tank must be filled, but less so for new renewable technologies such as heat pumps or district heating, whereby the user obtains energy directly from the network. Hence, we should only expect to detect an impact—if any—one year after each of the two $CO_2$ tax increases that took place during our observation period.

Because actual energy consumption is usually unknown to respondents, HWWE are the most closely-related information that can be collected through a survey. When asked about their HWWE, respondents can state whether they use their last bill to answer or if they only provide an estimation. They can moreover indicate whether the amount they pay is based on actual heat consumption or another factor such as the size of their home. That gives us an opportunity to check the consistency of our results when restricting our sample to households with the most accurate answers (based on bills) or who have a direct control on their heating bills (based on their own fuel consumption). It should be noted that the top and bottom 1% of HWWE per $m^2$ of

[8]See Weber et al. (2017) for details on SHEDS.

[9]The one-year lag is also valid for rented dwellings. In such cases, the owner purchases fuel in advance and establishes a final invoice for the tenants only at the end of the heating period.

surface observed in the sample have been dropped to remove probable aberrant responses[10,11].

The dataset also contains data on the type of fuel used for space heating and warm water. This information is used to construct our treatment variable by splitting the sample between fossil fuel users (i.e., the treatment group) and non-fossil fuel users (i.e., the control group)[12]. Oil and gas users constitute the treatment group, while all others (i.e., households using electricity, wood, heat pumps, solar panels or district heating) make up the control group. Respondents with an unspecified type of fuel have been removed from our sample because this information is necessary to allocate them to the treatment and control groups. Households connected to district heating have been kept because, although we do not know which energy source is used to produce heat, fossil fuels are only used in a small minority of heating plants (about 7% in Switzerland, see Hangartner and Ködel, 2021). We therefore assume they use heat produced from energy sources exempted from the $CO_2$ levy.

Table 2.1 presents the distribution of heating fuels for our sample and for the Swiss population. As can be seen, the share of fossil fuel users in the sample is relatively stable between 2016 and 2020. It is however slightly larger than the share of heating oil and gas users observed at the country-level. Overall, the share of non-fossil fuel users is comparable between our sample and Switzerland, although the distribution of specific fuels is not totally equivalent between the two, with deviations especially for wood, heat pumps, and district heating. These differences may be explained by the over-representation of urban households in our sample[13].

Our dataset also includes socioeconomic characteristics, geographic indications, environmental and energy-related information, as well as characteristics of the dwelling and the heating system. Table 2.A.1 (in appendix) presents all variables we use in the estimation of IPTW weights and later in the regression analyses. They cover all factors identified in the literature as influencing energy consumed for residential heating.

Our sample consists in a combination of longitudinal and repeated cross-sectional observations because not all respondents answered all survey waves. We however treat it as repeated cross-sections, as accounting for its partially longitudinal structure from an econometric perspective would cost a prohibitively large share of available observations. We nevertheless keep only households who have been living in their accommodation since 2015 and who did not change heating fuel during the 2016–2020 period, so that such changes do not affect the validity of

[10]We use HWWE per $m^2$ rather than HWWE itself in the trimming procedure because large HWWE are plausible for large accommodations. The excluded values are those for which the relation between heating expenses and accommodation size is unrealistic.

[11]Trimming has been performed independently for the treatment and control groups in each time period. Trimming at 2.5% and 5% thresholds has also been performed, without significant differences in the results (available on request).

[12]Only space heating is considered to allocate households between control and treatment groups. Warm water is not considered because it only represents a minor share of total HWWE (Narula et al. (2019) report that, in 2016, warm water accounted only for 16% of final energy consumption for heating and warm water in the residential sector in Switzerland) and warm water expenses generally cannot be disentangled from space heating expenses. Therefore, even if a household in the treatment group uses a non-fossil fuel for warm water, most of its HWWE come from heating and should thus be affected by the $CO_2$ levy. Conversely, households using fossil fuel for warm water only will be included in the control group even though they are in fact affected by the $CO_2$ tax, but only on a minor share of their expenses.

[13]37% of households in our sample live in a municipality of at least 20,000 inhabitants and 22% in a municipality of at least 50,000 inhabitants, against 30% and 17% for Switzerland in 2019, respectively (Source: Swiss Federal Statistical Office, *Statistique des villes suisses*, 2021).

| Fuel type | Switzerland | Sample | | | | |
|---|---|---|---|---|---|---|
| | 2017 | 2016 | 2017 | 2018 | 2019 | 2020 |
| Proportions (%) | | | | | | |
| Oil | 39.4 | 42.6 | 42.5 | 41.9 | 42.0 | 40.4 |
| Gas | 20.7 | 25.9 | 23.8 | 24.2 | 25.1 | 26.4 |
| Electricity | 6.9 | 6.7 | 6.2 | 5.7 | 5.6 | 4.6 |
| Wood | 10.1 | 5.3 | 5.6 | 6.0 | 5.1 | 5.2 |
| Heat pump | 17.9 | 12.3 | 15.2 | 14.6 | 14.8 | 16.2 |
| Solar | 0.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| District heating | 4.2 | 7.3 | 6.8 | 7.6 | 7.3 | 7.2 |
| Other | 0.6 | | | | | |
| Observations | | 2054 | 3305 | 2468 | 2004 | 1813 |

Note: Data for Switzerland come from Swiss Federal Statistical Office's *Survey on the energy sources of residential buildings*, 2017. Because we need to know whether households use fossil heating fuels or not, other—hence unspecified—types of fuel have been removed from our sample.

Table 2.1: Distribution of heating fuels

reported HWWE relative to the characteristics of the accommodation and are not correlated to the treatment variable—i.e., using fossil fuel for heating. We are thus able to limit the impacts of some of the drawbacks of not having a full panel to carry out our analysis.

We also emphasize that dropping households who changed heating fuel (and thus heating systems) is consistent with our objective of identifying short-run impacts of the $CO_2$ levy. One possible (desired) response to the tax increases is to switch from a fossil fuel heating system to a renewable heating system, thereby totally escaping the tax payment. Such changes are however likely to occur only in the relatively long run, as they involve major decisions and investments. In that sense, our estimates will voluntarily provide a lower bound of the $CO_2$ levy impacts. Our goal is to estimate the impact of behavioral changes that can be adopted in the short run, that is, changing some habits—e.g., heating at night or with windows open—in order to limit heating waste.

### 2.4.2 Descriptive statistics

Table 2.2 presents some descriptive statistics for the treatment and control groups, with all years pooled. Student's $t$-statistics for the difference in means between the two groups are provided in the last column. Most differences can be related to the fact that the control group includes more house-owners whereas the treatment group contains more tenants living in apartments. Being house-owner is correlated with a higher income and a stronger propensity to live outside urban areas, as owning real estate usually requires important financial resources and enough land availability. From a decision-making and practical perspective, it is also easier to choose a (non-fossil) heating fuel when owning one's accommodation, and when the latter is a (single-family) house. Such differences highlight the importance of the weighting strategy, which is expected to give larger weights to non-house owners in the control groups to achieve a satisfactory covariate balance and improve comparability between fossil fuel users and non-fossil fuel users.

### 2.4.3 Estimation of weights

To make treatment and control groups balanced, weights $w_i$ are constructed using PSs $e_i$ estimated with the aforementioned CBPS method. CBPS is implemented using the eponymous

| Variable | Treatment | | Control | | $t$-statistic |
|---|---|---|---|---|---|
| | Mean | S.D. | Mean | S.D. | |
| HWWE | 1406.33 | 980.14 | 1229.13 | 953.84 | 9.35 |
| Age | 51.43 | 14.88 | 49.15 | 14.50 | 7.93 |
| Tertiary education | 0.44 | 0.50 | 0.46 | 0.50 | −1.77 |
| Income | 7905.54 | 2920.42 | 8188.18 | 2945.44 | −4.89 |
| Household size | 2.29 | 1.36 | 2.52 | 2.01 | −6.45 |
| At least 1 child | 0.33 | 0.47 | 0.39 | 0.49 | −6.58 |
| Environmental adaptation | 3.57 | 0.95 | 3.60 | 0.93 | −1.69 |
| Energy literacy | 3.65 | 1.17 | 3.66 | 1.22 | −0.46 |
| Owner | 0.41 | 0.49 | 0.54 | 0.50 | −13.59 |
| House | 0.36 | 0.48 | 0.50 | 0.50 | −14.38 |
| Owner × House | 0.27 | 0.44 | 0.41 | 0.49 | −15.09 |
| Surface ($m^2$) | 119.06 | 67.22 | 135.54 | 75.40 | −11.50 |
| Construction year | 1990.10 | 149.02 | 1989.76 | 108.56 | 0.14 |
| Minergie | 0.09 | 0.29 | 0.28 | 0.45 | −23.00 |
| Living room temperature | 20.78 | 1.04 | 20.80 | 1.08 | −1.21 |
| City | 0.54 | 0.50 | 0.38 | 0.49 | 16.21 |
| Agglomeration | 0.29 | 0.45 | 0.31 | 0.46 | −2.34 |
| Countryside | 0.17 | 0.38 | 0.31 | 0.46 | −15.74 |
| Observations | 7786 | | 3858 | | |

Note: $t$-statistics for the difference in means between the treatment and control groups.

Table 2.2: Descriptive statistics

package in R (Imai and Ratkovic, 2014). A binary regression is estimated with the treatment status, i.e., a dummy taking the value 1 for households whose heating system uses fossil fuel (oil or gas) and 0 otherwise, as the dependent variable and all variables presented in Table 2.A.1 as independent variables. The latter have been selected because of their expected influence on both the probability of treatment and the outcome variable. They cover all relevant characteristics of households and their accommodations that are available in our dataset. Weights are constructed as described in Austin (2011): $w_i = T_i + (1 - T_i) \cdot e_i / (1 - e_i)$.

Table 2.3 provides some balance metrics for the unweighted and weighted samples. It reports standardized differences in means, variance ratios (for continuous variables only) (see Austin, 2009), and Kolmogorov-Smirnov (KS) statistics (see Austin and Stuart, 2015), both before and after adjustment through weighting for the treatment and control groups with all years pooled. The closer to 0 the difference in means and the KS-statistics and the closer to 1 the variance ratios, the better, as it indicates a more similar distribution of covariates between the treatment and control groups (Austin and Stuart, 2015; Kainz et al., 2017). All covariates become much more similar in distribution after adjustment, which implies that the comparability of the treatment and control groups improves substantially thanks to the weighting strategy. The estimated ATTs are therefore expected to be more accurate when weights are accounted for in the DID regressions.

## 2.5 Results

### 2.5.1 Regression analysis

Results from a series of regressions of the natural logarithm of deflated HWWE on treatment-year combination dummies, plus the set of aforementioned exogenous covariates, heating degree

| Variable | Standardized mean diff. | | Variance ratio | | KS-statistic | |
|---|---|---|---|---|---|---|
| | Unadjusted | Adjusted | Unadjusted | Adjusted | Unadjusted | Adjusted |
| Age | 0.153 | <0.001 | 1.052 | 0.981 | 0.079 | 0.017 |
| Tertiary education | −0.017 | <0.001 | | | 0.017 | <0.001 |
| Income | −0.087 | <0.001 | 1.004 | 0.984 | 0.041 | 0.011 |
| Household size | −0.170 | <0.001 | 0.459 | 0.773 | 0.060 | 0.005 |
| At least 1 child | −0.062 | <0.001 | | | 0.062 | <0.001 |
| Environmental adaptation | −0.033 | <0.001 | 1.038 | 0.975 | 0.012 | 0.008 |
| Energy literacy | −0.009 | <0.001 | 0.932 | 0.963 | 0.017 | 0.008 |
| Owner | −0.133 | <0.001 | | | 0.133 | <0.001 |
| House | −0.140 | <0.001 | | | 0.140 | <0.001 |
| Owner × House | −0.142 | <0.001 | | | 0.142 | <0.001 |
| Surface | −0.245 | <0.001 | 0.795 | 1.063 | 0.127 | 0.021 |
| Construction year | 0.002 | <0.001 | 1.884 | 1.051 | 0.234 | 0.125 |
| Minergie | −0.182 | <0.001 | | | 0.182 | <0.001 |
| Living room temperature | −0.024 | <0.001 | 0.918 | 0.852 | 0.033 | 0.031 |
| City | 0.156 | <0.001 | | | 0.156 | <0.001 |
| Agglomeration | −0.021 | <0.001 | | | 0.021 | <0.001 |
| Countryside | −0.135 | <0.001 | | | 0.135 | <0.001 |

Note: Variance ratios are only provided for continuous variables.

Table 2.3: Covariate balance statistics

days (HDDs), and regional fixed effects, are presented in Table 2.4[14,15]. We compare results from two adjustment methods: covariate adjustment only (i.e., standard DID with control variables), or both covariate adjustment and IPTW[16] with three different subsamples: (i) entire sample, (ii) respondents who used their bill to answer (i.e., no estimated HWWE), and (iii) respondents whose HWWE are based on their actual heat consumption. The restricted subsamples should allow to get more precise results, as estimated HWWE are noisy by definition and people whose HWWE are not based on their actual heat consumption have fewer incentives to react to the $CO_2$ levy because of the public good issue. Nevertheless, any restriction leads to a smaller sample, which in turn leads to increased risks of imprecision in the estimation procedure and a possible lack of external validity due to a more specific sample composition[17].

Results in Table 2.4 show that using fossil heating fuels is related to higher deflated HWWE than using non-fossil sources of energy by 12.2 to 17.2%, presumably because heating systems using fossil fuels are on average older and therefore less efficient in terms of calorific power per CHF spent than renewable heating systems. However, energy consumed for heating does not clearly diverge between the two groups over time. Although the coefficient for the interaction between the treatment indicator and the 2019 year dummy is significant at the 5% level in some specifications, the coefficient for the subsequent year is significant in only one spec-

[14]Coefficients for regional fixed effects are not displayed in Table 2.4 for the sake of space and because their values do not follow any clear pattern.

[15]We do not include energy price (in CHF/kWh) as an independent variable for two reasons. First, energy prices provided by the Swiss Federal Statistical Office vary based on consumption profiles and quantities bought, so that a choice should be made to a price for each fuel, implying some imprecision, as we do not know which price households actually pay. Second, no data is available regarding district heating, discarding many observations from the control group if the price variable is included. We however provide results when energy price is included in Table 2.B.2, where it can be seen that the variable is hardly significant in two specifications only. We therefore choose not to include this variable in our main results table. Energy price data are available at `https://www.bfs.admin.ch/bfs/en/home/statistics/catalogues-databases/tables.assetdetail.18324899.html` [accessed on August 17, 2021].

[16]Elze et al. (2017) call the latter the *doubly robust* IPTW method.

[17]Combining both restrictions leads to the loss of about 75% of the initial sample. We therefore refrain from combining the two restrictions.

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| Fossil fuel | 0.172*** | 0.142*** | 0.144*** | 0.172*** | 0.130** | 0.122** |
| | (0.034) | (0.049) | (0.043) | (0.036) | (0.051) | (0.048) |
| Fossil fuel × 2017 | 0.032 | 0.003 | 0.017 | 0.051 | 0.061 | 0.042 |
| | (0.044) | (0.061) | (0.055) | (0.050) | (0.068) | (0.063) |
| Fossil fuel × 2018 | −0.030 | −0.051 | −0.045 | −0.034 | −0.040 | −0.018 |
| | (0.048) | (0.066) | (0.059) | (0.054) | (0.073) | (0.069) |
| Fossil fuel × 2019 | −0.125** | −0.130* | −0.053 | −0.149** | −0.139** | −0.042 |
| | (0.052) | (0.068) | (0.066) | (0.059) | (0.071) | (0.078) |
| Fossil fuel × 2020 | −0.034 | −0.067 | 0.059 | −0.101 | −0.181** | 0.007 |
| | (0.053) | (0.074) | (0.068) | (0.064) | (0.089) | (0.080) |
| Year: 2017 | −0.101** | −0.061 | −0.022 | −0.084 | −0.107 | −0.021 |
| | (0.048) | (0.065) | (0.059) | (0.056) | (0.077) | (0.070) |
| Year: 2018 | −0.234*** | −0.134** | −0.138** | −0.194*** | −0.133* | −0.142* |
| | (0.050) | (0.068) | (0.062) | (0.059) | (0.080) | (0.074) |
| Year: 2019 | −0.248*** | −0.079 | −0.240** | −0.318*** | −0.118 | −0.316*** |
| | (0.077) | (0.100) | (0.099) | (0.089) | (0.119) | (0.113) |
| Year: 2020 | −0.334*** | −0.193*** | −0.317*** | −0.288*** | −0.094 | −0.283*** |
| | (0.045) | (0.066) | (0.056) | (0.055) | (0.078) | (0.067) |
| Age | 0.114*** | 0.101*** | 0.112*** | 0.115*** | 0.101*** | 0.117*** |
| | (0.006) | (0.008) | (0.009) | (0.008) | (0.013) | (0.013) |
| Tertiary education | 0.042*** | 0.059*** | 0.037* | 0.026 | 0.056** | 0.025 |
| | (0.015) | (0.019) | (0.020) | (0.020) | (0.026) | (0.024) |
| ln(income) | 0.183*** | 0.162*** | 0.148*** | 0.186*** | 0.175*** | 0.164*** |
| | (0.020) | (0.025) | (0.028) | (0.026) | (0.035) | (0.034) |
| Household size | 0.003 | 0.004 | 0.007 | −0.001 | −0.011 | 0.022 |
| | (0.008) | (0.009) | (0.018) | (0.012) | (0.028) | (0.018) |
| At least 1 child | 0.118*** | 0.081*** | 0.114*** | 0.111*** | 0.103** | 0.081** |
| | (0.021) | (0.025) | (0.038) | (0.029) | (0.052) | (0.040) |
| Environmental adaptation | −0.027*** | −0.007 | −0.012 | −0.023** | −0.002 | 0.003 |
| | (0.008) | (0.010) | (0.011) | (0.011) | (0.016) | (0.014) |
| Energy literacy | 0.065*** | 0.049*** | 0.056*** | 0.083*** | 0.057*** | 0.081*** |
| | (0.010) | (0.013) | (0.016) | (0.012) | (0.016) | (0.021) |
| Owner | 0.247*** | 0.242*** | 0.299*** | 0.340*** | 0.319*** | 0.411*** |
| | (0.055) | (0.075) | (0.080) | (0.066) | (0.091) | (0.098) |
| Owner × Energy literacy | −0.059*** | −0.073*** | −0.062*** | −0.092*** | −0.099*** | −0.090*** |
| | (0.013) | (0.018) | (0.019) | (0.016) | (0.022) | (0.023) |
| House | 0.059* | 0.041 | 0.210*** | 0.067* | 0.088 | 0.253*** |
| | (0.033) | (0.042) | (0.043) | (0.038) | (0.055) | (0.050) |
| Owner × House | 0.112*** | 0.152*** | 0.017 | 0.110** | 0.126** | −0.033 |
| | (0.038) | (0.048) | (0.050) | (0.045) | (0.063) | (0.058) |
| Surface | 0.021*** | 0.019*** | 0.018*** | 0.023*** | 0.021*** | 0.017*** |
| | (0.001) | (0.002) | (0.001) | (0.002) | (0.003) | (0.002) |
| Construction year | −0.001** | −0.002** | −0.002*** | −0.002** | −0.002** | −0.003*** |
| | (0.001) | (0.001) | (0.001) | (0.001) | (0.001) | (0.001) |
| Minergie | −0.190*** | −0.263*** | −0.172*** | −0.188*** | −0.254*** | −0.161*** |
| | (0.021) | (0.027) | (0.026) | (0.023) | (0.029) | (0.029) |
| Living room temperature | 0.043*** | 0.039*** | 0.044*** | 0.043*** | 0.045*** | 0.048*** |
| | (0.007) | (0.009) | (0.010) | (0.010) | (0.014) | (0.013) |
| City | 0.044** | 0.004 | 0.028 | 0.053** | 0.031 | 0.050* |
| | (0.018) | (0.022) | (0.024) | (0.023) | (0.031) | (0.030) |
| Countryside | 0.073*** | 0.053* | 0.080*** | 0.082*** | 0.073** | 0.099*** |
| | (0.022) | (0.028) | (0.026) | (0.025) | (0.034) | (0.029) |
| HDD | 0.010 | 0.035 | −0.002 | −0.031 | 0.016 | −0.029 |
| | (0.029) | (0.037) | (0.039) | (0.034) | (0.048) | (0.043) |
| Constant | 3.142*** | 3.014*** | 3.932*** | 4.263*** | 3.329** | 4.356*** |
| | (0.886) | (1.105) | (1.172) | (1.047) | (1.481) | (1.360) |
| IPTW | No | No | No | Yes | Yes | Yes |
| Estimated HWWE excl. | No | Yes | No | No | Yes | No |
| Actual consumption only | No | No | Yes | No | No | Yes |
| Obs. | 11644 | 6034 | 6274 | 11644 | 6034 | 6274 |
| Adj. $R^2$ | 0.186 | 0.173 | 0.208 | 0.179 | 0.165 | 0.208 |

Notes: ***$p$-value $< 0.01$; **$p$-value $< 0.05$; *$p$-value $< 0.1$. Region fixed effects are included in the estimation but not displayed. Age, surface and construction year have been divided by 10, and HDD by 100.

Table 2.4: Regression results

ification. These results suggest that there might have been a temporary decrease in energy consumption among fossil fuel users following the 2018 tax rate increase. This effect, however, did not last, so that no definite conclusion can be drawn regarding the short-run effectiveness of the $CO_2$ levy on Swiss households' energy demand. The absence of significant coefficients in other specifications also casts some doubts regarding the short-run effects detected in our statistical analysis. Although a false negative cannot be completely dismissed, different factors could explain our finding, such as the lack of control over one's own energy consumption for heating or a potentially inelastic demand for heating and warm water—which would be consistent with the literature on the price elasticity of energy demand (see Labandeira et al., 2017). It should be noted that, in most specifications, the coefficients for years 2018–2020 are negative and significant—with a larger value for 2020—suggesting that overall heating consumption diminishes over time, as deflated HWWE decrease. This trend is however not different between the treatment and control groups[18].

Most other coefficients are significant and have the expected signs, which shows that meaningful relationships are detected by our model where they exist. Concerning socioeconomic variables, age is linked to a higher heating consumption, a finding consistent with Brounen et al. (2012). This can be caused by the elderly's higher heating needs, because they might be more sensitive to cold than younger people. While results are not always significant regarding tertiary education when weights are introduced, income is positively connected to higher HWWE, with an estimated elasticity comprised between 14.8% and 18.6%. Presence of children in the household is also positively linked to higher HWWE.

Interestingly, energy literacy has diverging effects for owners and tenants: while it is linked to lower HWWE for owners, the coefficient is positive for tenants. Our hypothesis is that owners who are better informed about energy are able to lower their heating consumption, as they have means to effectively manage their consumption. On the other hand, tenants with high HWWE might learn more about energy-related issues but still remain unable to lower their HWWE by lack of decision-making power over their energy consumption for heating. It should also be noted that the owner dummy has a positive and significant coefficient, which means that owners have—on average and *ceteris paribus*—a higher heating consumption than tenants. Although this result seems counter-intuitive, an explanation might be that owners are on average wealthier than tenants. Like income, wealth lowers the relative marginal burden of HWWE on households' budgets.

Regarding the characteristics of the dwelling, we find that living in a house has a significantly positive effect when the sample is restricted to households whose HWWE are based on their actual heating consumption. On the other hand, when all types of households are considered, only house-owners seem to have larger HWWE. These results are certainly caused by the fact that more than 60% of households whose HWWE are based on their actual heating consumption are owners, so that the interaction between ownership status and living in a house loses significance when applying this restriction to the sample.

Unsurprisingly, households living in accommodations with larger surfaces have higher deflated HWWE, while those who live in more recent buildings or in Minergie[19] buildings have a

[18]We also tried to distinguish between heating oil and natural gas users, but results (available on request) are inconclusive and therefore not reported.

[19]Minergie is the most widespread construction label for new or renovated buildings in Switzerland. It certifies

lower heating consumption. Households living in accommodations whose average room temperature is higher also have higher HWWE. Living in the countryside is linked to higher heating consumption, potentially because of less energy-efficient homes and heating systems, but also because of lower external temperatures than in more densely populated areas.

Overall, even though a number of factors are found to exert an impact on Swiss households' heating demand, the 2016 and 2018 carbon tax increases do not seem to have provoked any clearly detectable short-run change in fossil fuel users' behaviors regarding the way they heat their home. This finding questions the adequacy of the design of the $CO_2$ levy as it was applied until 2022 concerning households. Expecting short-run reactions or increasing the tax rate further if nothing happens might not give them enough time to adapt or to invest in long-run energy-saving measures like renovations.

## 2.6 Conclusion and policy implications

Our results suggest that households do not quickly adapt their behaviors to the progressive increase of the $CO_2$ levy. Of course, it should be emphasized that only short-run effects are considered here; it is probable that taxing $CO_2$ also exerts longer-run effects, especially if the rate reaches higher levels. In particular, it can be expected to lead to more renovations in the future, as well as transitions to renewable energy sources for heating—two of the main goals of carbon taxation. Although deflated HWWE might not be the best proxy for heating demand, these results provide some evidence that stronger action is needed to enhance the effectiveness of the Swiss carbon taxation system on households' thermal fossil fuel consumption. As previously mentioned, fossil fuels' market prices are subject to large exogenous variability, which renders the impacts of the carbon tax hardly visible. Hence, the Swiss carbon tax under its 2008-2022 design seems to lack salience in the short run as households do not quickly react to either its mere presence (tax aversion) or its effect on prices. The ongoing reform of the $CO_2$ Act could improve this point, although it is not planned to increase the rate of the $CO_2$ levy above CHF 120 per tonne of $CO_2$ (Swiss Federal Council, 2022).

Another issue worth mentioning is that most respondents seem to not properly understand the functioning of the Swiss $CO_2$ levy. Burger et al. (2018) indeed underline the fact that a substantial proportion of the population misunderstands this instrument: a third of fossil fuel users believe they pay no tax at all, half of non-fossil fuel users incorrectly think they pay the carbon tax, and only 14% of all respondents more or less correctly guess how much they are receiving through the tax redistribution scheme, an information they can easily find on their health insurance bills[20]. Mildenberger et al. (2022) find similar results in both Switzerland and Canada. This limited knowledge suggests that Swiss households are not fully aware of how much the carbon tax actually affects them, which makes them unlikely to take (correct) action in response to the tax. As shown by Labandeira et al. (2017), the price-elasticity of demand for heating oil is generally low, especially in the short run, so that most short-run carbon tax effects are to be expected from the psychological impact of taxation, which seems only likely if households are correctly informed.

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that buildings attain a certain level of housing comfort, but also of energy-efficiency. It is supported by the federal and cantonal governments. More information on `https://www.minergie.ch` [accessed on April 22, 2021].

[20]In Switzerland, residents have to directly pay their health insurance bills. The amounts redistributed as proceeds from the $CO_2$ levy are explicitly mentioned as deductions on these bills.

In addition, some households might lack the capacity of taking action to decrease the tax burden because their heating bills are not based on their actual consumption but on another factor such as the size of their home, which is the standard case for tenants and apartment-dwellers. A “split incentive issue” may then arise (see, e.g., Gillingham et al., 2012), i.e., a situation where households have little incentive to lower their heating demand because of the minor impact it would have on their own HWWE. Moreover, tenants and apartment-dwellers have less decision power over renovations, which means that even if they wanted to, they would not be able to improve the energy efficiency of their homes. Therefore, a significant share of Swiss households cannot be expected to substantially react to the $CO_2$ levy, even in the longer run, as they have little incentives and/or capacity to do so.

From a policy perspective, these findings have important implications. Although the $CO_2$ levy is based on sound economic reasoning and its general principle is not to be debated anymore, some specific aspects of its design could be improved. First, the $CO_2$ levy seems imperfectly designed to nudge (most) households, as it only targets (the minority of) those who can directly act on their heating demand. Putting more emphasis on non-pricing measures targeting owners such as renovation subsidies and stricter regulations on energy efficiency and the use of fossil fuels could help, as would the development of district heating projects in densely populated areas (see Narula et al., 2019). The strengthening of support measures planned in the reform of the $CO_2$ Act could improve the situation in that regard (see Swiss Federal Council, 2022).

Second, people are on average not well informed about how they are affected, which means it is unlikely to steer behavior in the intended direction, hence contributing to the insignificant effect estimated in the regression analysis. Improved communication from the authorities would be needed in that regard—it would also help to distinguish exogenous fuel price fluctuations on the market from the tax, which could strengthen its psychological impact.

Third, as the $CO_2$ levy is one of the main tools the Swiss government has set up to fight climate change as of today, its apparent lack of (short-run) effectiveness challenges its relevance: complementary and alternative measures might be more effective concerning households and needed to reach sufficient $CO_2$ emission abatement (see Ó Broin et al., 2015). The additional subsidies for buildings’ energy-efficient overhauls that should be implemented in the reform of the $CO_2$ Act could help reducing emissions from the residential sector. It is yet uncertain, though, whether increasing the $CO_2$ levy rate above CHF 120 in parallel would not have been more effective than only focusing on “pull” measures. The question of the financing of a broader subsidy program than the existing one should also be raised: part of revenue from the $CO_2$ levy is currently used to support energy-efficient renovations. If the $CO_2$ tax rate is not raised anymore, their financing might be threatened over time. In the current system, carbon tax and subsidies go hand in hand, which might cause inefficiencies in the longer run.

Finally, the short-run dimension of the issue of households’ reaction must also be emphasized, as between 2008 and 2022 the tax rate was increased if $CO_2$ emission reduction thresholds were not met, and the achievement of these thresholds was checked biennially. Using short-run efficiency is a criterion to guide a carbon tax was therefore important in Switzerland, but this method might not be the most effective in terms of results in the residential sector, because it does not fully take its specific features into account.

Raising the tax incrementally every second year may in fact prove detrimental to its effectiveness. As widely discussed in the psychological literature (see, e.g., Kurz et al., 2015), a number of environmentally relevant behavior patterns are frequent, stable, and persistent. In this context, small tax increases might be largely ignored by consumers and could be insufficient to trigger a reaction in the short run. Simultaneously, consumers could be displaced to a new psychological reference-point after each small tax increment, thereby yielding only modest reactions even when the tax has become relatively large. On the contrary, implementing larger step-changes would probably lead to quicker and more substantial behavioral adaptations[21]. A counter-argument against large tax increases is of course that social acceptability is more complicated to achieve in such cases (World Bank, 2019). Policy makers in charge of carbon taxation clearly face a difficult trade-off between efficiency and social acceptability.

Further *ex-post* empirical work should look at longer-run trends in fossil heating fuel consumption to see how investment decisions evolve over time. The question of the socially optimal tax rate as well as the optimal tax rate increases should also be investigated in order to better inform policy makers on the path that should be followed to efficiently lower $CO_2$ emissions caused by households, while ensuring social acceptability and people compliance (see Metcalf, 2021). Research on households' preferences toward heating could also provide more information on how to design efficient nudges that could be implemented in complement to carbon taxation.

[21]Regarding long-run investments such as heating system replacement and renovation, the current system might work as far as people are informed of the $CO_2$ emissions abatement trajectory set by the authorities. Yet, without any clear announcement effect, the nudge provoked by incremental tax increases might not be sufficient to stimulate investment. In particular, as it is not possible to know in advance whether emissions targets will be reached or not, and thus whether the $CO_2$ levy rate will increase or not, individuals have lower incentives to invest, because the profitability of such investment is uncertain beforehand.

## 2.A Appendix A: List of variables

| Variable | Scale | Description |
|---|---|---|
| Socioeconomics | | |
| Age | Integer | Age of the respondent. |
| Tertiary education | Binary | The respondent has a tertiary level of education. |
| Income | Continuous | Monthly income of the household. |
| Household size | Integer | Number of people in the household. |
| At least 1 child | Binary | At least one child is present in the household. |
| Environment and energy | | |
| Environmental adaptation | 1–5 | The respondent agrees that he/she is ready to take steps to adopt environmentally friendly behaviors even if it causes daily inconveniences (totally disagree–totally agree). |
| Energy literacy | 0–5 | Level of energy literacy of the respondent measured as the number of correct answers to the following true/false questions:<br>• The biggest share of energy consumed in a Swiss household is for heating purposes. (True)<br>• $CO_2$ emissions play a crucial role in global warming. (True)<br>• Simply lowering the heating temperature in an average household by 1°C can help to cut down the heating demand by 6%. (True)<br>• Coal is a renewable energy resource. (False)<br>• Hydroelectric power plants account for 10% of total Swiss electricity production. (False) |
| HDD | Continuous | Heating degree days. |
| Accommodation | | |
| Ownership | Binary | The household owns its accommodation. |
| Type of accommodation | Categorical | The type of accommodation in which the household lives (house or flat). |
| Year of construction | Integer | Year of completion of the accommodation's construction. |
| Minergie | Binary | The accommodation complies with Minergie or better energy-efficiency standards. |
| Living room temperature | Continuous | Average temperature in the living room during the day (in °C). |
| Residential environment | Categorical | The type of area in which the household lives (city, agglomeration, countryside). |

Table 2.A.1: List of variables

## 2.B Appendix B: Supplementary table

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| log(energy price) | 0.070* | 0.066 | 0.086* | −0.024 | −0.066 | 0.018 |
| | (0.038) | (0.054) | (0.046) | (0.059) | (0.086) | (0.064) |
| Fossil fuel | 0.242*** | 0.203*** | 0.212*** | 0.220*** | 0.196* | 0.175*** |
| | (0.043) | (0.065) | (0.051) | (0.060) | (0.102) | (0.067) |
| Fossil fuel × 2017 | 0.038 | −0.005 | 0.020 | 0.070 | 0.006 | 0.022 |
| | (0.049) | (0.073) | (0.059) | (0.067) | (0.107) | (0.073) |
| Fossil fuel × 2018 | −0.013 | 0.013 | −0.034 | −0.042 | −0.007 | −0.042 |
| | (0.053) | (0.079) | (0.063) | (0.074) | (0.125) | (0.085) |
| Fossil fuel × 2019 | −0.123** | −0.072 | −0.047 | −0.185** | −0.141 | −0.064 |
| | (0.058) | (0.082) | (0.070) | (0.079) | (0.114) | (0.090) |
| Fossil fuel × 2020 | 0.007 | 0.016 | 0.087 | −0.088 | −0.174 | −0.006 |
| | (0.060) | (0.092) | (0.073) | (0.102) | (0.149) | (0.100) |
| Year: 2017 | −0.103* | −0.059 | −0.019 | −0.141* | −0.096 | −0.033 |
| | (0.053) | (0.076) | (0.063) | (0.077) | (0.127) | (0.086) |
| Year: 2018 | −0.251*** | −0.208** | −0.148** | −0.221*** | −0.207 | −0.153 |
| | (0.056) | (0.081) | (0.066) | (0.082) | (0.141) | (0.094) |
| Year: 2019 | −0.271*** | −0.131 | −0.275*** | −0.240** | −0.052 | −0.277** |
| | (0.082) | (0.111) | (0.103) | (0.110) | (0.157) | (0.121) |
| Year: 2020 | −0.388*** | −0.282*** | −0.361*** | −0.301*** | −0.091 | −0.282*** |
| | (0.052) | (0.085) | (0.061) | (0.089) | (0.131) | (0.085) |
| Age | 0.112*** | 0.100*** | 0.108*** | 0.104*** | 0.107*** | 0.117*** |
| | (0.006) | (0.008) | (0.009) | (0.014) | (0.020) | (0.017) |
| Tertiary education | 0.040** | 0.057*** | 0.032 | 0.016 | 0.072** | 0.039 |
| | (0.016) | (0.020) | (0.020) | (0.029) | (0.036) | (0.027) |
| ln(income) | 0.178*** | 0.156*** | 0.143*** | 0.174*** | 0.156*** | 0.171*** |
| | (0.021) | (0.027) | (0.029) | (0.036) | (0.050) | (0.040) |
| Household size | 0.003 | 0.006 | 0.007 | 0.002 | −0.022 | 0.017 |
| | (0.008) | (0.009) | (0.019) | (0.015) | (0.042) | (0.019) |
| At least 1 child | 0.125*** | 0.079*** | 0.115*** | 0.125*** | 0.106 | 0.083* |
| | (0.022) | (0.026) | (0.039) | (0.037) | (0.080) | (0.046) |
| Environmental adaptation | −0.029*** | −0.012 | −0.013 | −0.026** | −0.013 | −0.010 |
| | (0.008) | (0.010) | (0.011) | (0.013) | (0.018) | (0.014) |
| Energy literacy | 0.064*** | 0.050*** | 0.059*** | 0.096*** | 0.064*** | 0.095*** |
| | (0.010) | (0.013) | (0.017) | (0.017) | (0.024) | (0.026) |
| Owner | 0.255*** | 0.243*** | 0.316*** | 0.419*** | 0.328*** | 0.463*** |
| | (0.058) | (0.079) | (0.084) | (0.087) | (0.126) | (0.121) |
| Owner × Energy literacy | −0.059*** | −0.071*** | −0.065*** | −0.106*** | −0.094*** | −0.105*** |
| | (0.014) | (0.019) | (0.020) | (0.020) | (0.030) | (0.028) |
| House | 0.080** | 0.066 | 0.240*** | 0.099** | 0.116* | 0.326*** |
| | (0.034) | (0.044) | (0.045) | (0.048) | (0.067) | (0.056) |
| Owner × House | 0.094** | 0.122** | −0.005 | 0.092 | 0.098 | −0.077 |
| | (0.039) | (0.051) | (0.052) | (0.057) | (0.077) | (0.065) |
| Surface | 0.021*** | 0.018*** | 0.017*** | 0.022*** | 0.019*** | 0.016*** |
| | (0.001) | (0.002) | (0.001) | (0.002) | (0.003) | (0.002) |
| Construction year | −0.001** | −0.002** | −0.003*** | −0.003** | −0.003* | −0.004*** |
| | (0.001) | (0.001) | (0.001) | (0.001) | (0.002) | (0.001) |
| Minergie | −0.179*** | −0.244*** | −0.170*** | −0.156*** | −0.236*** | −0.140*** |
| | (0.022) | (0.029) | (0.027) | (0.028) | (0.037) | (0.033) |
| Living room temperature | 0.043*** | 0.040*** | 0.045*** | 0.049*** | 0.049** | 0.057*** |
| | (0.008) | (0.010) | (0.010) | (0.014) | (0.022) | (0.017) |
| City | 0.030 | −0.012 | 0.018 | 0.029 | 0.006 | 0.045 |
| | (0.019) | (0.023) | (0.025) | (0.030) | (0.043) | (0.035) |
| Countryside | 0.080*** | 0.050* | 0.084*** | 0.089*** | 0.075* | 0.109*** |
| | (0.022) | (0.029) | (0.026) | (0.030) | (0.042) | (0.032) |
| HDD | 0.007 | 0.042 | −0.008 | −0.008 | 0.046 | −0.012 |
| | (0.030) | (0.038) | (0.039) | (0.041) | (0.062) | (0.048) |
| Constant | 3.094*** | 2.651** | 3.924*** | 3.861*** | 2.883 | 3.817** |
| | (0.912) | (1.138) | (1.200) | (1.301) | (1.996) | (1.537) |
| IPTW | No | No | No | Yes | Yes | Yes |
| Estimated HWWE excl. | No | Yes | No | No | Yes | No |
| Actual consumption only | No | No | Yes | No | No | Yes |
| Obs. | 10805 | 5546 | 5894 | 10805 | 5546 | 5894 |
| Adj. $R^2$ | 0.188 | 0.175 | 0.211 | 0.183 | 0.172 | 0.22 |

Notes: ***$p$-value < 0.01; **$p$-value < 0.05; *$p$-value < 0.1. Region fixed effects are included in the estimation but not displayed. Age, surface and construction year have been divided by 10, and HDD by 100.

Table 2.B.2: Regression results including energy price

# Chapter 3

# The public acceptance of the Swiss $CO_2$ levy

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**Abstract** This chapter investigates public opinion on the Swiss $CO_2$ levy and its 2020 revision by using a discrete choice experiment answered by a sample of 586 respondents living in Switzerland. The experiment is designed to elicit citizen preferences among various taxation attributes and is followed by a referendum voting experiment on various $CO_2$ levy proposals. Based on latent class modeling approaches, we find that the population is composed of two distinct but relatively uniform preference profiles: the *Pro-tax reform* and the *Anti-tax reform*. Respondents belonging to the first group tend to favor higher carbon tax rates and a redistribution of proceeds benefiting low-income individuals, whereas those in the second group prefer status quo, i.e., lower rates and a uniform redistribution of proceeds across all taxpayers. Findings from the voting experiment point to a general support among the *Pro-reform*, but an uncertain approval from the *Anti-reform* group.

**Keywords:** Carbon tax, preference heterogeneity, public opinion, latent class, discrete choice experiment.

**JEL classification:** C25, D72, D78, H23, Q48, Q54.

## 3.1 Introduction

Taxing greenhouse gas (GHG) emissions is a solution favored by many economists for tackling anthropogenic climate change. Such policies nevertheless do not benefit from general public support, as observed for instance in the recent "yellow vests" protests in France[1]. Given that the acceptance of a policy is crucial to its effective long-term implementation (see Dunlap, 1989), the design of environmental policies based on taxation needs to be adapted to public preferences. Securing public support requires understanding of the diversity of the population and the reasons for public resistance among various clusters of society. This is especially valid for environmental taxes, which aim to correct negative externalities. In fact, the proceeds of such taxes are generally earmarked for a specific purpose, as opposed to contributing to general government revenues (see World Bank, 2019). Moreover, these taxes can be used to cut other distortionary taxes, giving rise to a so-called double dividend (Goulder, 1995). Public opinion on carbon taxation is therefore more complex than the usual aversion to taxes, and standard tools like the traditional left versus right political prism alone might not be sufficient to explain it.

Public opinion toward environmental policies has received a lot of attention from scholars (e.g., Dunlap, 1989; Aklin et al., 2013; Valeri et al., 2016; Bakaki and Bernauer, 2018), and much work on this topic underlines the importance of accounting for preference heterogeneity (see, e.g., Rhodes et al., 2017). On the specific case of carbon taxes, although plenty of research has already been carried out (e.g., Kallbekken and Sælen, 2011; Thalmann, 2004; Amdur et al., 2014; Baranzini and Carattini, 2017), little is known about the link between preferences for policy attributes and individual characteristics. A deeper investigation of such links would help policy-makers design optimal taxation schemes and target promotion campaigns to specific population groups. Considering the general public as a monolithic mass instead of a plurality of preferences can indeed induce a loss of useful information on the perception of various aspects of carbon taxes. Studies point to highly probable correlation between environmental preferences and self-reported placement on the conventional left-right political scale (see, e.g., Cruz, 2017; Kallbekken and Sælen, 2011; Harring and Jagers, 2013). Other factors such as attitudes and perceptions regarding the environment can play an equally important role but have however received less attention.

This chapter opens with a brief survey of empirical literature on the elicitation of preferences regarding environmental taxation. It also provides a quantitative analysis of individuals' valuation of (or aversion to) various attributes of a carbon taxation scheme using the case of Switzerland's $CO_2$ levy, a carbon tax applied on non-motor fossil fuels[2]. A main focus is on unraveling systematic relationships between these preferences and a selection of explanatory variables including sociodemographic factors. The possible contrast between conventional political tendencies and environmental preferences is studied via a selection of self-reported measures of attitudes and perceptions.

In order to identify how a carbon tax should be designed to receive the maximum public support, we use a discrete choice experiment (DCE). DCEs allow to reveal and compare prefer-

[1]The "yellow vests movement" (*Mouvement des gilets jaunes*) started in opposition to an intended increase in fuel tax rate. See for instance The Economist (27.11.2018): "What, and who, are France's 'gilets jaunes'?"

[2]In Switzerland, fossil motor fuels are primarily taxed through the mineral oil tax, independently of their $CO_2$ content.

ences for different policy attributes. With relatively distinct features in international comparison (World Bank, 2019), the Swiss case lends itself to a realistic DCE. First, the tax rate has gradually increased since its introduction in 2008, from CHF 12 to CHF 96 per ton of $CO_2$ ($tCO_2$) and it could legally be raised to a maximum of CHF 120. Moreover, between 2019 and 2021, the Swiss $CO_2$ levy was under revision by the Federal Assembly, with a proposed increase in its maximum potential rate from CHF 120 to CHF 210 per $tCO_2$—which has eventually been rejected on June 13, 2021. Second, the proceeds are redistributed in the form of building retrofit subsidies through the government's *Building Program* (one third) and lump-sum payoffs to individuals and firms (two thirds)[3]. We consider that the Swiss population has been exposed to public debates on the existing system and could therefore realistically evaluate a departure thereof. Third, the $CO_2$ levy has a positive net financial impact for certain individuals, depending on their consumption of non-motor fossil fuels—i.e., mainly heating oil and natural gas[4]. This feature provides a context with more or less clear potential "winners" and "losers" among households.

Data from the DCE are analyzed with latent class (LC) models. The results reveal two classes that correspond to distinct *citizen profiles*, which we dub as *Pro-tax reform* and *Anti-tax reform* on the basis of their response patterns and self-reported perceptions and attitudes. Results also highlight the contrasting differences between the two groups. In particular, if members of the first group show a preference for *higher* tax rates and a redistribution of proceeds benefiting low-income households, the other group favors lower tax rates and uniform transfers. Whether a revision of the $CO_2$ levy would be accepted in a referendum is however uncertain: if the first class is likely to accept it, the second one does not display any particular support.

The adopted approach goes one step beyond the existing literature (e.g., Sælen and Kallbekken, 2011; Carattini et al., 2017), as it explicitly accounts for the origin of preference heterogeneity in the model. The results demonstrate the benefits of choice experiments, particularly in the segmentation of the population in groups with different preferences, and further research should thus acknowledge the probable presence of clustered heterogeneity in the population.

The remainder of this chapter is structured as follows. Section 3.2 reviews the relevant literature. Section 3.3 presents the experiment and the dataset. Section 3.4 explains our modeling approach. Section 3.5 presents the results. Section 3.6 presents an analysis of the 2021 referendum on the actual $CO_2$ levy reform. Finally, Section 3.7 discusses policy implications and concludes.

## 3.2 Public opinion on environmental policy

### 3.2.1 Conceptual framework

The literature on public opinion toward policies uses varying expressions to qualify its object of study. Even though some authors use them interchangeably, we adhere to the definitions

[3] The total amount redistributed to individuals (firms) comes from the tax proceeds collected from individuals (firms). Each Swiss resident receives a uniform lump sum under the form of a rebate on their health insurance bills, whereas each company gets an amount proportional to its total payroll.

[4] According to the latest data available from the Federal Statistical Office's *Buildings and Dwellings statistics*, about 60% of the residential buildings used heating oil (39.4%) or natural gas (20.7%) for heating in 2017. Similar figures were obtained in the *Swiss Household Energy Demand Survey* (see Burger et al., 2018). Therefore, a substantial share of about 40% of the Swiss households use non-fossil fuels for heating, and these are among the net beneficiaries (along with possibly some of the small consumers) from the $CO_2$ levy.

proposed by Dreyer and Walker (2013), who distinguish between three concepts: acceptability, acceptance, and support. Acceptability and acceptance represent passive behaviors without commitment such as a stated willingness-to-accept for a policy measure or willingness-to-pay for a mitigation project, whereas support is an active stance in terms of intent or action, like revealed financial contribution, participation in social movements or voting in favor of a specific policy.

Dreyer and Walker (2013) propose a further distinction between acceptability and acceptance, applying the former to policies *prior* to their implementation, while considering the latter for *already implemented* policies. In the case of incremental changes to existing policies, the timing distinction between acceptability and acceptance could seem irrelevant, as the two become interlinked. The likely presence of a *status-quo* bias (see Fernandez and Rodrik, 1991; Samuelson and Zeckhauser, 1988) and a temporal effect of experiencing a policy on its acceptance also makes this distinction useless in many circumstances where policies change progressively. Therefore, in this chapter we distinguish between acceptance and support, while leaving out the distinction between acceptability and acceptance, the former being less useful in the context we consider—i.e., the reform of an already implemented carbon tax.

Another useful distinction needs to be made between public acceptance and social acceptance. Whereas the former refers to the "aggregated degree of acceptance by individual citizens" (Wolsink, 2018, p.288), the latter is a multidimensional and dynamic construct encompassing different aspects of acceptance. When considering the acceptance of renewable energy innovations, Wüstenhagen et al. (2007) distinguish between three dimensions: sociopolitical acceptance (by key stakeholders, the general public and decision-makers), community acceptance (by local stakeholders, residents and authorities) and market acceptance (by consumers, producers and investors). Wolsink (2010) argues that this conceptual framework can also be applied to other types of policies such as climate change adaptation strategies. Carbon taxation can, to some extent, fit into this framework, especially regarding the sociopolitical and market dimensions; community acceptance is less relevant because such environmental policies usually have no specific local impacts, unlike the construction of a wind farm, for instance. Social acceptance is thus more complex than public acceptance, which is only one of its multiple aspects. In our study, given that our primary interest is to investigate preferences of Swiss residents, we only consider *public* acceptance (and support) of carbon taxes, not its *social* acceptance[5].

### 3.2.2 The role of individual characteristics

Empirical studies generally consider public opinion regarding environmental policy in one of two ways: they either focus on individual characteristics and preferences to explain environmental concern[6], or look at policy design elements and their effects on public opinion[7]. As existing environmental policies are relatively limited in scope and comparability, the identification of

[5]For a deeper conceptual discussion of social acceptance, see Dermont et al. (2017).

[6]We consider here a measure for the broad public concern for environmental quality, as defined by Dunlap (1975). Referring to this as the "environmental concern", Dunlap's definition encompasses public perception of environmental issues, support for environmental policies, as well as acceptance measures such as willingness to pay for pollution abatement, among others. This concept helps to draw generalities on the whereabouts of its components, among which public opinion on environmental policies.

[7]Drews and van den Bergh (2016) also underline the role played by contextual factors such as weather, social norms, business cycle fluctuations or media coverage and framing of climatic issues, but our data do not allow us to integrate such aspects in our analysis. We therefore do not cover them in the present literature review.

the effect of policy attributes on support and acceptance using real-world data can be complex. In fact, most studies addressing the effect of policy attributes rely on stated preferences data collected through hypothetical experiments. Such experimental data moreover provide insights about the interactions between individual characteristics and policy attributes, which is not addressed in many studies. Experimental studies are discussed in more details in the next section dealing with carbon taxation; here, we focus on the effects of individual characteristics.

The importance of individual characteristics in explaining preferences about environmental policies is well documented. In particular, political orientation and partisanship seem to play a central role. Studying a body of US college students, Dunlap (1975) is among the first to report a clear association between political orientation and environmental concern, suggesting a positive (negative) association of environmentalist preferences with political inclination to the left (right). This finding is confirmed by numerous further studies (Cruz, 2017). Trust in politics and authorities is also positively linked to support of environmental policies such as higher carbon tax rates (Hammar and Jagers, 2006; Harring and Jagers, 2013; Wan et al., 2017). Levi (2021) uses machine learning methods to estimate the impacts of different factors on attitudes regarding climate policies, including carbon taxes, based on a sample of more than 44,000 respondents from 23 countries. He finds that the main predictor of acceptance of carbon taxes and other climate policies is the feeling of personal responsibility regarding climate change. He also finds that indicators such as trust in political institutions strongly—and positively—influence the acceptance of carbon taxes. The political and institutional context where a carbon taxation policy is implemented thus has a major influence on its acceptance by the public.

Socioeconomic factors such as gender, age, income, education, and residential environment are among the most frequently included covariates. Table 3.1 summarizes the patterns of associations with environmental concern found in a selection of studies. In general, the positive association with education and living in a densely populated area seems to be conclusive. On the other hand, possible associations with gender, age, and income remain ambiguous. Concerning income, Franzen and Vogl (2013) find a positive association between GDP per capita and environmental concern in their cross-country analysis, suggesting that the level of economic development increases people's concern for environmental issues. Income might thus be more relevant to consider from a macro than a microeconomic perspective in this context.

Econometric models can be used to characterize environmental preferences in an empirical setting. In particular, stated preference data can be used to identify distinct clusters of individuals with relatively homogeneous preferences, referred to as latent classes (LC). This approach, also known as latent segmentation, is in line with the premise that individuals with similar preferences coordinate their actions in a small number of political parties. The LC approach, though uncommon in carbon taxation studies, has been used extensively in other environmental studies. Two variants can be observed. In the first variant, the LC model is applied to a single DCE outcome to specify a finite mixture model (more on this below). The second variant is the LC application to a selected number of individual measures of environmental preferences. The latter can be used independently of DCE outcomes, or in combination with them. We will clarify the distinction in the following section.

The usefulness of the two LC variants is illustrated by the following examples. First, Rhead et al. (2018) use a LC model to create a typology of environmental attitudes in the UK. Their findings suggest that a prior clustering based on response patterns in a questionnaire can sig-

| Reference | Gender: female | Age | Personal income | Education | Living in a city | Political orientation (L to R) | Trust in authorities |
|---|---|---|---|---|---|---|---|
| Aklin et al. (2013) | + | ? | ∩ | + | ∼ | · | · |
| Ercolano et al. (2014) | − | ∼ | ∩ | + | · | − | + |
| Franzen and Vogl (2013) | + | ∩ | · | + | · | − | + |
| Harring and Jagers (2013) | · | · | ∼ | · | + | − | + |
| Hsu et al. (2008) | + | · | + | + | · | · | · |
| Kallbekken and Sælen (2011) | − | · | + | · | · | − | + |
| Leiserowitz (2006) | ? | · | · | + | · | − | · |
| Levi (2021) | + | ∪ | + | + | + | − | + |
| Rotaris and Danielis (2019) | + | − | + | + | + | − | · |
| Schumacher (2014) | ∼ | − | · | + | · | · | · |
| Swenson and Wells (1997) | ∼ | ∼ | + | + | + | · | · |
| Thalmann (2004) | ∼ | − | ? | + | + | − | · |
| Torgler and García-Valiñas (2007) | + | − | ∩ | + | + | − | · |
| Van Liere and Dunlap (1980) | ? | − | ? | + | + | − | · |
| Ziegler (2017) | ? | ? | · | ∼ | · | − | · |

Notes: +/− indicates a positive/negative association; ∪/∩ indicates a U/inverted U-shape association; ∼ indicates an absence of association; ? indicates an ambiguous association. L/R stands for left/right political orientation. · indicates that the relationship is not investigated.

Table 3.1: Individual factors influencing environmental concern

nificantly increase the prediction power of environment-related behaviors. Second, Blasch and Farsi (2014) show that LC models outperform other models in analyzing results from a DCE for identifying the willingness-to-pay for voluntary carbon offsets in Switzerland. In fact, their results point to a possibility of misleading willingness-to-pay estimates with other models.

### 3.2.3 Carbon taxation and stated preferences

Carattini et al. (2018) provide a thorough review of a large number of studies on public attitudes toward carbon taxes. They conclude that higher tax rates generally induce a resistance among the public (see, e.g., Thalmann, 2004; Brännlund and Persson, 2012; Carattini et al., 2017). However, they also observe that, in numerous studies, earmarking tax revenues for environmental purposes increases acceptance (e.g., Sælen and Kallbekken, 2011; Gevrek and Uyduranoglu, 2015), as does redistributing them progressively to households (see for instance Gevrek and Uyduranoglu, 2015; Brännlund and Persson, 2012). Cutting other taxes to benefit from a double dividend seems to be a less popular solution, though. Limiting households' actual and perceived costs induced by a policy is also likely to improve its acceptance (Stadelmann-Steffen and Dermont, 2018). Costs induced by environmental policies are indeed found to be influential in the formation of opinion by individuals (Dermont, 2019). The importance of the distributional impacts of carbon and energy taxes is also recognized in a recent meta-analysis by Ohlendorf et al. (2021). Through their literature review, Maestre-Andrés et al. (2019) highlight the importance of the perception of the fairness of a carbon pricing policy to increase its acceptance by the public. They investigate findings regarding different aspects of fairness—perceived personal consequences, distributional effects and procedural aspects, as well as the use of revenues—and conclude that although people generally dislike a regressive distribution of the burden of the policy, on average they prefer that revenues are used to fund renewable energy projects rather than to reduce the regressive effects of the policy. Strengthening the progressiveness of the policy is nevertheless found to increase its acceptance by the public. These stylized facts provide essential information on the potential features of a desirable carbon tax, which could be used in various survey designs.

There is also suggestive evidence of a gradual increase in acceptance once the taxes enter into force. For instance, Murray and Rivers (2015) find an increase in the acceptance of British Columbia's carbon tax three years after its implementation. Noting that acceptance increase has been observed in other environmental taxation domains such as waste taxes, Carattini et al. (2018) relate such improvements to experience. The socially tolerable level of taxation might increase with time, since people can be expected to progressively become used to the new "normal" level of carbon taxation. This phenomenon, linked to the so-called Peacock-Wiseman hypothesis of increasing acceptance of higher levels of public expenditure and taxation (Peacock and Wiseman, 1961), suggests that society can change of reference point with respect to the size of governmental activities after a shock. In the present context, social tolerance for rising carbon prices can increase once people are used to them, so that higher fossil fuel prices become the new normality over time. Thus, in contrast with many predictions from the literature, overcoming oppositions to carbon taxation appears possible if temporal aspects are taken into account.

From a methodological perspective, most studies use stated preference methods, which range from self-reported attitudes and preferences in response to direct survey questions (e.g., Harring and Jagers, 2013; Dreyer and Walker, 2013) to experimental methods such as contingent valuations and discrete choice experiments (e.g., Sælen and Kallbekken, 2011; Rotaris and Danielis, 2019). Our focus is on the few studies that used DCEs. These experiments allow a random variation in attributes, thus offering a great potential for the identification of the relative effects of various policy attributes and the investigation of how individual characteristics interact with policy attributes. In particular, we focus on five studies, three of which (Brännlund and Persson, 2012; Carattini et al., 2017; Beiser-McGrath and Bernauer, 2019) focus exclusively on tax attributes while the other two (Sælen and Kallbekken, 2011; Gevrek and Uyduranoglu, 2015) account for interaction effects with individual characteristics.

In their analysis of the Swedish case using mixed logit models, Brännlund and Persson (2012) report a decrease in acceptance when the personal cost of carbon taxation increases, as well as a distaste for a regressive distribution of the costs to society. They also find that citizens generally prefer the abatement of $CO_2$ emission to be done in the rest of Europe rather than locally in Sweden. Carattini et al. (2017) analyze data from a DCE conducted in Switzerland and find that higher tax rates reduce acceptance, while redistributing proceeds as lump-sum transfers or social cushioning increase it. They however find that environmental earmarking has either no or a negative impact on acceptance, a result that contradicts most previous findings on the issue. Beiser-McGrath and Bernauer (2019) investigate preferences for carbon tax attributes with a DCE carried out in Germany and the United States and contrast the results they obtain in the two countries. They find that revenue recycling increases respondents' willingness-to-pay at levels likely to induce a significant lowering of GHG emissions in both Germany and the USA. They also notice that support for higher carbon tax rates is larger in the US than in Germany and relate this result to the lower social cost of carbon in Germany than in the US (see Ricke et al., 2018).

Sælen and Kallbekken (2011) conduct a DCE on hypothetical fuel tax increases in Norway. They incorporate attitudinal variables in their mixed logit model and interact them with dummies indicating the proposed uses of additional revenues (redistribution or environmental earmarking). Their findings suggest that earmarking revenues for environmental purposes increases acceptance from people who expect to benefit from earmarked revenues, as well as from people who do not expect fuel taxation to be effective *per se*. They also find that redistributing revenues increases acceptance, but less strongly than environmental earmarking. In their DCE carried out in Turkey, Gevrek and Uyduranoglu (2015) add interaction terms between education, employment status and environmental awareness and the attribute levels of their carbon tax proposals, and also use as alternative method a LC model to account for the heterogeneity of respondents' profiles. They find that individuals with higher environmental awareness are significantly more likely to choose a proposal with a progressive redistribution of revenues or with revenues earmarked for environmental purposes. Their LC model identifies two classes: the first one consists in individuals who are more likely to be employed, who have a higher level of education and who are more environmentally aware than the second one. The first class shows preference for a progressive redistribution of tax revenues or for earmarking in favor of environmental policies, whereas the second class shows weaker support for those attributes but prefers earmarking revenues for income redistribution. The second class also displays stronger distaste for the costs induced by carbon taxes than the first class. Results from the LC model hence generally corroborate those from the model with interaction terms, but also provide a more subtle understanding of the heterogeneity of preferences for carbon tax attributes.

As shown by this literature overview, the analysis of DCE data can be carried out with a variety of econometric models dubbed as random utility models. Given the strong heterogeneity in individual preferences, many researchers favor models that can account for unobserved heterogeneity by including random parameters (e.g., mixed logit model) or a finite mixture of coefficients (latent class logit model). The latter approach is particularly interesting as it allows correlation between preference heterogeneity and explanatory variables, an advantage over random parameter models which assume heterogeneity to follow a pre-determined continuous distribution across individuals (see Greene and Hensher, 2003). Moreover, the LC models can readily be extended to include additional meaningful covariates providing a more subtle characterization of the public opinion with respect to various individual factors, as in Gevrek and Uyduranoglu (2015). Such extensions are possible in random-coefficient models but require an increasing number of coefficients, which could render the estimations intractable for estimation and interpretation.

In the following sections we present an application to the case of $CO_2$ taxation in Switzerland. Throughout this application, we provide more details about various methodologies and illustrate their relative merits. Our focus is upon experimental data—more precisely a DCE—and the LC approach, in particular its potential use for characterizing public opinion beyond the usual political left-right scale. With an ongoing debate on possible reforms of an existing taxation scheme and potential future referenda, the context of Switzerland—at the time of writing—lends itself to an analysis of acceptance as well as support via voting behavior.

## 3.3 Experiment Design and Data

Our analysis relies on stated preference data from a sample of 586 Swiss respondents. These data are collected through a DCE conducted within the 2019 wave of the *Swiss Household Energy Demand Survey* (SHEDS)[8].

The experiment is structured into two consecutive stages aiming to identify measures of ac-

[8]See Weber et al. (2017) for more details. The SHEDS sample is constructed to be representative of the Swiss population in terms of gender (female or male), age group (18-34, 35-54, 55+), linguistic region (French or German-speaking) and living situation (home-owner or tenant).

| Maximum tax rate | Shares: redist.—sub. | Redistribution method | Recipient of subsidies |
|---|---|---|---|
| ⋄ CHF96 (25.45 per 100l) | ⋄ 0%—100% | ⋄ Uniform lump-sum | ⋄ Building Program |
| ⋄ CHF120 (31.80 per 100l) | ⋄ 33%—67% | ⋄ Inversely proportional to income | ⋄ Foreign aid for the environment |
| ⋄ CHF160 (42.40 per 100l) | ⋄ 67%—33% | | ⋄ Local community initiatives |
| ⋄ CHF210 (55.65 per 100l) | ⋄ 100%—0% | | |
| ⋄ CHF270 (71.55 per 100l) | | | |

Note: Underlined attribute levels indicate the characteristics of the current $CO_2$ levy (SQ).

Table 3.2: Attribute levels

| | **Proposition 1** | **Proposition 2** | **Status quo** |
|---|---|---|---|
| **Maximum tax rate** | CHF 160 (CHF 42.40 per 100l heating oil/100kg gas) | CHF 270 (CHF 71.55 per 100l heating oil/100kg gas) | CHF 120 (CHF 31.80 per 100l heating oil/100kg gas) |
| **Redistribution:**<br>- Share<br>- Method | 0%<br>- | 33%<br>Inversely proportional to income | 67%<br>Lump-sum |
| **Subsidy:**<br>- Share<br>- Beneficiary | 100%<br>Local community initiatives | 67%<br>Foreign aid for the environment | 33%<br>Building program |

Figure 3.1: Example of choice task

ceptance and support, respectively. In the first stage, a series of six choice tasks is displayed. Each task is composed of three $CO_2$ levy proposals, among which one corresponds to the *status quo* (SQ), that is, the current $CO_2$ levy. In each choice task, respondents are asked to select the proposal they prefer.

Each proposal is defined by four attributes capturing the main features of the $CO_2$ levy:
1) Maximum tax rate, i.e., the highest potential tax rate that can legally be levied[9].
2) Share of tax proceeds redistributed to individuals as direct transfers, with the remaining share for public subsidies.
3) Redistribution method (only for non-zero distributed share) defining the transfers as uniform lump sums (the current method) or progressive (i.e., inversely proportional to income).
4) Recipient of subsidies (only when subsidy share is non-zero): *Building Program* (current state), foreign aid for the environment, or local community initiatives.

Chosen attribute levels are displayed in Table 3.2. The maximum tax rate is displayed both in CHF per $tCO_2$ and in CHF per 100l of heating oil or 100kg of natural gas. An example of a choice task is displayed in Figure 3.1.

The second stage of the experiment aims to measure the respondent's support in a possible

[9]In Switzerland, the rate of the $CO_2$ levy increases when $CO_2$ emission abatement targets are not met at certain dates set in advance. The maximum tax rate is thus the ceiling that legally limits these increases.

vote, which is a realistic outcome in Switzerland. In this stage, which follows the choice tasks, the respondents are asked to give their vote in a hypothetical referendum. Each respondent is provided with maximum three choice tasks (hereafter referred to as the "vote task"), each representing one tax proposal. The presentation of attributes is identical to that of the choice tasks in the first stage (as in Figure 3.1). These tax proposals are randomly selected from the tax options that the respondent has selected as preferred alternatives in the first stage's choice tasks. The set of proposals always contains the SQ, even for those who never selected it in the first stage of the experiment. For each respondent, the proposals are displayed one by one. In each vote task, respondents can answer either *Yes*, *No* or *Abstain*[10].

The experiment also includes a preliminary section prior to the choice tasks and a series of follow-up questions. In the preliminary section, the $CO_2$ levy and the whereabouts of its reform—then under discussion in the Federal Assembly—are presented. This section includes tailored information on how carbon taxation specifically impacts the respondents depending on their current heating system. The follow-up questions are designed to assess the respondents' perception of the DCE (e.g., difficulty to respond or attribute non-attendance) and their general opinion on carbon taxation (e.g., the efficiency of taxing GHG emissions to lower them). Overall, attribute non-attendance does not seem to be particularly prevalent, although more than 57% of respondents found it hard to choose the proposals they preferred. We therefore expect the data to adequately capture the preferences of the respondents.

## 3.4 Econometric approach

In line with random utility theory (McFadden, 1974b; Manski, 1977), we assume that respondents make their decision on the basis of a stochastic utility function and a separable random term. In other words, each individual $i$ facing alternative $j$ in choice task $t$ maximizes a random utility function of the form $U_{ijt} = V_{ijt} + \varepsilon_{ijt}$, where $V_{ijt}$ is a deterministic component specified by observables and $\varepsilon_{ijt}$ is a residual term representing idiosyncratic variations.

The deterministic component $V_{ijt}$ can be written as:

$$V_{ijt} = x'_{ijt}\beta \tag{3.1}$$

where $x_{ijt}$ is a vector of independent variables and $\beta$ is a vector of parameters representing the marginal utility of corresponding attributes. In addition to alternative $j$'s attributes for respondent $i$, $x_{ijt}$ could include interaction terms between attributes and respondent characteristics. In our model, this vector includes a SQ dummy in addition to the attributes presented in Table 3.2.

We use the conditional logit (CL) model proposed by McFadden (1974b). Another closely related model is the multinomial logit (MNL) model (see McFadden, 1974a) that is readily adapted to labeled options—hence providing alternative-specific marginal utilities for each attribute. However, the distinction between CL and MNL models is more conceptual than technical, because the two models can be nested in a single general framework (see for instance Hoffman and Duncan, 1988).

[10]Abstaining has not been specifically framed in the experiment. Respondents could take it as not wanting to answer, being unable to decide, or preferring the *status quo* to any policy change.

Let $c_{ijt} = 1$ when individual $i$ selects option $j$ in task $t$, and 0 otherwise. The probability that alternative $j$ is selected by individual $i$ in choice task $t$ in the CL model is defined as

$$P\left(c_{ijt} = 1\right) = \frac{e^{x'_{ijt}\beta}}{\sum_j e^{x'_{ijt}\beta}} \tag{3.2}$$

where $\beta$ is the vector of model parameters to be estimated.

The basic CL model assumes that the utility parameters $\beta$ are the same for all respondents. This assumption could be restrictive for capturing the strong heterogeneity usually observed in individual preferences. Relaxing this assumption is crucial for identifying the diversity of preferences in our data. Moreover, a corollary of this assumption in a logit model is odds-proportionality, hence the independence of irrelevant alternatives (IIA) restriction. An additional advantage of integrating heterogeneous parameters among respondents is to relax the IIA restriction.

To account for heterogeneity of preferences in the population, we use three different approaches, which are presented in Table 3.3. The first one relies on a Mixed (or random coefficient) model, in which the coefficients are assumed to follow a continuous distribution (usually normal) across individuals (Hensher and Greene, 2003). Covariates can also be included as interaction terms.

Our second and third approaches are based on the latent class CL model (LC-CL). In this type of models, unobservable clusters denominated as latent classes are identified based on answer patterns to a set of clustering variables. As explained by Greene and Hensher (2003), LC models assume that parameters are discretely distributed across a certain number of classes $s = 1, ..., S$, with no specific distribution assumption on classes. The number of latent classes is decided by fitting models with an increasing number of classes and by comparing them using statistical criteria such as the Akaike or Bayesian information criteria (AIC or BIC, see Tein et al., 2013). Individual LC membership probabilities $\pi_{is} = P(i \in s)$ are usually modeled with a separate MNL model with respondent characteristics $z_i$ as covariates (see Greene and Hensher, 2003).

The LC model contrasts with the Mixed model in that the Mixed model assumes a continuous distribution of utility parameters across individuals with a specific pre-assumed functional form, whereas the LC model posits no distribution assumption. The random distribution of parameters in the Mixed model is also required to be uncorrelated with the actual outcomes. However, there is no restricting condition on the fixed parameters in the LC model. This could be an important advantage for the LC approach, because the heterogeneity of preferences could be correlated with the utility parameters. For instance, respondents who have a lower marginal valuation of taxes could be more likely to opt for the SQ option.

We use two variants of the LC-CL model: the simultaneous LC-CL (SimLC) model and the two-step LC-CL (2SLC) model. In the SimLC model, $\pi_{is}$ are estimated simultaneously to class-specific preference parameters $\beta_s$ (see Table 3.3): stated preference data from the DCE are used as clustering variables. The 2SLC model is an extension of the model proposed by Patunru et al. (2007). LC membership probabilities $\tilde{\pi}_{is}$ are estimated in a first step using attitudinal and perception-related variables regarding the environment and environmental policy as clustering variables instead of stated preferences from the DCE. Then, predicted $\tilde{\pi}_{is}$ are introduced in the likelihood function as exogenous parameters to estimate preference parameters $\tilde{\beta}_s$ in a second

| Model | Assumptions | Model parameters | Log-likelihood function | Estimation method | Modeling of heterogeneity | References |
|---|---|---|---|---|---|---|
| Conditional logit (CL) | Odds-proportionality | $\beta$ | $\Sigma_i \log\left\{\Pi_t \Pi_j \left(\frac{e^{x'_{ijt}\beta}}{\Sigma_j e^{x'_{ijt}\beta}}\right)^{c_{ijt}}\right\}$ | ML | No modeling of heterogeneity in parameters | McFadden (1974b) |
| Mixed logit | Random coefficients, no correlation between random parameters | $\beta_i = \beta + z'_i\gamma + \omega_i$, $\omega_i \sim N(0,\Sigma)$ | $\Sigma_i \log\left\{\int\left[\Pi_t \Pi_j \left(\frac{e^{x'_{ijt}\beta_i}}{\Sigma_j e^{x'_{ijt}\beta_i}}\right)^{c_{ijt}}\right] f(\beta_i)\, d\beta_i\right\}$ | Simulated ML | Modeling of preference heterogeneity as continuous and random, arbitrary choice of distribution | McFadden and Train (2000); Hensher and Greene (2003) |
| Simultaneous latent class CL (SimLC) | LC inferred from choice data | $\beta_s$, $\pi_{is} = \frac{e^{z'_i\gamma_s}}{\Sigma_s e^{z'_i\gamma_s}}$ | $\Sigma_i \log\left\{\Sigma_s \pi_{is}\left[\Pi_t \Pi_j \left(\frac{e^{x'_{ijt}\beta_s}}{\Sigma_j e^{x'_{ijt}\beta_s}}\right)^{c_{ijt}}\right]\right\}$ | E-M and ML | Clustered (discrete) heterogeneity modeled with covariates and consistent with choice data | McCutcheon (1987); Greene and Hensher (2003) |
| Two-step latent class CL (2SLC) | LC inferred from attitudes and perceptions | $\tilde{\beta}_s, \tilde{\pi}_{is} = \frac{e^{\tilde{z}'_i\gamma_s}}{\Sigma_s e^{\tilde{z}'_i\gamma_s}}$ | $\Sigma_i \log\left\{\Sigma_s \tilde{\pi}_{is}\left[\Pi_t \Pi_j \left(\frac{e^{x'_{ijt}\tilde{\beta}_s}}{\Sigma_j e^{x'_{ijt}\tilde{\beta}_s}}\right)^{c_{ijt}}\right]\right\}$ | E-M and ML | Clustered (discrete) heterogeneity modeled with covariates and independent of choice data | Patunru et al. (2007) |

$\beta$ is a vector of estimated marginal utility parameters; $f(\cdot)$ is the multivariate normal distribution function; $z_i$ is the vector of respondent characteristics; $\omega_i$ is a vector of random parameters with $\Sigma$ as covariance matrix; $\pi_{is}$ is the probability that individual $i$ belongs to class $s = 1, ..., S$. ML = maximum likelihood; E-M = expectation-maximization algorithm (see Morey et al., 2006).

Table 3.3: Econometric models

step. This procedure has the advantage of being consistent with McFadden's (1986) theoretical framework on decision-making: exogenous factors—such as socioeconomics—shape attitudes and perceptions, which in turn jointly shape choice preferences. In our case, resulting LCs can be understood as modeling the different *citizen profiles* of respondents regarding environmental policy, analogously to Rhead et al. (2018). However, $\tilde{\pi}_{is}$ do not maximize the fit of the choice model, unlike $\pi_{is}$ in the SimLC model. It should be noted that the SimLC models used to analyze data from the choice tasks and the vote tasks are independent, while the same $\tilde{\pi}_{is}$ are used for both types of data in the 2SLC model.

Clustering variables used in the first step of the 2SLC model include some key factors capturing respondents' perceptions and attitudes regarding the environment and environmental policy. A full description is provided in the lower part of Table 3.A.1. The first variable is the willingness-to-adopt an environmentally-friendly behavior despite the inconveniences it might cause, while the second is the feeling of being unable to lower one's GHG emissions. These two variables relate to attitudes toward the environment. The third is the trust in information on energy and energy-saving provided by scientists. This variable captures the extent of the confidence (or skepticism) respondents have regarding "official" information. The fourth is the perception that carbon taxes are effective to lower $CO_2$ emissions from firms and individuals. Respondents are assigned to four groups: those who consider taxing $CO_2$ emissions is efficient in both cases, those who believe it is only efficient for firms, those who only believe it is efficient for individuals, and those who do not consider this policy as efficient at all. The last variable is whether the respondent supports the *School strike for climate* movement. It is taken as an indicator of the degree of agreement with the position that more ambitious actions to fight anthropogenic climate change need to be taken without further delay.

We integrate further respondent characteristics—covariates $z_i$—as determinants of the variation of utility parameters in our models. These covariates consist of socioeconomic, geographic and political variables. Our choice of variables is guided by the literature discussed in Section 3.2. In particular, we use gender and age groups, higher education, residential environment, linguistic region, and political orientation. A full description is provided in the upper part of Table 3.A.1. These covariates capture the main personal-level factors that might influence class membership probabilities[11].

We compare results using both the SimLC and the 2SLC approaches to analyze data from our DCE, as they complement each other thanks to the respective strengths and weaknesses presented above. We also contrast these results with those from the CL and the Mixed CL models. This allows to highlight the importance of modeling heterogeneity with observed variables to better understand preferences and their determinants.

[11]Income is not included because numerous respondents (44 out of 586) did not provide this information, causing an important loss of observations. Moreover, if included, its impact on class membership probabilities is not statistically significant. We also tested for the impact of being home-owner and of whether the respondent uses oil or gas for heating, but both variables did not have any impact on results and have thus been dropped.

| | Sample | SimLC (choice) Class A | SimLC (choice) Class B | SimLC (vote) Class A | SimLC (vote) Class B | 2SLC Class A | 2SLC Class B | Switzerland |
|---|---|---|---|---|---|---|---|---|
| N | 586 | | | | | | | |
| Class size | | 48.65 | 51.35 | 77.67 | 22.33 | 53.6 | 46.4 | |
| Gender: female | 48.46 | 51.33 | 45.75 | 47.17 | 52.97 | 54.72 | 41.23 | 50.79 |
| Age | | | | | | | | |
| 18-34 | 21.84 | 26.65 | 17.29 | 19.89 | 28.63 | 24.83 | 18.39 | 25.64 |
| 35-54 | 40.96 | 44.01 | 38.06 | 42.22 | 36.55 | 42.71 | 38.93 | 35.13 |
| 55+ | 37.2 | 29.34 | 44.65 | 37.89 | 34.82 | 32.46 | 42.68 | 39.23 |
| Tertiary edu. | 48.12 | 49.29 | 47.02 | 51.08 | 37.83 | 54.92 | 40.26 | 31.14 |
| Residential env. | | | | | | | | |
| City | 50.68 | 54.57 | 47.00 | 51.99 | 46.14 | 58.97 | 41.11 | 62.89 |
| Agglomeration | 28.16 | 24.72 | 31.41 | 28.79 | 25.96 | 22.44 | 34.76 | 21.34 |
| Countryside | 21.16 | 20.71 | 21.58 | 19.22 | 27.90 | 18.58 | 24.14 | 15.77 |
| Romandie | 23.55 | 24.52 | 22.63 | 23.33 | 24.33 | 26.52 | 20.11 | 25.34 |
| Swiss nationality | 91.98 | 91.53 | 92.40 | 91.06 | 95.16 | 90.25 | 93.97 | 75.18 |

Notes: Relative frequencies expressed in percentages are displayed. For Switzerland, frequencies of gender, age groups and nationality are displayed for residents aged above 18 in 2018; residential environment and Romandie for residents aged above 15 in 2018; tertiary education for residents aged above 18 in 2017.

Table 3.4: Descriptive statistics

## 3.5 Results

### 3.5.1 Descriptive statistics

The first and last columns of Table 3.4 present descriptive statistics for the sample used in the analysis and for the Swiss population[12]. Males and middle-aged people are slightly overrepresented in our sample in comparison to the Swiss population. It also appears that more educated, rural people, and Swiss nationals are overrepresented in our sample. Central columns of Table 3.4 are described in the next section.

### 3.5.2 Latent class analysis

Before conducting the regression analysis, the optimal number of (latent) classes needs to be determined for the LC models[13]. Models with the lowest BIC and adjusted BIC (Sclove, 1987) are selected, following Nylund et al.'s (2007) recommendations. Models with two classes generally perform best in terms of these two information criteria (see Table 3.5) and this solution is therefore chosen[14].

As can be seen in Table 3.6, diagnostics of the LCA conducted for the SimLC model on choice data show that the split between the two classes is clear for this model: the share of respondents $Q$ with a class membership probability $\pi_{is}$ at least as high as $Q$ is slightly above 88%, which

[12]Statistics for Switzerland are obtained from databases of the Swiss Federal Office of Statistics, namely the *Population and households statistics* and the *Structural survey*.

[13]LCAs for the two SimlC models have been performed with R's package `apollo` (Hess and Palma, 2019), while the LCA conducted for the first step of the 2SLC model has been carried out with R's package `poLCA` (Linzer and Lewis, 2011). `poLCA` allows for missing values in the clustering variables, so that no observation needs to be dropped from the sample.

[14]BICs of two-class models are significantly lower than those of models with more classes, which supports their validity from a statistical point of view (see Kass and Raftery, 1995). Moreover, our models become noisy when estimated with more than two classes, in that classes are not well defined and do not significantly differ in their characteristics.

| No. of classes | SimLC (choice) BIC | SimLC (choice) Adj. BIC | SimLC (vote) BIC | SimLC (vote) Adj. BIC | 2SLC BIC | 2SLC Adj. BIC |
|---|---|---|---|---|---|---|
| 1 | 6975.32 | 6949.90 | 2278.88 | 2253.47 | 6167.78 | 6132.86 |
| 2 | 6170.19 | 6109.82 | 2213.28 | 2152.92 | 6017.16 | 5944.14 |
| 3 | 6241.93 | 6149.79 | 2361.62 | 2269.49 | 6055.44 | 5944.33 |
| 4 | 6369.33 | 6245.41 | 2425.29 | 2301.40 | 6109.56 | 5960.36 |

Notes: For the 2SLC model, the information criteria of the first step, i.e., the estimation of $\tilde{\pi}_{is}$, are displayed. Covariates are not included in any model.

Table 3.5: LCA: Information criteria

| Model | Entropy | $[\pi_{is} > Q]$ | Avg. PCP Class A | Avg. PCP Class B | Min. PCP Class A | Min. PCP Class B | Max. PCP Class A | Max. PCP Class B | Class size Class A | Class size Class B |
|---|---|---|---|---|---|---|---|---|---|---|
| SimLC (choice) | 0.851 | 88.23 | 96.41 | 95.65 | 51.06 | 50.44 | 100.00 | 100.00 | 48.65 | 51.35 |
| SimLC (vote) | 0.763 | 82.08 | 96.45 | 78.93 | 50.16 | 50.46 | 100.00 | 99.60 | 77.67 | 22.33 |
| 2SLC | 0.674 | 80.20 | 91.57 | 88.75 | 50.22 | 50.07 | 100.00 | 99.99 | 53.60 | 46.40 |

Notes: All statistics except entropy are expressed in percentages. PCP stands for posterior class probability.

Table 3.6: LCA: Diagnostics

means that more than 88% of respondents belong to a class with a probability of at least 88%. The average posterior class probabilities (Avg. PCP)[15] for Classes A and B are both about 96%. The relative entropy[16] of the model is also high, at about 0.85. The size of the two classes is also quite even, with an estimated average probability of belonging to Class A of 49% and to Class B of 51%.

The SimLC model on vote data performs less well in that regard, as the split between the two classes appears as less clear-cut. The size of Classes A and B is very unequal, as the former accounts for more than three quarters of the sample. Diagnostics for the 2SLC model are also less good than for the SimLC model on choice data, but the size of the two classes is more balanced than for the SimLC model on vote data. The average PCPs of the 2SLC model also suggests that respondents generally have a high probability of belonging to the class they would modally be assigned to.

Results from the logistic regression of class membership probabilities on covariates are presented in Table 3.7. LCA in the SimLC model on choice data shows that being aged over 55 and self-identifying as rightist in politics decrease the probability of belonging to Class A. Other covariates have no statistically significant effect. LCA for the SimLC model on vote data shows that having a tertiary level of education increases the probability of belonging to Class A for this model, but only with a weak statistical significance. LCA for the 2SLC model shows that having a tertiary level of education increases the probability of belonging to Class A, while a right-wing political orientation decreases it. Living in an urban area also has a weakly significant positive effect. Coefficients for other variables are not significant in any of the models.

To better understand the nature of the classes, it is necessary to look more closely at their characteristics. Central columns of Table 3.4 display some descriptive statistics on the latent

[15]The average posterior class probability is, for each class, the average class membership probability of respondents modally assigned to it (Masyn, 2013).

[16]Relative entropy is an index of the model's overall precision in the assignment of respondents to classes: a value of 1 indicates perfect assignment—i.e., all respondents belong to a class with a probability of 1—and a value of 0 means that the model is not better than a random guess (Masyn, 2013; Ramaswamy et al., 1993).

|  | Constant | Female | Age: 18-34 | Age: 55+ | Tertiary edu. | City | Countryside | Romandie | Political orientation |
|---|---|---|---|---|---|---|---|---|---|
| SimLC: choice | 1.28*** | 0.06 | 0.29 | −0.57*** | −0.02 | 0.25 | 0.23 | 0.02 | −0.32*** |
|  | (0.39) | (0.19) | (0.25) | (0.21) | (0.19) | (0.22) | (0.27) | (0.23) | (0.06) |
| SimLC: vote | 1.17** | −0.13 | −0.54 | −0.03 | 0.54* | 0.04 | −0.51 | −0.01 | 0.03 |
|  | (0.52) | (0.26) | (0.38) | (0.30) | (0.28) | (0.32) | (0.35) | (0.30) | (0.08) |
| 2SLC | 2.66*** | 0.45 | 0.25 | −0.36 | 0.63** | 0.60* | 0.21 | 0.34 | −0.77*** |
|  | (0.57) | (0.28) | (0.35) | (0.30) | (0.27) | (0.31) | (0.37) | (0.31) | (0.10) |

Notes: ****p*-value < 0.01; ***p*-value < 0.05; **p*-value < 0.1. MNL coefficients for Class A.

Table 3.7: LCA: Regression results

|  |  | Class A |  |  | Class B |  |  |
|---|---|---|---|---|---|---|---|
|  | Sample | Choice | Vote | 2SLC | Choice | Vote | 2SLC |
| Env. adaptation |  |  |  |  |  |  |  |
| Not ready | 11.77 | 8.55 | 11.31 | 2.56 | 14.83 | 13.40 | 22.42 |
| Uncertain | 34.30 | 33.94 | 33.03 | 28.86 | 34.65 | 38.72 | 40.59 |
| Ready | 53.92 | 57.51 | 55.66 | 68.59 | 50.53 | 47.89 | 36.99 |
| Inability to abate |  |  |  |  |  |  |  |
| No | 48.29 | 55.23 | 50.72 | 63.52 | 41.72 | 39.87 | 30.70 |
| Unsure | 36.18 | 32.86 | 34.17 | 24.84 | 39.32 | 43.18 | 49.28 |
| Yes | 15.53 | 11.91 | 15.12 | 11.64 | 18.95 | 16.96 | 20.02 |
| Trust in scientists |  |  |  |  |  |  |  |
| Low | 14.68 | 10.46 | 14.18 | 5.52 | 18.67 | 16.40 | 25.25 |
| Medium | 24.74 | 22.12 | 22.93 | 16.34 | 27.23 | 31.06 | 34.46 |
| High | 55.63 | 63.06 | 58.99 | 73.48 | 48.60 | 43.97 | 35.01 |
| Eff. of carbon tax |  |  |  |  |  |  |  |
| Never | 28.16 | 23.71 | 23.28 | 12.89 | 32.37 | 45.13 | 45.79 |
| Individuals only | 3.92 | 3.59 | 4.01 | 2.57 | 4.24 | 3.63 | 5.49 |
| Firms only | 29.52 | 26.78 | 31.09 | 27.01 | 32.12 | 24.08 | 32.42 |
| Always | 38.40 | 45.93 | 41.63 | 57.52 | 31.26 | 27.16 | 16.30 |
| Support climate strikes |  |  |  |  |  |  |  |
| No | 36.01 | 25.58 | 35.09 | 10.51 | 45.89 | 39.20 | 65.46 |
| Unsure | 31.40 | 30.28 | 29.84 | 30.61 | 32.46 | 36.82 | 32.31 |
| Yes | 32.59 | 44.15 | 35.07 | 58.87 | 21.65 | 23.98 | 2.23 |

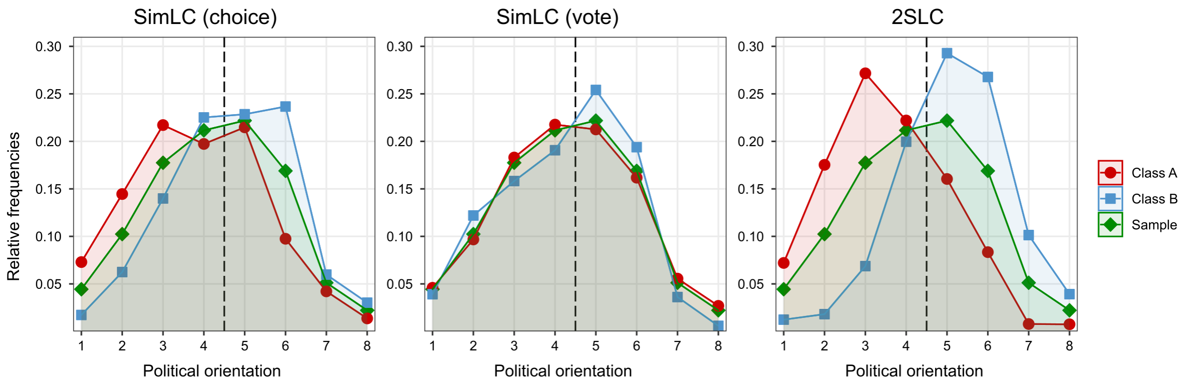
Notes: Relative frequencies expressed in percentages are displayed. Frequencies of missing values are not included in the table.

Table 3.8: Distribution of clustering variables

classes and Table 3.8 presents the distribution of the clustering variables used in the 2SLC model for each class in all three models. Table 3.4 suggests that Class A is generally younger and more urban than the average, and contains more female and people with a tertiary level of education, whereas Class B's composition lies to the opposite. As can be seen in Table 3.8, patterns of answers[17] differ between the SimLC models on choice and vote data for each class, but they are more similar between the SimLC model on choice data and the 2SLC model. Beyond these differences, relative frequencies of answers for the three models show that, in general, Class A is composed of more environmentally-friendly respondents, while Class B seems more neutral in that regard. Even though the composition of the classes is not strictly identical across LC models, their average composition is very comparable in all cases.

Interestingly, both left and right-wing individuals are present in the two classes in all models, although members of Class A are on average more left-leaning than those of Class B, as shown in Figure 3.2. Political orientation is hence likely to be associated to differences in preferences

[17]There are 324 possible patterns, and 178 of them are present in the data when missing values are not considered.




Note: 1 = extreme left, 8 = extreme right.

Figure 3.2: Political orientation, by class

regarding the environment and environmental policy, but it is not deterministic. Political conservatism is generally associated with lower concern for environmental issues, but the connection between the two might be context-specific, as argued by Nawrotzki (2012)—a point supported by our LCA. This underlines the limits of the left-versus-right linear political scale in analyzing the position of social groups regarding the environment and environmental policy, as environmentalism might reach beyond classical political divides (see Pilbeam, 2003). Segmenting society in groups with similar profiles regarding environmental perceptions and attitudes therefore requires a holistic view of the situation and should account for the specificity of the sociopolitical context.

### 3.5.3 Analysis of choice preferences

To analyze choice data, the SimLC and 2SLC models are run and compared to a CL model and a Mixed CL model[18]. The SQ, i.e., the current $CO_2$ levy, is the reference; that is, the coefficients for attribute levels from the SQ are set to 0, so that estimated coefficients show the impact of non-SQ attribute levels on respondents' utilities. The tax rate is expressed as a deviation from the SQ rate (i.e., CHF 120) in hundreds of CHF. A set of dummy variables captures the effects of the allocation of proceeds, in deviation from the current situation where 67% are redistributed and 33% are dedicated to subsidies. Results are displayed in Table 3.9.

Based on the CL model, respondents seem to prefer proposals with a revenue allocation scheme that contains both subsidies and redistribution. Results also reveal a distaste for using subsidies for environmental assistance abroad—that is, respondents prefer emission abatement to be done within Switzerland, unlike Swedish citizens in Brännlund and Persson (2012). The SQ also seems to have some intrinsic value for respondents compared to alternatives, as shown by the significant and positive coefficient for the SQ dummy. Other attributes, including the levy rate, do not have any significant impact on the likelihood that a proposal is selected.

Results from our Mixed model are more complex to interpret, as each coefficient is interacted with individual-level characteristics in an attempt to explain the source of preference heterogeneity through covariates in addition to the random component of the parameter. Coefficients for these interactions are presented in Table 3.B.2. Results show that being female decreases the

[18]All model regressions have been performed with R's package `apollo` (Hess and Palma, 2019).

| | CL | Mixed | | SimLC | | 2SLC | |
|---|---|---|---|---|---|---|---|
| | | $\mu$ | $\sigma$ | Class A | Class B | Class A | Class B |
| SQ | 0.56*** | 0.12 | 2.03*** | −0.34** | 0.94*** | −0.07 | 1.02*** |
| | (0.10) | (0.62) | (0.16) | (0.14) | (0.22) | (0.16) | (0.19) |
| Rate | −0.09 | 0.71 | 2.05*** | 0.92*** | −1.79*** | 1.26*** | −1.90*** |
| | (0.06) | (0.48) | (0.21) | (0.23) | (0.42) | (0.22) | (0.34) |
| Rate (squared) | | | | −0.51*** | 0.53* | −0.70*** | 0.63*** |
| | | | | (0.14) | (0.31) | (0.14) | (0.24) |
| Redist. 100% — Sub. 0% | −0.59*** | −1.06 | 1.37*** | −0.67*** | −0.69*** | −0.90*** | −0.29 |
| | (0.10) | (0.75) | (0.28) | (0.15) | (0.25) | (0.16) | (0.22) |
| Redist. 67% — Sub. 33% | Ref. | Ref. | Ref. | Ref. | Ref. | Ref. | Ref. |
| Redist. 33% — Sub. 67% | −0.03 | −0.76 | 0.69* | −0.06 | −0.43 | −0.09 | −0.12 |
| | (0.11) | (0.64) | (0.40) | (0.14) | (0.27) | (0.15) | (0.20) |
| Redist. 0% — Sub. 100% | −0.35*** | −1.13* | 1.24*** | −0.34*** | −0.61*** | −0.41*** | −0.44** |
| | (0.10) | (0.62) | (0.27) | (0.13) | (0.22) | (0.14) | (0.20) |
| Redistribution: Uniform | Ref. | Ref. | Ref. | Ref. | Ref. | Ref. | Ref. |
| Redistribution: Progressive | 0.12 | 0.83 | 1.41*** | 0.45*** | −0.66*** | 0.39*** | −0.37*** |
| | (0.07) | (0.51) | (0.19) | (0.11) | (0.19) | (0.11) | (0.14) |
| Subsidies: Building Program | Ref. | Ref. | Ref. | Ref. | Ref. | Ref. | Ref. |
| Subsidies: Foreign aid | −0.58*** | −0.74 | 1.82*** | −0.37*** | −1.43*** | −0.53*** | −0.98*** |
| | (0.10) | (0.70) | (0.25) | (0.13) | (0.26) | (0.15) | (0.24) |
| Subsidies: Local initiatives | 0.10 | 0.38 | 1.31*** | 0.35*** | −0.50** | 0.15 | 0.05 |
| | (0.08) | (0.54) | (0.23) | (0.13) | (0.22) | (0.14) | (0.18) |
| Obs. | 3516 | 3516 | | 3516 | | 3516 | |
| McFadden's $R^2$ | 0.11 | 0.27 | | 0.23 | | 0.17 | |
| AIC | 6926.00 | 5791.59 | | 6021.27 | | 6481.78 | |
| CAIC | 6983.32 | 6364.80 | | 6214.73 | | 6610.75 | |
| BIC | 6975.32 | 6284.80 | | 6187.73 | | 6592.75 | |
| Adj. BIC | 6949.90 | 6030.60 | | 6101.94 | | 6535.56 | |

Notes: ****p*-value < 0.01; ***p*-value < 0.05; **p*-value < 0.1. 1000 MLHS (Hess et al., 2006) inter-individual draws have been generated for random parameters in the Mixed model.

Table 3.9: Results: choice preferences

marginal utility from higher tax rates, as does right-wing political orientation, while having a tertiary level of education increases it. Political orientation is also found to exert a negative impact on the marginal utilities from the progressive redistribution of proceeds and from directing subsidies to foreign aid for the environment. Being aged between 18 and 34 however positively impacts the latter's marginal utility, while living in the French-speaking region of Switzerland has a positive effect on the preference coefficient for the use of subsidies for foreign aid. Overall, although some factors seem to have impacts on their own when taken separately, little general conclusion can be drawn from these results due to the way this model handles individual-level covariates. Random heterogeneity across respondents is important, though, given the large and significant values of most estimated standard deviations in Table 3.9.

While environmental orientation can be expressed as a continuum, it is likely that the individuals' positions cluster in several distinct groups. Based on this assumption, we attempt to identify a number of classes that can be interpreted as factions with relatively homogeneous preferences with regard to environmental taxation. Indeed, the LC models are much more informative regarding the source of heterogeneity than the Mixed model, as the two classes described in Section 3.5.2 are found to have very heterogeneous preferences regarding attribute levels.

Given their preferences as revealed by the DCE, we dub Class A as *Pro-tax reform* (or *Pro-reform* in short) and Class B as *Anti-tax reform* (or *Anti-reform*)[19]. Indeed, in the results from the SimLC model, Class B displays strong preference for the SQ, while Class A displays a distaste for it. The proposed maximum rate of the $CO_2$ levy also affects each group differently: the *Pro-reform* gain in utility as the rate becomes higher, while the utility of the *Anti-reform* diminishes as the rate increases. This finding nuances previous conclusions from the literature on carbon taxes—that is, that people dislike high tax rates (see Carattini et al., 2018)—by underlining that this behavior corresponds only to a share of society, while there exists another share who seems to support the role of carbon taxation in fighting GHG emissions and thus prefers higher tax rates to make the policy more effective. In our model, a quadratic term is included to capture the fact that even if some respondents might prefer higher levy rates than the current one, it is likely that there exists a maximum value above which their marginal utility would nevertheless become negative. Our results seem to confirm that intuition, with a utility-maximizing rate of approximately CHF 210 for the *Pro tax*. Interestingly, this amount happens to correspond to the maximum rate proposed in the new version of the $CO_2$ Act.

Results from the SimLC model also show that the absence of subsidies and redistribution lowers both classes' utilities. Their preferences nevertheless differ regarding the progressiveness of the $CO_2$ levy, as the *Pro-reform* utility is higher if proceeds are redistributed as an inverse function of income, while the *Anti-reform* prefer uniform lump-sum transfers. Both groups prefer subsidies not to be used for foreign environmental aid, with a significantly stronger aversion for the *Anti-reform*: a *t*-test for the difference between the two coefficients gives a test statistic of $-3.65$. The *Pro-reform* also prefer proposals in which subsidies are directed toward local community initiatives, while the utility of the *Anti-reform* is lower when it is the case.

Results from the 2SLC model corroborate those from the SimLC, with only minor differences. The *Pro-reform* are now found to be indifferent between the SQ and alternative proposals, and the use of subsidies for local community initiatives has no impact on their utility. The *Anti-reform* are indifferent regarding the presence or absence of subsidies and their use for local community initiatives. The fact that similar results are obtained with the simultaneous and the two-step LC methods supports the premise that the same latent structure of society regarding public opinion on carbon taxation can be captured with different types of clustering variables. Using variables that have a broader reach than experiment-specific choices enables to reveal the same general information on preferences than them, but with the advantage of not being constrained by the framework of the DCE. The meaning of the LCs obtained with the 2SLC model is thus more general than that of the of LCs from the SimLC model. There is therefore strong evidence for the presence of two distinct *citizen profiles* within Switzerland's population, with opposing preferences regarding the design of the $CO_2$ levy.

In terms of statistical performance, whether the SimLC model or the Mixed model is the most powerful is difficult to determine. Consistent AIC (CAIC, see Nylund et al., 2007) and BIC suggest the SimLC model performs better, while AIC and adjusted BIC suggest the opposite. Judging the two models on a purely statistical basis is hence not possible. We express a preference for the LC method for several reasons. First, its capacity to synthesize heterogeneity in an easily un-

[19]The *Pro-reform* show also more environmentalist perceptions and attitudes than the *Anti-reform*, as discussed in Section 3.5.2.

derstandable factor—the latent classes—make it more useful to analyze how preferences differ within a population. The high degree of separation of the two classes also supports the idea that preferences tend to cluster in homogeneous groups instead of continuously differing across respondents. On the other hand, the Mixed model is difficult to interpret regarding its handling of covariates, and it relies on unverifiable and arbitrary distributional assumptions for the random component of the parameters. A modeling strategy based on distinct classes is thus favored, also because it does not impose any restrictive distribution assumption on preference heterogeneity or any restriction on their possible correlation with other unobserved factors captured by the model's residuals.

Overall, LC models are more informative than the CL and the Mixed models because they underline how the observed heterogeneity in the sample impacts preferences and responses. The *Pro-reform* have a preference for higher carbon tax rates, a redistribution of proceeds that benefits low-income households and for using part of the proceeds for environmental subsidies, while the *Anti-reform* prefer to stick with the SQ, as they favor low tax rates and uniform lump-sum redistribution. In absence of any form of clustering, these important differences would remain unnoticed. Integrating covariates using a latent variable thus appears more meaningful than simple interaction terms.

### 3.5.4 Analysis of voting preferences

Analyzing data from the hypothetical votes is less straightforward to conceptualize than for the choice data. Given their nature, what we test for here is the impact of each alternative's attributes on its probability of being voted *Yes* by a respondent, conditional on having been selected as the preferred alternative in a choice task[20]. We are thus looking at the transition from *being preferred to other proposals* to *being supported in a referendum*, that is, from relative (passive) preference—i.e., acceptance—to active support. Note that the model is binary, as the *No* and *Abstain* options have been merged to form the reference category of non-support[21]. Regression results are shown in Table 3.10.

The CL model provides few significant results: the absence of subsidies or their use for foreign environmental aid both lower support, while the progressive redistribution of proceeds seems to increase it—although the latter relation is only weakly significant. The Mixed model does not provide much more information: the sole meaningful result lies in the large heterogeneity across respondents, as revealed by the values of estimated standard deviations. Coefficients for covariates presented in Table 3.B.3 are not very informative either.

From the SimLC model, it appears that the impact of the progressive redistribution of proceeds is not significant for any of the two groups, and the use of tax proceeds to finance foreign environmental aid has a significant negative impact for the *Pro-reform* only. The most interesting result is that the *Pro-reform* have a higher propensity to vote *Yes* than the *Anti-reform*—everything else being equal—as shown by the significant positive coefficient for the constant for the *Pro-reform* and the large negative constant for the *Anti-reform*. The significant positive constant for the *Pro-reform* is also found with the 2SLC model, but the constant for the *Anti-reform* is however

[20]This means that hypothetical votes on the current $CO_2$ levy of respondents who never chose the SQ in the choice tasks have been removed from the sample. Otherwise, the meaning of results would lack consistency.

[21]Results do not significantly differ if a MNL model with all three options are considered instead and separate coefficients are estimated for each. The binary CL model is preferred for parsimony and readability reasons.

| | CL | Mixed | | SimLC | | 2SLC | |
|---|---|---|---|---|---|---|---|
| | | $\mu$ | $\sigma$ | Class A | Class B | Class A | Class B |
| Constant | 0.45*** | 0.82 | 2.27*** | 1.25*** | −4.82* | 0.81*** | 0.11 |
| | (0.09) | (0.69) | (0.47) | (0.15) | (2.53) | (0.15) | (0.15) |
| Rate | 0.04 | 0.24 | 1.20* | −0.53 | 0.02 | 0.50 | −1.31*** |
| | (0.10) | (0.97) | (0.62) | (0.37) | (1.20) | (0.46) | (0.50) |
| Rate (squared) | | | | 0.28 | 0.82 | −0.26 | 0.70* |
| | | | | (0.27) | (0.89) | (0.32) | (0.37) |
| Redist. 100% — Sub. 0% | −0.64*** | −2.54 | 1.15 | −0.75*** | −7.44*** | −1.14*** | −0.29 |
| | (0.18) | (1.72) | (1.03) | (0.23) | (2.43) | (0.31) | (0.27) |
| Redist. 67% — Sub. 33% | Ref. | Ref. | Ref. | Ref. | Ref. | Ref. | Ref. |
| Redist. 33% — Sub. 67% | −0.11 | −0.29 | 0.07 | −0.15 | −0.04 | −0.33 | 0.05 |
| | (0.19) | (1.77) | (0.49) | (0.24) | (0.65) | (0.31) | (0.29) |
| Redist. 0% — Sub. 100% | −0.25 | 0.35 | 3.69** | −0.09 | −2.01** | −0.23 | −0.48* |
| | (0.16) | (1.86) | (1.75) | (0.23) | (0.89) | (0.26) | (0.29) |
| Redistribution: Uniform | Ref. | Ref. | Ref. | Ref. | Ref. | Ref. | Ref. |
| Redistribution: Progressive | 0.27* | 1.63 | 2.71** | 0.29 | 0.31 | 0.64*** | −0.19 |
| | (0.14) | (1.44) | (1.10) | (0.19) | (0.63) | (0.23) | (0.24) |
| Subsidies: Building Program | Ref. | Ref. | Ref. | Ref. | Ref. | Ref. | Ref. |
| Subsidies: Foreign aid | −0.42** | 0.80 | 2.70** | −0.72*** | 3.59 | −0.54** | −0.49 |
| | (0.18) | (2.05) | (1.33) | (0.25) | (2.56) | (0.26) | (0.37) |
| Subsidies: Local initiatives | −0.08 | 0.45 | 2.79*** | −0.39* | 3.87 | 0.02 | −0.11 |
| | (0.14) | (1.33) | (1.07) | (0.20) | (2.50) | (0.25) | (0.22) |
| Obs. | 1645 | 1645 | | 1645 | | 1645 | |
| McFadden's $R^2$ | 0.03 | 0.12 | | 0.10 | | 0.06 | |
| AIC | 2235.64 | 2158.10 | | 2115.78 | | 2185.14 | |
| CAIC | 2286.88 | 2670.54 | | 2288.73 | | 2300.44 | |
| BIC | 2278.88 | 2590.54 | | 2261.73 | | 2282.44 | |
| Adj. BIC | 2253.47 | 2336.39 | | 2175.95 | | 2225.25 | |

Notes: ****p*-value < 0.01; ***p*-value < 0.05; **p*-value < 0.1. 1000 MLHS (Hess et al., 2006) inter-individual draws have been generated for random parameters in the Mixed model.

Table 3.10: Results: vote preferences

close to 0 in this case. The absence of subsidies or their use for foreign environmental aid lower the propensity of the *Pro-reform* to vote *Yes*, as is an increase in the tax rate for the *Anti-reform*. Redistributing proceeds as an inverse function of income also increases the probability that the *Pro-reform* vote *Yes* in a referendum. Overall, the *Pro-reform* display global support for the $CO_2$ levy; the *Anti-reform* seem however not to support it, or at least to be indifferent or undecided.

In terms of statistical performance, the Mixed model is less powerful than the two LC models, which supports our prior that heterogeneity tends to be clustered rather than continuously distributed across respondents. Our preference for latent classes is again confirmed in this case, although their capacity to explain differences in voting behaviors is not very strong.

## 3.6 Analysis of the June 2021 referendum

On June 13, 2021, the Swiss population was asked to vote on the proposed reform of the Federal Act on the Reduction of $CO_2$ emissions[22]. The reform included an increase in the maximum rate of the $CO_2$ levy to CHF 210, a CHF 30 to 120 tax on flight tickets, and an increase in the mineral oil tax of maximum 12 cents per liter, which would be used to compensate fossil fuel sellers for the investments they are legally forced to make to reduce the emissions of $CO_2$ caused by the consumption of the fuels they sell. The new $CO_2$ Act would also set the new emissions abatement target to be reached by 2030: a 50% reduction with respect to $CO_2$ emissions from 1990. Although the reform differed from the hypothetical situation used in the DCE analyzed in this chapter in that it included additional taxes, it was mostly framed as a referendum on the $CO_2$ levy and an increase in its rate—i.e., a vote on a deepening of carbon taxation in Switzerland.

Udris (2021) analyzes Swiss media's coverage of the vote on the $CO_2$ Act reform. He notes that media coverage was relatively high before the vote in comparison to other federal votes of the preceding 3 years. The advertisement campaign on that referendum was also one of the strongest since 2013 and was mainly led by the reform proponents (Heidelberger and Bühlmann, 2021). Media were on average positive about the reform, with only one newspaper expressing mostly negative view about it[23]. Udris also reports that the question of the additional costs induced by a higher $CO_2$ levy received significant media attention, as it was the main line of arguments of the opponents to the reform. Although many media balanced this argument with references to the redistribution of the tax revenue, only few of them criticized this framing of the question: the fact that an effective climate policy would necessarily imply additional costs, at least in the short term, has seldom been reported. Finally, Udris highlights that comments in media from politicians, as well as from economic and civil society actors, were mostly positive, except those from the Swiss People's Party (a populist right-wing party) and from economic actors and lobbies. He nevertheless also underlines that the generally positive comments from other center and right-wing party representatives did not necessarily reflect the views of their voter base, which was more critical of the reform. Even though media and politicians were mostly positive regarding the $CO_2$ Act reform, the actual opinion of voters remained relatively uncertain before the vote.

The outcome of the referendum was a rejection by 51.6% of voters, with a participation rate of 59.7%. Figure 3.3 displays voting outcomes by districts: in those in green, a majority of voters accepted the reform, whereas in those in purple, a majority rejected it—the darker the color, the larger the majority. As can be seen, support for the reform was stronger in urban areas, whereas it was significantly lower in more rural parts of the country.

The outcome of the referendum corroborates the mixed results from the voting experiment presented in Section 3.5.4, with the *Anti-reform* ending up voting against the new $CO_2$ levy while the *Pro-reform* voted in its favor. The difficulty to predict the outcome of this vote is reflected by the fact that only a small majority of voters rejected the reform, which could hardly be foreseen.

[22]At the same time, votes were held on the COVID-19 Act, the Federal Act on Police Measures to Combat Terrorism, and two popular initiatives against the use of pesticides and water pollution. It was thus not the sole important topic discussed in political debates at that time.

[23]It was the *Weltwoche*, a weekly newspaper owned and edited by the Swiss People's Party's member and National councilor Roger Köppel. The Swiss People's Party was the only governing party at the federal level to reject the reform.

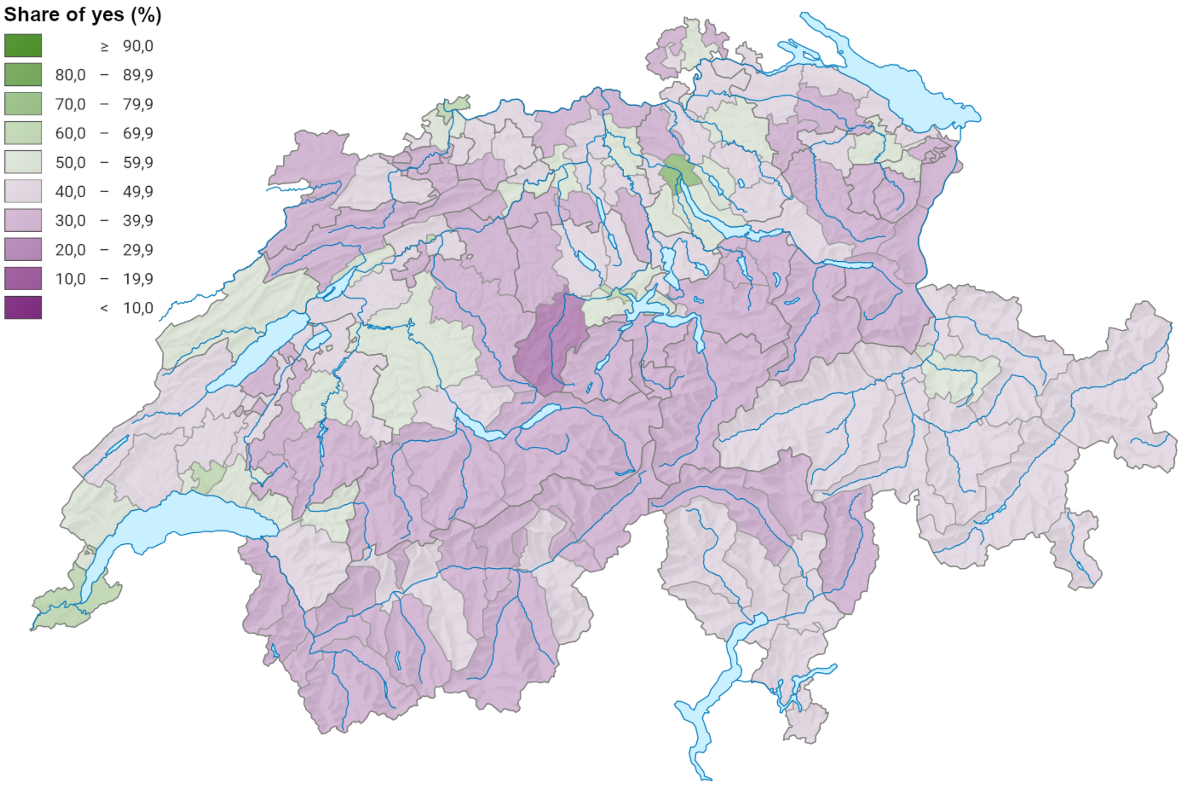



Figure 3.3: Results of the June 2021 referendum on the $CO_2$ levy by district

Source: Swiss Federal Statistical Office, *Swiss Political Atlas*, available at:
`https://www.atlas.bfs.admin.ch/maps/12/fr/16066_15864_15863_259/25039.html` [accessed May 11, 2022].

The role of individual-level factors to explain support to the reform can be investigated thanks to survey data collected after the referendum as part of the VOX project, which analyzes the outcomes of all federal votes in Switzerland by mandate of the Federal Council. The VOX data are currently gathered and analyzed by the private company GFS.Bern (see GFS.Bern, 2021) and made public online[24]. It is thus possible to use them to carry out a regression analysis in order to estimate the effects of factors similar to those used in the DCE. The results of the logistic regression of the vote on the reform of the $CO_2$ levy[25] are displayed in Table 3.11.

The comparison between the first specification and the two others is interesting: when only demographic variables are considered, being a female has a strongly significant positive effect on the probability of voting in favor of the reform, as is having a tertiary level of education. However, when variables related to political preferences, trust, and values, are included, the influence of sex vanishes and that of education decreases in magnitude, while these new variables all have significant effects. Unsurprisingly, the more a respondent lies to the right of the political spectrum, the less likely she is to support the reform. On the other hand, preferring a country that prioritizes environmental protection over economic interests increases the probability of voting *Yes*, and trust in science and the Federal Council is related to a higher level of support. The increase in McFadden's pseudo-$R^2$ also shows that the inclusion of these additional variables

[24]Geographical information on respondents is however not freely available.

[25]The dependent variable is a dummy equal to 1 if the respondent voted in favor of the reform and 0 if she voted against. Respondents who did not vote or who abstained have been removed from the sample.

| | (1) | (2) | (3) |
|---|---|---|---|
| Constant | −0.426*** | 1.006*** | 0.104 |
| | (0.105) | (0.293) | (0.339) |
| Female | 0.335*** | −0.035 | 0.038 |
| | (0.088) | (0.120) | (0.129) |
| Age: 18-34 | 0.061 | −0.100 | 0.003 |
| | (0.129) | (0.175) | (0.188) |
| Age: 55+ | 0.028 | 0.030 | 0.035 |
| | (0.100) | (0.133) | (0.144) |
| Tertiary education | 0.694*** | 0.477*** | 0.375*** |
| | (0.090) | (0.122) | (0.132) |
| Political orientation | | −0.530*** | −0.355*** |
| | | (0.035) | (0.044) |
| Trust in Federcal Council | | 0.426*** | 0.339** |
| | | (0.140) | (0.154) |
| Trust in science | | 0.771*** | 0.656*** |
| | | (0.149) | (0.163) |
| Environment > Economy | | 1.162*** | 0.991*** |
| | | (0.129) | (0.137) |
| Swiss People's Party | | | −0.837*** |
| | | | (0.232) |
| The Liberals | | | −0.013 |
| | | | (0.191) |
| The Center | | | 0.194 |
| | | | (0.199) |
| Green Liberal Party | | | 1.269*** |
| | | | (0.264) |
| Social Democratic Party | | | 1.119*** |
| | | | (0.226) |
| Green Party | | | 2.781*** |
| | | | (0.528) |
| Obs. | 2201 | 1830 | 1728 |
| McFadden $R^2$ | 0.023 | 0.287 | 0.338 |

Notes: ****p*-value < 0.01; ***p*-value < 0.05; **p*-value < 0.1. The reference category for political parties comprises the nonaligned and people who identify with more than one party.

Table 3.11: VOX regression results

strongly increases the relative difference in log-likelihoods between the null and the proposed models—that is, Models (2) and (3) better predict the response pattern than Model (1).

When dummies for the main political parties represented in the Federal Assembly are included, they highlight the antagonism of preferences between those who identify with left-wing parties (Social Democratic Party, Green Party) and ecologist parties (Green Party, Green Liberal Party), and those who identify with the main party that rejected the new $CO_2$ levy, i.e., the Swiss People's Party. Respondents identifying with the two main center-right parties (The Center[26] and The Liberals) do not display different preferences from the reference category, which consists in the nonaligned and those who identify with more than one party. This illustrates the division of voting intentions within these parties, between the official support of the parties themselves and mixed intentions of their members, as underlined by Udris (2021).

[26]The Center is the new party resulting from the merger of the Christian Democratic People's Party and the Conservative Democratic Party. Some local sections of these parties have not changed name or merged, but respondents who answer identifying with either of them are treated as identifying with The Center.

The analysis carried out by GFS.Bern (2021) with the VOX data gives the same results as those presented above. The authors of this study report that socioeconomic and demographic variables are only weakly associated with vote decisions. On the other hand, they find that political preferences, trust in climate experts and environmental associations, and preferring environmental protection to economic prosperity are all positively correlated to voting *Yes* to the $CO_2$ Act reform. A majority of survey respondents who supported the reform indicated that environmental protection was the main reason for their vote. For their opponents, the main reasons for their rejection of the reform were economic, e.g., that the cost-benefit ratio for the reform was not correct, but other types of reasons like general considerations on the quality of the $CO_2$ Act or the respondent's sympathy for it also played an important role. The agreement of respondents to different arguments in favor or against the Act also highlights the division of voters, in that arguments for the reform found a large majority to back them among *Yes* voters, whereas arguments against the reform were generally well accepted by its opponents. The polarization of opinions shown by GFS.Bern (2021) is consistent with the DCE results presented in Section 3.5 and with the analysis of VOX data carried out above.

On top of the role played by aforementioned individual-level factors, it should be noted that the outcome of the vote may have been influenced by the other objects in ballots at the same time. In particular, the opposition from inhabitants of rural areas and farmers to the two initiatives on pesticides and water pollution, which are also environment-related topics, could have fueled the *No* to the reform of the $CO_2$ Act (Stadelmann-Steffen and Rihm, 2022). The context in which the vote happened is thus likely to have influenced voting behaviors and hence the fate of the reform, given the small margin of victory for its opponents.

Overall, the importance of political, perception-related, and attitudinal factors seems higher than that of socioeconomic ones, which is also the conclusion of GFS.Bern (2021). Support for a more ambitious taxation of $CO_2$ emissions therefore depends mostly on values and not so much on inherent characteristics such as sex or age. This finding corroborates the fact that only few of the coefficients of individual-level socioeconomic variables used in the analysis of the DCE data are significant. Although political orientation here seems to be one of the main predictors of vote, it should be underlined that all coefficients show *ceteris paribus* marginal effects. If environmental preferences had been solely determined by political orientation, then correlations between these variables would have probably interfered. Environmental concern is therefore not only a matter of preference for the left or the right of the political spectrum. Its impact on preferences regarding carbon taxes deserves to be assessed beyond political partisanship.

## 3.7 Conclusion

Carbon taxation is an important instrument used by governments trying to implement an energy transition. Public opinion, however, is not always favorable and the literature demonstrates the breadth of individual heterogeneity in this domain. DCE is a powerful tool to identify various sources of heterogeneity as well as moderating effects in valuation of policy attributes. We illustrate the extent of individual heterogeneity and how to adequately model it with several econometric methods using an application to the debate on the 2020 Swiss $CO_2$ levy reform. Focusing on measures of acceptance and support, we implement two choice experiments in an online survey answered by 586 respondents. The first experiment, aimed at measuring acceptance, is based on preferences between randomly assigned taxation schemes, while the second focuses on a support measure through a hypothetical voting exercise. Overall, our results favor LC models that can classify the individuals into distinctive clusters with relatively homogeneous preferences.

We identify two classes of respondents, which can be described as roughly corresponding to *Pro-tax reform* and the *Anti-tax reform* citizen profiles, given their respective preferences. The *Pro-tax reform* display also more environmentalist perceptions and attitudes than the *Anti-tax reform*. While showing contrasting policy preferences with regard to key attributes of a carbon tax, this grouping goes beyond the usual left-right political divisions, although political orientation still plays a more important role than, e.g., socioeconomic and demographic factors. The *ex-post* analysis of the June 13 referendum with the VOX data supports the results of the DCE, in particular regarding the heterogeneity of preferences and their clustering in two opposing groups. Explaining the origin of this heterogeneity through the variables included in the LCA estimation procedure helps to understand the ideological structure of public opinion and the social context surrounding its expression. Accounting for such factors is crucial to analyze and characterize preferences for environmental policy attributes, and we recommend that future studies in this area pay a more systematic attention to it.

The results from our LC models have substantial policy implications, in that gaining support from one social group might cost support from another. This finding highlights the diversity of environmental preferences and their inherent oppositions, an important aspect of political acceptance in a democratic context, which could be overlooked with less sophisticated models. While our acceptance experiment identifies two clearly defined preference groups, the hypothetical voting exercise is less conclusive, calling for further research on differences between acceptance and active support with respect to carbon taxes. In particular, preference formation processes (see Druckman and Lupia, 2000) should be investigated further in the context of environmental policy, so that support and resistance to carbon taxes are better understood.

From a policy perspective, our findings point to three important conclusions for Switzerland and, by extension, to other countries. First, given that the optimal tax rate diverges between the two identified groups, increasing the current rate, as is planned by the Federal Assembly, might not receive support from a majority of the population. Second, the extent of the presence of environmentalism in the political arena, beyond left-right divisions, should not be underestimated. The diversity of preferences should be taken into account when designing carbon taxation instruments, as populations in countries with different political cultures and preferences might respond differently to a similar policy proposal. Finally, overcoming the opposition between preference groups might prove challenging, if not impossible, because of the degree of polarization between their opinions. The framing of political objects such as carbon taxes therefore require some precaution to avoid being trapped between two lines of arguments with no common ground for a compromise.

## 3.A Appendix A: List of variables

| Exogenous covariates | Scale | Description |
|---|---|---|
| Socioeconomic | | |
| Female | Binary | The respondent is female. |
| Age | Categorical | Age group of the respondent (18-34, 35-54, 55+). |
| Tertiary edu. | Binary | The respondent has a tertiary level of education. |
| Geographic | | |
| Residential env. | Categorical | The type of area in which the respondent lives (city, agglomeration, countryside). |
| Romandie | Binary | The respondent lives in the French-speaking part of Switzerland. |
| Political | | |
| Pol. orientation | 1–8 | The respondent's self-placement on a left-right political scale (far left–far right). |
| **Clustering variables** | | |
| Env. adaptation | 1–3 | The respondent claims she is ready to take steps to adopt environmentally friendly behaviors even if it causes daily inconveniences (not ready–uncertain–ready). |
| Inability to abate | 1–3 | The respondent agrees that she cannot do much to lower her $CO_2$ emissions (no–unsure–yes). |
| Trust in scientists | 1–3 | The respondent's level of trust for information from scientists on energy and energy-saving (low–medium–high). |
| Eff. of carbon tax | Categorical | The respondent believes that taxing $CO_2$ emissions is effective to push individuals and firms to lower their $CO_2$ emissions (never–individuals only–firms only–always). |
| Support climate strikes | 1–3 | The respondent supports the *School strike for climate* movement (no–unsure–yes). |

Table 3.A.1: Variables used in LCA

## 3.B Appendix B: Supplementary tables

| | SQ | Rate | Red. 100% Sub. 0% | Red. 33% Sub. 66% | Red. 0% Sub. 100% | Red.: Prog. | Sub.: F.A. | Sub.: Local in. |
|---|---|---|---|---|---|---|---|---|
| Female | −0.21 | −0.57** | −0.17 | 0.11 | 0.27 | −0.13 | 0.11 | 0.55* |
| | (0.32) | (0.24) | (0.36) | (0.33) | (0.31) | (0.25) | (0.34) | (0.28) |
| Age: 18-34 | −0.16 | −0.11 | −0.14 | 0.18 | 0.01 | 0.17 | 0.84** | 0.39 |
| | (0.41) | (0.31) | (0.47) | (0.39) | (0.40) | (0.32) | (0.43) | (0.37) |
| Age: 55+ | 0.31 | −0.27 | −0.20 | 0.16 | 0.20 | −0.31 | −0.49 | −0.28 |
| | (0.35) | (0.27) | (0.41) | (0.38) | (0.35) | (0.29) | (0.41) | (0.32) |
| Tertiary edu. | −0.12 | 0.56** | −0.59 | 0.24 | −0.27 | −0.08 | −0.56 | −0.33 |
| | (0.31) | (0.24) | (0.37) | (0.32) | (0.31) | (0.25) | (0.35) | (0.28) |
| City | 0.05 | 0.51* | −0.05 | 0.61 | 0.14 | 0.15 | 0.55 | 0.05 |
| | (0.39) | (0.28) | (0.45) | (0.39) | (0.38) | (0.30) | (0.44) | (0.34) |
| Countryside | −0.21 | 0.05 | −0.47 | −0.07 | 0.07 | 0.63* | 0.44 | 0.05 |
| | (0.46) | (0.31) | (0.54) | (0.47) | (0.44) | (0.36) | (0.51) | (0.42) |
| Romandie | 0.57 | −0.27 | 0.11 | 0.64* | 0.56 | 0.17 | −0.03 | 0.73** |
| | (0.36) | (0.26) | (0.40) | (0.37) | (0.34) | (0.28) | (0.42) | (0.30) |
| Pol. orientation | 0.07 | −0.35*** | 0.06 | 0.00 | −0.02 | −0.24*** | −0.21** | −0.16* |
| | (0.09) | (0.08) | (0.11) | (0.10) | (0.09) | (0.08) | (0.11) | (0.09) |

Notes: ***$p$-value < 0.01; **$p$-value < 0.05; *$p$-value < 0.1.

Table 3.B.2: Mixed logit covariates: choice preferences

| | Cons. | Rate | Red. 100% Sub. 0% | Red. 33% Sub. 66% | Red. 0% Sub. 100% | Red.: Prog. | Sub.: F.A. | Sub.: Local in. |
|---|---|---|---|---|---|---|---|---|
| Female | 0.02 | −0.04 | 0.35 | 0.14 | −1.22 | −0.55 | −0.70 | −0.11 |
| | (0.33) | (0.49) | (0.75) | (0.83) | (0.97) | (0.72) | (1.05) | (0.75) |
| Age: 18-34 | −1.11** | 0.03 | −0.65 | −0.23 | −1.51 | 1.44 | 2.11* | 1.84* |
| | (0.45) | (0.63) | (0.97) | (0.94) | (1.29) | (1.01) | (1.20) | (1.07) |
| Age: 55+ | 0.22 | 0.71 | −1.77* | −0.89 | −1.52 | −0.40 | 0.22 | 1.01 |
| | (0.37) | (0.58) | (0.91) | (0.92) | (1.09) | (0.80) | (1.17) | (0.88) |
| Tertiary edu. | 0.32 | 0.35 | −0.04 | 0.37 | 0.10 | −0.16 | 1.38 | 0.06 |
| | (0.33) | (0.50) | (0.77) | (0.81) | (0.99) | (0.71) | (1.05) | (0.73) |
| City | 0.02 | −0.24 | −0.72 | 0.23 | 1.58 | −0.41 | −2.04 | −0.05 |
| | (0.38) | (0.61) | (0.84) | (0.93) | (1.19) | (0.84) | (1.38) | (0.92) |
| Countryside | −0.72 | −1.07 | 0.79 | 1.39 | 0.76 | −0.55 | −1.03 | 0.28 |
| | (0.46) | (0.80) | (1.13) | (1.22) | (1.29) | (0.97) | (1.62) | (1.09) |
| Romandie | 0.13 | −0.22 | 0.16 | 1.22 | 0.07 | −0.06 | −1.35 | −0.23 |
| | (0.38) | (0.55) | (0.86) | (1.01) | (0.98) | (0.90) | (1.20) | (0.86) |
| Pol. orientation | 0.03 | −0.14 | 0.50** | −0.08 | −0.09 | −0.13 | −0.20 | −0.24 |
| | (0.10) | (0.15) | (0.25) | (0.26) | (0.30) | (0.21) | (0.33) | (0.22) |

Notes: ***$p$-value < 0.01; **$p$-value < 0.05; *$p$-value < 0.1.

Table 3.B.3: Mixed logit covariates: vote preferences

# General conclusion

## 4.1 Main contributions

In this thesis' introduction, three interrelated research questions are raised. The first one is the viability of carbon taxes as means to raise fiscal revenue in the long term as part of an environmental tax reform. It is an important issue to consider, given that this revenue can be used to cut preexisting distortionary taxes, but also to support GHG emissions abatement projects, which are necessary to tackle anthropogenic climate change. The problem is that carbon taxes, like most environmental taxes, are meant to boost the reduction of their base: the final goal of a $CO_2$ tax as an instrument of climate policy is to help eventually reaching carbon neutrality, which means its tax base would completely vanish in the long term partly due to the tax itself. If the revenue from carbon taxation is used to cut other taxes, it means that environmental tax reform is not sustainable from a fiscal perspective, as previously cut taxes might need to be reestablished to collect enough revenue, which would have a detrimental impact on production and probably cause a loss of efficiency in the economy.

As a solution, Chapter 1 proposes a model based on the production function proposed by Keen et al. (2019), which includes energy as a necessary input to capital. Energy is modeled as coming from either fossil fuels or renewables, with distinctive U-shaped unit cost functions for each, so that it is rational and effective to use both sources of energy in the profit maximization process. The model suggests to progressively turn to the taxation of renewable energy sources as the use of fossil energy shrinks. Levying a $CO_2$ tax is equivalent to levying a unit tax on fossil fuels with different rates depending on the precise fuel considered and its carbon content: taxing $CO_2$ therefore means taxing fossil energy. The point is that energy is a necessary input to production: without energy of any kind, there is no production process. Energy required to activate physical capital is particularly needed and will always be—a machine cannot move without energy, just like humans need the energy they generate from food to live and move.

The necessity of using energy to produce implies that it can form a relatively stable and reliable tax base in the long term, as other production inputs cannot easily be substituted to it. It is hence possible to tax $CO_2$ emissions to encourage the transition from fossil fuels to renewables while at the same time starting to tax renewables to collect new fiscal revenue instead of increasing, e.g., taxes on consumption or income. The stability of fiscal revenue is also important because revenue from taxes on fossil fuels is often used to finance emissions abatement programs such as building refurbishments, as well as public infrastructures like roads. The taxation of renewables can also be justified from a Pigovian point of view, as generating energy with technologies like solar panels or wind turbines causes negative externalities: increase in land use, threats to biodiversity, landscape, and built heritage, use of polluting products to construct them, and so on. On principle, it can therefore be efficient to tax renewables, just like it is for fossil fuels.

Numerical simulations illustrate that it is possible to substitute taxes on energy to taxes on consumption or income without causing any damage to the economy if energy efficiency improves over time. The point is that energy demand is quite inelastic in the long term because it depends on the amount of capital used, as well as on its energy intensity and its energy efficiency. To produce more while using less energy, improvements in energy efficiency are required by design, which is intuitive. Environmental tax reform therefore needs enhancements in energy efficiency to be more effective.

Although the first chapter mainly focuses on theoretical considerations related to the use of revenue from carbon taxes, it also questions their environmental effectiveness. Whereas theory and *ex-ante* simulations usually predict that higher fossil fuel prices should provoke a transition to other energy sources, the low price-elasticity of energy use from all sources, especially in the short term (see Labandeira et al., 2017), questions this argument. There is also a lack of *ex-post* empirical investigations on the effectiveness of real-world carbon taxes from an environmental point of view. As can be seen in the recent review by Green (2021), such studies are scarce, especially at a microeconomic level, so that the real world effectiveness of $CO_2$ taxation still needs to be analyzed from new perspectives. It is precisely this gap in the literature that Chapter 2 contributes to fill. In this chapter, the short-term impact of the Swiss $CO_2$ levy on households' energy demand for heating and warm water is considered. The $CO_2$ levy only applies to non-motor fossil fuels, so that households are directly affected by it mainly through their use of heating oil and natural gas for heat generation.

With survey data covering the period running from 2016 to 2020, a difference-in-differences regression model is run to try to identify the effect on fossil fuel consumption of the 2016 and 2018 $CO_2$ levy rate increases. The treatment group consists of fossil fuel users, whereas the control groups is made of households whose heating systems rely on other, non-fossil technologies such as heat pumps or wood. Inverse probability of treatment weights are introduced in the estimation procedure to improve the balance of the distribution of covariates between the treatment and control groups to make them more comparable.

Results show that none of the two tax rate increases had any short-term impact on real heating and warm water expenditures in the treatment group with respect to the control group, although they decreased over the years in both groups. This finding does not rule out the possibility of longer-term effects on households, but existing limits and constraints on households' heating demand could hinder their actions. The fact that most households in Switzerland do not own their home or live in apartments, and therefore cannot freely choose or renovate their heating systems, is one impediment, as is the fact that many households' heating expenditures are set independently from their direct energy use, so that the tax lacks incentivizing power. The lack of salience of the $CO_2$ levy might also be to blame. In conclusion, the $CO_2$ levy might not be well designed to impact households, so that its environmental effectiveness seems limited on that regard.

An apparent lack of effectiveness can be an issue regarding this thesis' third research question: the acceptance of carbon taxes by the general public. As argued in the general introduction, once implemented, a policy needs to be accepted by the people to survive, and its reforms must also receive enough support to be accepted and effectively implemented. Chapter 3 investigates this topic by combining both an experimental approach and a short analysis of the results of the June 13, 2021, referendum on the reform of the $CO_2$ Act in Switzerland. Although the acceptance of carbon taxes already received the attention of many researchers, most studies either consider preferences for policy design features or the impact of individual-level factors on support for carbon taxation in general. However, the interaction between the two (individual and policy-level factors) has barely been investigated. The contribution of this chapter to the literature is thus to bridge this gap.

Data from a discrete choice experiment based on the then ongoing reform of the Swiss $CO_2$ levy are analyzed with the help of two types of econometric approaches aiming at representing preferences while accounting for heterogeneity between individuals: random coefficients (or mixed) and latent class logistic regression models. If random coefficients assume that heterogeneity is continuously distributed among individuals according to a predetermined density function, latent classes model heterogeneity as discretely distributed, with no specific assumption on the functional form of the distribution. The latter approach is preferred as it provides more meaningful results by revealing how preferences diverge between two social groups with identifiable characteristics: the *Pro-reform* and the *Anti-reform*. The former group is generally more left-leaning and more environmentally concerned, whereas the second group is politically more rightist and more neutral regarding environmental issues. Socioeconomic factors do not play a significant role in the determination of the two groups.

Preferences for carbon tax attributes in the *Pro-reform* group show that it supports an increase in the maximum rate, which is a new and interesting finding with regard to previous literature, where a higher rate is generally associated with a decrease in support. On the other hand, the *Anti-reform* stick to the *status quo*, i.e., the current situation in 2019. Given the relatively even representation of the two groups among respondents, no clear-cut prediction regarding a referendum on the $CO_2$ levy reform could be made.

The actual referendum on the new version of the $CO_2$ levy took place on June 13, 2021, and resulted in a loss by a small margin of the reform proponents. Political preferences are the main explanatory factor, with a clear support from the left and mixed-to-negative reactions from the right. Again, socioeconomic factors do not significantly affect voting behavior—at least directly. Support for more ambitious carbon taxation policies therefore needs an overcoming of left-right political divides to gain in feasibility in a democratic context.

The overall conclusion of the three aforementioned chapters is that carbon taxation is a multi-faceted topic that raises many different issues at every stage of its existence: inception, design, implementation, application, evolution. All these issues are interrelated: theoretical considerations influence the design of carbon taxes, which then impact their effectiveness. Effectiveness is crucial to their acceptance by the public, and thus to their political survival. Public opinion is also not neutral *vis-à-vis* the design and features of carbon taxes. Anticipations by policy-makers of forthcoming difficulties to gain support from the public shape the design of $CO_2$ taxes, as are effectiveness considerations. The whole process of creating a real-world carbon tax is therefore iterative, and all stages matter. Results gathered and presented in this thesis might only be drops in the ocean of scientific knowledge on carbon taxation, yet they can help it not to dry out with time. The contributions of the present collection of studies show that there are still new elements to analyze and learn on $CO_2$ taxes to make them better policy instruments for the common good.

## 4.2 Policy recommendations for Switzerland and abroad

Throughout this thesis, Switzerland has served as case study to test research hypotheses and draw conclusions and policy recommendations. Switzerland is indeed an interesting case for policy evaluations because of its application of direct democracy principles, which reinforce the need for both acceptable and effective policies. Thanks to this focus, it is possible to gather all the findings from the three chapters to make a few policy recommendations on carbon taxation in general and the Swiss $CO_2$ levy in particular.

A first observation is that climate policy in Switzerland is not well harmonized. Several policies exist in parallel to cover relevant sectors (see Swiss Federal Office for the Environment, 2018), but they do not necessarily take into account other policies that either indirectly do contribute to reducing $CO_2$ emissions or that oppose climate policy instruments. A good example is the mineral oil tax: it increases the market price of gasoline and diesel, which can be expected to have a negative impact on their use, like a carbon tax. Although it is not designed as a climate policy instrument, it implicitly acts like one. However, revenue from this tax is used to maintain and develop Swiss roads, which encourages their use instead of favoring modes of transport that do not consume fossil fuels such as trains. Moreover, because of the mineral oil tax, the $CO_2$ levy does not apply to fossil motor fuels. From a climate policy perspective, the mineral oil tax is therefore somewhat aberrant. Given that transport is the main source of $CO_2$ emissions in Switzerland, as shown in the general introduction, this situation hinders the effectiveness of climate policy as a whole.

Considering all existing instruments, even those that are not explicitly designed as climate policies, and ensuring their harmonization and coherence are primordial to effectively achieve Switzerland's climate goals. Existing fossil fuel subsidies, even if they are indirect (see OECD, 2022), should also be removed, because they undermine the effects of climate policy instruments. In short, climate policy should not be considered as a mere addition to already existing policies, but it should encompass them all in a coherent unified framework.

The Swiss Federal Council (2022) has submitted it plan for the 2024 complete overhaul of the $CO_2$ Act to the Federal Assembly. The main difference with the rejected 2021 reform is that "push" measures such as a higher $CO_2$ levy rate or a tax on flight tickets have been scrapped in favor of "pull" measures such as more subsidies for energy-efficient renovations, charging stations for electric vehicles, or the replacement of heating systems working with fossil fuels. There should also be an extension of exemption possibilities for firms wishing not to pay the $CO_2$ levy by committing to reduce their $CO_2$ emissions: all companies should be able to apply for an exemption, not only energy-intensive ones or those operating in specific economic sectors.

This change of paradigm can be expected to have significant implications regarding the direction of climate policy in the coming years. The partial renouncement to the polluter-payer principle by extending exemptions to paying the $CO_2$ levy might have perverse side-effects: indeed, the Buildings Program that supports energy-efficient renovations is funded by the revenue from the $CO_2$ levy. The Federal Council also suggests to increase the share of revenue from the $CO_2$ levy allocated to this program from one third to 49%, with no cap on the maximum amount. This means that the Buildings Program funded by the $CO_2$ levy is a central piece of Switzerland's future climate strategy. Yet, extending exemptions for firms implies that revenue from the $CO_2$ levy can be expected to decrease quite significantly after their acceptance. Moreover, if the

Buildings Program is effective, $CO_2$ emissions from the residential sector should also decrease, so that less tax proceeds are available to finance new investments, although they are still needed. The pace of renovations might thus slow down even though it should be sustained at a high speed to fulfill the goal of reaching zero net $CO_2$ emissions by 2050.

Another issue regarding the extension of exemptions to the $CO_2$ levy is that it is unknown whether the $CO_2$ abatement plans undertaken by companies to lower the emissions are more effective than forcing them to pay the $CO_2$ levy in environmental terms. Finally, there are fairness issues related to these exemptions in that they only concern firms. Households have no choice but to pay the tax. The only way for them to avoid it is to change their heating systems. The problem is that only a minority of Swiss households own their home and can therefore take such decision: in 2020, home owners only represented 36.2% of all households, of which one third own an apartment, not a house[27]. The decision power of most households is hence close to nil regarding their heating systems. These households nevertheless pay for the Buildings Program, but they are not certain to benefit from it, neither are they free to change their heating systems and not pay the $CO_2$ levy anymore. The implications of the $CO_2$ levy are thus very different across taxpayers, causing a potential inequality of treatment among them. The 2024 $CO_2$ Act does not address these issues, and even reinforces them, to some extent. Focusing on "pull" measures also raises some questions regarding the effectiveness of the reform in the absence of significant coercive measures as complements to incentives. The financing of all proposed subsidies is an issue worth mentioning here, too.

In fact, one problem with the $CO_2$ levy, and carbon taxes in general, is that international fossil fuel prices have usually more visible impacts on market prices than carbon tax rates, as highlighted in Figure 2.1 in Chapter 2. It is the case because of frequent fluctuations as well as potentially large changes in international prices, which can completely offset carbon taxes' impact on prices, like at the end of 2014. It becomes harder to nudge people and firms with taxes if their price effects are not easily noticed. An optimal planning of $CO_2$ emissions abatement over the long term is hence complicated to achieve because of these uncertainties.

If one wishes to improve the predictability of future fossil fuel prices to allow for a better planning of carbon emissions reduction over time, a solution would be to implement a dynamically adjusting tax on all fossil fuels. The tax rate would be equal to the difference between a predetermined final fuel price and the current fuel price before taxes. The idea would be to control the market price of fossil fuels over time so as to progressively increase it and encourage the transition to non-fossil energy sources[28]. Future fossil fuel prices would thus be fully predictable, so that an optimal $CO_2$ emissions reduction strategy can be planned by all economic agents with little to no uncertainty over it. It would hence be possible to set the final market prices of fossil fuels at a level compatible with the Paris Agreement targets. Such a strategy could even be extended at an international level, with a harmonized price of $CO_2$ emissions[29] that would help to prevent the relocation of polluting activities to countries with low carbon prices—i.e., carbon leakages.

[27]See https://www.bfs.admin.ch/bfs/fr/home/statistiques/construction-logement/logements/conditions-habitation/locataires-proprietaires.assetdetail.21245849.html [accessed October 29, 2022].

[28]In such as system, it could be possible that fossil fuels are momentarily subsidized, though, depending on exogenous price fluctuations.

[29]OECD's minimum corporate tax could be an inspiration in that regard.

Carbon leakages are indeed another point that the 2024 reform of the $CO_2$ Act fails to address properly. No measure is explicitly planned to prevent them, unlike the proposed introduction of the Carbon Border Adjustment Mechanism (CBAM) in the EU[30]. The CBAM is a policy that should be in place from 2026 in the EU to force importers of some carbon-intensive goods to buy carbon certificates equivalent to the difference between the $CO_2$ price paid by the producer and the weekly average auction price of EU ETS allowances. The CBAM should first apply to a small selection of goods: cement, iron and steel, aluminum, fertilizers, and electricity. Switzerland should take inspiration from this mechanism, especially because most of its carbon footprint is composed of $CO_2$ emissions caused abroad (Swiss Federal Office for the Environment, 2018).

In general, a striking feature of climate policies in Switzerland and abroad is their relatively slow reaction time in comparison to the targets they aim to reach. The IPCC already clearly warned about the impact of anthropogenic GHG emissions in 1990 (see IPCC, 1992). The reluctance of policy-makers to undertake ambitious actions to fight climate change since then means that the design of today's climate policies is lagging behind in terms of environmental effectiveness. The fact that the $CO_2$ levy rate has been raised so often because intermediate emissions targets had not been met supports the idea that Switzerland's climate policy is currently not sufficient to reach its goals.

The current energy crisis caused by the Russian invasion of Ukraine in February 2022 highlights how dependent to fossil fuels European economies are. Rising oil and gas prices coupled with the risk of energy shortages provoke a major questioning of Switzerland's reliance on fossil fuels and energy imports[31]. The unintended consequence of this crisis might be that energy transition could be hastening in order to quickly lower the country's dependence on fossil fuels.

Another interesting consequence is that energy conservation measures have been implemented very swiftly, and additional ones might be needed if energy reserves were to shrink too quickly. The impact of these measures will need to be assessed *ex-post*, but the fact that so little time has been necessary to take them in comparison to "official" climate policies from the $CO_2$ Act highlights how political theses issues are. In times of crisis, energy conservation measures are emergency needs. In normal times, they are questions of political preferences, even though scientific evidence on the need to quickly take action to reach carbon neutrality is abundant (see, e.g., IPCC, 2022). The reluctance to make sacrifices today to prevent a forthcoming ecological crisis is puzzling, from this point of view[32]. The political framing of environmental issues is certainly an impediment to a proper transition to clean energy sources and sustainable energy use. It should be a matter of scientific facts, not of politics.

## 4.3 Insights for future research

Since the conclusion of the 2015 Paris Agreement (UNFCCC, 2015), $CO_2$ emissions need not just to be curbed, but to reach a level where they are sufficiently low to be fully compensated by natural and engineered absorption, i.e., carbon neutrality. Carbon taxation is a common

[30]See `https://ec.europa.eu/commission/presscorner/detail/en/qanda_21_3661` [accessed October 29, 2022].

[31]See `https://www.uvek.admin.ch/uvek/en/home/energy/energy-security-ukraine-war.html` [accessed October 29, 2022].

[32]See Swiss Federal Office for the Environment (2022) regarding the reactions to the proposed 2024 reform of the $CO_2$ Act from the main political parties, economic lobbies, and civil society groups.

choice of instrument to reach this goal, usually joint to other measures such as regulation and subsidies, because a carbon tax is unlikely to lead to a complete withdrawal from fossil fuels only by itself. An aspect of carbon taxation that has not been widely investigated is its role *within* a broader package of instruments and measures aiming at fighting anthropogenic climate change. Interactions with other policies would be interesting to consider, because in the real world, $CO_2$ taxation is not the sole tool of environmental policy applied at the same time in a country.

A potential issue is the overlapping of different policies, like taxing emissions already subject to regulation or traded in an emissions trading scheme without adapting the rate in comparison to emissions that are only taxed. If several policies aiming at the same goal are jointly implemented, empirical estimates of the impact of the introduction of a carbon tax might be too optimistic, as they might comprise the role played by other measures. Another potential issue is the opposition between carbon taxes and existing policies such as subsidies or fiscal exemptions regarding energy use: consistency is crucial to an effective decarbonization policy. Analyzing carbon taxes within these complex policy environments could shed new light on the theoretical and practical grounds of carbon taxation.

Another topic needing further research is the estimation of tax-elasticities of $CO_2$ emissions, both at macroeconomic and sectoral levels. Empirical studies of carbon taxes often consider the *presence* of a carbon tax as a binary variable, with little consideration for the impact of the *rate* and its variations on short-term and long-term emissions. The problem of the coverage of and exemptions to carbon taxes also matter, in that it is often difficult, if not impossible, to distinguish between taxed and untaxed $CO_2$ emissions, or to identify which effective tax rate applies to emissions from which source. The types of fossil fuels used are also fundamental, in that carbon taxes are levied on their consumption. Depending on fuel substitution possibilities, the effect of taxing $CO_2$ emissions might be stronger or weaker.

Recent efforts by Rafaty et al. (2020) are important in that regard, because they try to estimate the impact of the effective price of $CO_2$ emissions on them in a set of countries. This is a promising direction for new studies, as there is a real need for tangible numbers on the sensitivity of carbon emissions to their price at different time horizons. Setting the carbon tax rate at the value delivering the intended level of emissions abatement is fundamental from a Pigovian perspective, as welfare maximization stems from the choice of an optimal tax rate. Being able to differentiate between sectors and to dynamically adapt carbon prices to the situation also require reliable empirical estimates of elasticities.

Finally, even though public preferences concerning $CO_2$ taxes have already received a lot of attention, the impact of the social and political environment in which collective preference on carbon taxation is formed should be studied further. Context is a core factor shaping the impact of individual characteristics on preferences for carbon tax attributes: designing a $CO_2$ tax is complex given all the information needed to obtain an optimal balance between contradictory imperatives. Public opinion might nevertheless not support what technocrats consider as optimal. Reaching a consensus, or at least a sufficient majority, to back a policy proposal requires a deep understanding of the context in which public opinion develops. Part of the difficulty of implementing carbon taxes stems from this lack of understanding of the peculiar environment in which each policy proposal is assessed by the public. The role of political parties, institutions, and culture, in particular regarding the relation with environmental issues, should be analyzed in relation to the acceptance or rejection of carbon taxes, both at the conceptual level of being in favor of $CO_2$ taxation *per se* and at the more down-to-earth level of a specific proposal with explicit attributes. Generalizations on the role of specific factors should not be made without enough information on their actual generalizability in terms of transferability to other contexts; otherwise, policy recommendations might fall short of relevance.

Overall, a general direction that new research on carbon taxation could, and certainly should, take is toward accounting for the complexity of studied issues. Simple and clear findings are easier to understand and communicate, but ambitious and effective environmental policy requires precise and detailed results to reach a higher level of knowledge in this area. Comparative studies are fundamental in that regard: they can help identifying the role played by specific elements and their interactions within a broader context. Carbon taxes are usually national or subnational policies implemented without coordination with other jurisdictions, whereas anthropogenic climate change is a global issue needing a global response. Transnational aspects of carbon taxation could highlight their synergies and conflicts in a world in need of ambitious political action to solve one of the biggest challenges humanity ever faced.

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