Efficient and Equitable Policy Design: Taxing Energy Use or Promoting Energy Savings?

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ABSTRACT

Should energy use be lowered by using broad-based taxes or through promoting and mandating energy savings through command-and-control measures and targeted subsidies? We integrate a micro-simulation analysis, based on a representative sample of 9,734 households of the Swiss population, into a numerical general equilibrium model to examine the efficiency and equity implications of these alternative regulatory approaches. We find that at the economy-wide level taxing energy is five times more cost-effective than promoting energy savings. About 36% of households gain under tax-based regulation while virtually all households are worse off under a promotion-based policy. Tax-based regulation, however, yields a substantial dispersion in household-level impacts whereas heterogeneous household types are similarly affected under a promotion-based approach. Our analysis points to important trade-offs between efficiency and equity in environmental policy design.

Keywords: Environmental policy, Instrument choice, Market-based instruments, Command-and-control, Efficiency, Equity, Heterogeneous households, Microsimulation, General equilibrium

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1. INTRODUCTION

Fossil-based energy use generates environmental externalities. Should such energy use be lowered using taxes or through promoting and mandating energy savings? The choice and design of regulatory instruments is a crucial environmental policy decision. The toolkit of instruments comprises two fundamental categories. Market-based instruments (MBIs)—such as, for example, emissions taxes, tradable emissions allowances, and subsidies for pollution abatement—harness and channel the power of the market toward achieving environmental goals through an economic incentives approach to regulation. Command-and-control (CaC) instruments—such as, for example, technology mandates and performance standards—impose requirements on production processes or outputs of firms. In evaluating alternative regulatory strategies, economists have tended to focus on efficiency, or its close relative, cost-effectiveness (Goulder and Parry, 2008; Metcalf, 2009). The public acceptance of a policy, however, often critically depends on its distribution of costs and benefits in society. While recent work has assessed the distributional impacts of MBIs (e.g., Bovenberg

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et al., 2005; Bento et al., 2009; Rausch et al., 2010, 2011; Sterner, 2012; Fullerton and Monti, 2013; Rausch and Schwarz, 2016), surprisingly little is known about the household-level incidence of CaC regulation and potential trade-offs with efficiency at the aggregate economy level. In particular, this is surprising as CaC approaches are ubiquitous in real-world environmental policies in many countries and, in fact, often seem to be the preferred choice over market-based regulation.

This paper contributes by providing insights into the efficiency and distributional impacts of alternative policy designs aimed at lowering energy use and carbon dioxide (CO_2) emissions. We focus on comparing two fundamentally different paradigms of environmental regulation: (1) a *Steering* approach that exploits economic incentives arising from taxes on energy use; and (2) a *Promotion* approach that builds on promoting and mandating measures for saving energy through the use of CaC measures as well as sector-specific subsidy programs. We contribute to the sparse literature on assessing the distributional impacts of non-tax regulation (see Fullerton and Muehlegger, 2017, for an overview). Specifically, our *Promotion* scenario comprises a detailed representation of emissions standards for new passenger vehicles, efficiency standards for electrical appliances, and targeted subsidies to promote energy-saving investments for buildings and industrial electricity use. While our analysis is motivated by and focuses on climate and energy policy in Switzerland (Federal Council, 2015a,b), it offers general insights into the fundamental theme of policy instrument choice and design for efficient and equitable environmental regulation.

Our analysis of assessing the economic efficiency and the incidence among heterogeneous households of various MBIs and CaC measures to reduce energy use is two-pronged. We begin by briefly reviewing the basic conceptual considerations for policy instrument choice and design focusing on describing the channels through which regulation affects economic outcomes. The main contribution of the paper, however, lies in going beyond a mere qualitative understanding of the effects of alternative regulatory measures by providing a quantitative assessment to gauge the importance of the different channels affecting instrument performance in the context of the real economy. We develop a quantitative framework which integrates a detailed micro-household simulation analysis into a numerical multi-commodity general equilibrium framework. Our quantitative framework captures the policy-induced economic responses which determine the efficiency and equity of environmental regulation at the aggregate economy and household level. Specifically, our model features an economy-wide representation of sectoral production and consumption activities—including detail on the supply and use of energy—while capturing cross-market effects as well as aggregate economy resource (income) constraints. Importantly, the model incorporates all 9,734 households from a representative sample of the Swiss household population as individual economic agents, thus enabling us to analyze in rich detail the heterogeneous behavioral responses to and welfare impacts of alternative regulatory designs at the household level in a general equilibrium framework.

Our main findings are as follows. First, devising cost-effective regulation requires considering instrument choice *and* instrument design. We find that the promotion-based regulation entails costs on the order of five times higher than the costs of broad-based tax regulation. On the one hand, this is due to that fact that promotion-based instruments render energy services too inexpensive by either explicitly subsidizing energy-saving capital (e.g., in the case of buildings programs) or working as implicit output subsidies on specific energy services combined with an implicit tax on polluting ways of generating those services (e.g., through emissions standards for passenger vehicles and efficiency standards for electrical appliances). On the other hand, promotion-based regulation, according to our scenario, reduces emissions too strongly in the transport sector.

Second, tax-based regulation leads to a substantial variation in household-level impacts whereas different household types are similarly affected under a promotion-based approach. The reason is that tax-based regulation leads to substantial changes in both output prices for energy and non-energy goods and factor prices (wages and capital) while under a promotion-based regulation prices are largely unaffected. Given the large heterogeneity of consumers in terms of preferences (expenditure patterns) and endowments (income sources), the price changes under tax-based regulation bring about highly dispersed impacts at the household level. A related insight born out by our analysis is that focusing on mean impacts for specific socio-economic groups (e.g., income deciles) obscures substantial within-group variation of impacts. This is particularly important as the within-group variation of impacts swamps the variation in mean impacts across groups.

Third, while tax-based regulation leads to a more dispersed distribution of household-level impacts, a large fraction of households (about 36%) gain under tax-based regulation (with rebating of carbon tax revenues) while almost all households are worse off under a promotion-based policy. In particular, we show that the cost of promotion-based regulation largely materializes through the need to finance energy subsidies but is "hidden" to the extent that output and factor price impacts are small. Households that gain under tax-based regulation are those with relatively small expenditure shares on energy goods, high shares of income derived from (inflation-indexed) government transfers, and low overall income, who thus disproportionately benefit from per-capita rebates. The incidence across income deciles under tax-based regulation, however, depends importantly on how the tax revenues are recycled: it is progressive with per-capita rebates and yields a regressive outcome if rebates are proportional to income.

Fourth, grouping households according to socio-economic characteristics other than income, we find that under tax-based regulation retired households experience small welfare gains, house owners are more negatively affected than renters, and rural households are relatively worse off than households living in urban and agglomeration areas. In contrast, under promotion-based regulation *all* of these household groups incur substantial welfare losses, although the variation in impacts across groups is much smaller. Overall, our analysis thus expounds important trade-offs between efficiency and equity for environmental policy design.

The remainder of this paper is organized as follows. Section 2 provides a conceptual discussion of the efficiency and incidence effects of alternative regulatory instruments. Section 3 presents our quantitative framework, including data sources and computational strategy. Section 4 describes our scenarios for counterfactual policy analysis. Section 5 presents and discusses our simulation results. Section 6 concludes.

2. RECAPPING THE BASIC CONCEPTUAL CONSIDERATIONS FOR INSTRUMENT CHOICE IN ENVIRONMENTAL POLICY

When designing environmental regulation to reduce CO_2 emissions and energy use, policy makers face a choice across alternative instruments. The broader toolkit of instruments includes emissions taxes, tradable emissions allowances ("cap-and-trade"), subsidies for emissions reductions, performance standards, technology mandates, or R&D subsidies to foster low-emission technologies. The appraisal of instruments typically proceeds along various dimensions such as cost-effectiveness, incidence of regulation, environmental effectiveness, legal framework, and administration. These different dimensions for instrument choice are intertwined and subject to potentially complex trade-offs.[1] The fact that actual climate policy in many countries, including

1. For example, while one instrument might be superior to another on cost-effectiveness grounds, it may be inferior on distributional grounds. Also, the ranking of instruments within one dimension can change pending on the specific design of

Switzerland, is characterized by a myriad of different instruments reflects the complexity and ambiguity of different evaluation criteria. This paper focuses on evaluating regulation with respect to two key dimensions: economy-wide cost-effectiveness and household-level incidence. Before turning to our quantitative analysis, we first provide a brief conceptual review of the performance of different policy instruments with respect to these two criteria.

2.1 Cost-effectiveness

Standard textbook economics calls for comprehensive *where-flexibility* to assure cost-effectiveness in CO_2 emission reduction (Metcalf, 2009): to meet some emission reduction at minimum cost, emission abatement should take place across all emission sources where it is cheapest. This where-flexibility has to include all different channels of abatement: *(i)* input substitution (fuel switching, efficiency improvements), *(ii)* scale adjustment in production output and consumption demand, and *(iii)* the use of potential end-of-the-pipe technologies such as carbon capture and sequestration. In the following we discuss different market-based and non-market-based instruments and how they perform in terms of where-flexibility.[2]

MBIs give a uniform incentive for least-cost abatement through a common (market) price for emissions or their reduction. Most prominent in this category are emissions taxes and tradable emissions allowances, which absent uncertainty, have been shown to be equivalent regarding cost-effectiveness. Emission taxes or cap-and-trade have also been favorably appraised in terms of cost-effectiveness within a broader (general equilibrium) cost perspective where initial tax distortions are taken into account.[3] Subsidies for investments in emission abatements also constitute a market-based instrument that can offer incentives to find the cheapest abatement possibilities and implement them. There exist a number of reasons why subsidies can undermine cost-effectiveness. First, they fail to exploit the *where-flexibility* at sectoral level (i.e., they subsidize different, potentially expensive, technologies for abatement in buildings). Second, there is a large potential for free-riding. Third, by reducing the overall cost of the final energy services (for example, living area heated or vehicle kilometers driven for household energy demand or units of output produced in the case of energy intensive industries), they result in market demands for energy services that are above what the cost-efficient taxes would entail.

CaC or direct regulatory instruments include technology mandates and performance standards commanding, for example, some fixed input–output ratios which restrict comprehensive *where-flexibility* thereby causing a deviation from the cost-effective pattern of abatement via various channels. Thus, CaC regulation is usually inferior in cost-effectiveness terms as compared to MBIs. Technology mandates and performance standards impose restrictions on the flexibility of how abatement can be achieved via input substitution and output adjustment. Mandates are most restrictive in prescribing directly how a production process has to take place. In order to equate marginal abatement cost (MAC), a mandate policy hinges on perfect information across different production technologies. Otherwise, there will be excess cost from regulation due to inefficient input substitution or end-of-pipe treatment. Performance standards—such as energy efficiency standards for buildings or

the instrument. While one instrument may perform better on grounds of cost-effectiveness within the sector it operates on, it may lose out if cost-effectiveness on a broader scope (e.g., at an economy-wide level) is considered.

2. See Goulder and Parry (2008) for a more elaborate discussion.

3. The fundamental argument here is that these instruments raise government revenue that could be employed to lower pre-existing tax distortions, thereby reducing the excess cost of raising public revenues for public good provision. Such a beneficial revenue-recycling effect thus provides a weak double dividend (Goulder, 1995)—the economic cost of restricting the use of CO_2 in production and consumption can be lowered by revenue recycling.

household appliances or fuel standards for cars—allow for more flexibility but generally still do not produce a cost-effective pattern of emission abatement.

An economy-wide CO_2 emission standard which could be implemented as a tradable performance standard across all segments of the economy would indeed equalize MAC as economic agents dispose of flexibility how to meet the standard. As with technology mandates, abatement via output reduction is, however, suboptimal also for the case of performance standards. The reasoning behind is that both instruments are effectively blending constraints which translate into implicit input taxes and implicit output subsidies (Holland et al., 2009): The rents on emission regulation on the input side get recycled internally through subsidies to output. As a consequence the output price will be lower with mandates or standards compared to emission taxes. This in turn means that there is too little abatement via the output channel which must be offset by additional (more costly) efforts via input substitution or end-of-the pipe abatement efforts.

2.2 Household-level incidence

Environmental regulation creates cost and rents which translate into the incidence for households via changes in commodity prices (*the expenditure side*), factor remuneration and potential transfers (*the income side*). On *the expenditure side*, environmental regulation will be regressive to the extent that it increases prices for commodities where low-income households tend to spend larger shares of their budgets (Poterba, 1989; Hasset et al., 2011). Such commodities typically include electricity, home heating fuels, gasoline, and other energy-intensive goods. The ranking of environmental instruments under equity concerns would be inversely correlated to their potency of raising the prices for energy-/emission-intensive commodities. CaC regulation tends to increase prices to a smaller extent and are thus likely to yield smaller adverse effects on the expenditure side as compared to environmental taxes. Obviously, the incidence on the expenditure side will hinge also on the relative ease of how consumers can substitute away from more costly commodities. On *the income side*, environmental regulation changes the productivity and thus the remuneration to labor, capital, and specific resources (e.g., energy resources). More specifically, emission regulation will drive down the rents to specific resources in emission-intensive industries with inelastic supply characteristics—a cost increase on the input side will not pass through via higher output prices but will be shifted back to factors of production which are supplied inelastically (for example, resource rents or technology-specific capital).

Another key driver of the incidence is how rents from regulation are recycled. With MBIs regulatory rents can be recycled by the government explicitly via direct transfers or tax reforms that attenuate regressive effects (for example, tax reductions in favor of low-income groups such as payroll tax rebates or higher income tax thresholds). With CaC regulation rents are implicit and get recycled via output subsidies to the regulated sectors—the direct implications are lower output prices and a smaller decrease in the rent to sector-specific resources. However, the general equilibrium incidence across households also hinges on the indirect effects for all other factor and commodity prices. With regulation based on subsidies, the income side incidence depends on how subsidies are financed.

3. DESCRIPTION OF THE DATA AND MODEL

This section provides an overview of our quantitative framework which integrates an economy-wide multi-sector general equilibrium model with a microsimulation analysis of households. Our numerical approach for coupling the general equilibrium model with the microsimulation model follows Rutherford and Tarr (2008) and Rausch et al. (2011). We first describe the various data sources used for calibration of the model. A brief description of the model structure and our computation method for solving the economic equilibrium model with a very large number of households follows.

3.1 Data

The numerical model employed in this study is based on national accounts and household survey data. National accounts provide information on value flows between different sectors of the economy, households, and the government. Household survey data indicates how aggregate household expenditure for different commodities and income from different production factors are distributed among single households. We harmonized the two data sources to construct a balanced set of accounts for the model's base year.

3.1.1 National economic accounts and energy data

For the aggregate Swiss economy, value flows are given by the social accounting matrix (SAM), and are complemented by physical energy flow data in the "National Accounting Matrix including Environmental Accounts (NAMEA)" (Nathani et al., 2013). The SAM provides information on economic transactions among firms, households, and government agents. The physical energy flow data allow for inferring CO_2 emissions associated with energy demand.

In its original form, the SAM distinguishes 66 industries and commodity groups and 20 categories for final demand. Table 1 provides an overview of our commodity aggregation. We identify eleven sectors of energy supply and conversion separating various fuels (motor fuels, heating oil, natural gas, coal, crude oil) and secondary energy carriers (comprising various forms of electricity and heat). The choice of aggregation for the 21 non-energy sectors is guided by the considerations to separately identify sectors which are large in terms of economic size (i.e. contribution to gross value-added), exhibit a high energy-intensity, enable representing the sectors covered by the Swiss Emission Trading System (ETS), or sectors that are targeted with specific policy measures (for example, private transportation, household energy demand, industrial sectors). Three final demand sectors represent private and government consumption, and investment demand. The social accounting data further provides payments of payroll taxes, income taxes, value-added taxes, import tariffs by commodity, sector-specific output taxes, subsidies, and energy-related taxes including mineral oil taxes.

3.1.2 Micro-household data and data reconciliation

On the household side, a representative sample of the Swiss population of households is portrayed by the 2009–2011 Swiss Household Budget Survey "Haushaltsbudgeterhebung (HABE)". The HABE survey is conducted on an annual basis by the Swiss Federal Statistical Office (BFS). Each year, it collects information for roughly 3,000 households on expenditure patterns and income sources. Household data is weighted according to the inclusion probability.[4] The weights are adjusted for sampling bias and calibrated to the observed distribution of the Swiss population

4. The inclusion probability of a member of the population is its probability of becoming part of the sample during the drawing of a single sample.

Table 1: Overview of model resolution: sectors, electricity generation technologies, and household groups.

Sectors ($i \in I$)	
Non-energy	Agriculture (agr), Paper† (pap), Chemicals† (che), Plastics† (pla), Other non-metallic mineral products† (nme), Basic metals† (bme), Fabricated metal products† (fmp), Medical and precision instruments (med), Manufacturing (man), Machinery and equipment (mch), Office machinery, computers (omc), Radio, TV and communication equipment (elt), Trade and repair except motor vehicles (wht), Real estate (est), Services (ser), Construction (cns), Final demand public/purchased transport (trc), Intermediate transportation services (try), Motor vehicles, trailers (veh), Trade and repair of motor vehicles; retail sale of automotive fuel (trd), Air transportation† (atp)
Energy supply & conversion	Motor fuels (benz), Heating oil (hoil), Other mineral oil products (omop), Nuclear fuel (nuc), Crude oil (cru), Coal† (coa), Natural gas (gas), Electricity generation† (ele), Electricity distribution & transmission (edt), Electricity from waste incineration† (ewi), Heat from waste incineration† (hwi)
Final demand	Private consumption by representative household, government consumption, investment demand
Electricity generation technologies ($p \in P$)	Hydro power, Nuclear power, Power from fossil fuels, Power from renewable energy sources

Notes: † Indicates sectors that are subject to the Swiss Emissions Trading System (ETS) which covers energy-intensive industries.

(Cornali Schweingruber et al., 2007). To increase sample size, the underlying data set aggregates three waves of survey data from the consecutive years 2009–2011 (BFS, 2012a, 2012b, and 2013) using annual weights published by BFS (2014). Thus, we can base our model of household expenditure and income on a set of 9,734 observations of household accounts. Besides the information on income expenditure, the HABE data include other information such as household composition, age of household members, urbanization degree, and ownership status of housing.

The weighted sum of income and expenditures of households reported in HABE has to be reconciled with the national accounts in the SAM. A match between national aggregates and household based data in the base year calibration of the model is required for consistent evaluation of counterfactual scenarios.[5] In a first step, we impute missing data based on information about households' expenditures and socio-economic characteristics (income, renting or owning a house, etc.).[6] In a second step, the national consumption in terms of COICOP "Classification of Individual Consumption According to Purpose" categories was then imposed on the household data by scaling the weighted household consumption from the survey by the respective factor for each consumption category. Similarly, household data on wage income was scaled to meet the national aggregate.[7]

5. The aggregated household consumption in the HABE and SAM accounts can differ significantly for several reasons: (i) missing households: in contrary to the national accounts, the HABE data does not consider non-profit institutions serving households (NPISH) and collective households, (ii) differences in definition of cost (for example, health care and education expenditure), (iii) missing response on certain questions, and (iv) misreported items (for example, expenditures on alcohol).

6. For more information on imputation techniques, see, for example, Bethlehem et al. (2011) and Rubin (1987). Imputation was used to correct incomplete observations in the HABE data with respect to thermal fuel consumption of households, for which an unrealistically high share of households does not report any spending.

7. Operating surplus of economic sectors includes profits that are directly reinvested and thus a direct link to capital rents of investors cannot be made. Based on historical observations, about half of the operating surplus generates actual income to households, while the remainder is directly reinvested.

Savings are also in the household survey and were scaled to match aggregate household savings from the SAM. The remaining difference between income and expenditure of households was attributed to direct transfers between households and the government.

3.2 Household heterogeneity in energy use: a first look at the data

Figure 1 summarizes shares of different energy goods in total household expenditure for different income deciles of the Swiss population. The data show that for thermal fuels and electricity, households in the lower income deciles tend to spend a higher share of their expenditures on these energy goods than do households in the higher income deciles. This makes low income households more vulnerable toward increases in prices of heating fuels and electricity. No clear trend can be observed for motor fuels. But notably, the variation of expenditure shares for energy goods among households of any income decile is large compared to the differences of mean expenditure shares across deciles.

Figure 2 shows how income is composed of the income sources wages, capital rents, and government transfers. Government transfers make up a large fraction of household income for low income households, whereas higher income households earn an increasing share of income from labor.

3.3 Model overview

Here, we briefly outline the main key features of our numerical model. Appendix 7.4 contains a complete algebraic description of the model's equilibrium conditions.

3.3.1 Heterogeneous households

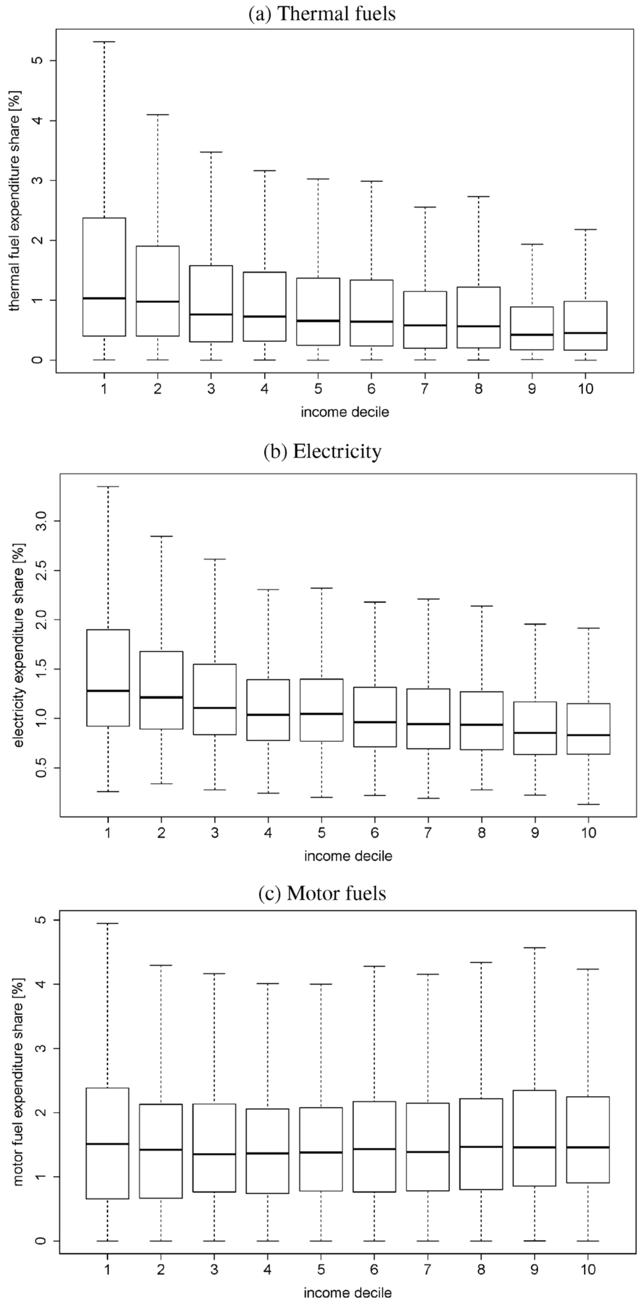
All 9,734 households from the HABE survey are represented as individual economic agents in the general equilibrium model. This enables us to account for the heterogeneity of the entire Swiss household population along the two dimensions expenditure and income. The utility functions of households are calibrated such that they reproduce expenditures at initial prices according to the (harmonized) HABE data, and labor supply, endowments of capital, and entitlements to government transfers are distributed such that the income patterns in the HABE data are achieved.

For counterfactual scenarios, the model fixes labor supply and savings at business-as-usual levels. Household savings are used for purchasing a composite investment good. Given goods and factors prices, households maximize their utility by allocating income received from government transfers, wages and rents on capital to consumption. Utility from consumption is described by a nested constant-elasticity-of-substitution (CES) utility function (see the upper panel in Figure 9 in the appendix). In the cases of private electrical appliances (pea) and private personal transport (ppt) households consume energy *services* that are produced by combining durable goods (vehicles and electrical appliances) with the respective energy goods (motor fuels and electricity) and by employing higher quality durable goods the quantity of energy goods per unit of energy services can be reduced.

3.3.2 Production technologies and firm behavior

In each industry, gross output is produced using primary inputs of labor and capital together with intermediate inputs that are composed of domestically produced goods and imported

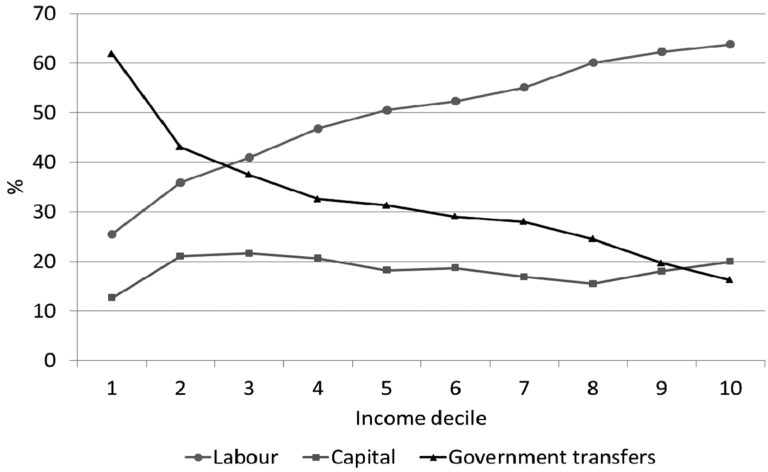
Figure 1: Within- and across-income decile distribution of household-level energy expenditure shares.



Notes: Boxes show the interquartile (IQR) range and solid lines within the box show the mean.

goods. We employ CES functions to characterize the substitutability between the different inputs of production (see the lower panel in Figure 9 in the appendix). Given input prices (gross of taxes and subsidies), firms minimize production costs subject to physical technology constraints. Firms operate in perfectly competitive markets selling their products at a price equal to marginal costs. Capital

Figure 2: Mean income shares for deciles of annual income by income source



and labor are assumed to be mobile across Swiss industries. We assume that Swiss and foreign investors view investments inside or outside Switzerland as perfect substitutes. This implies that rents on capital are determined by the international interest rate on which Swiss policy has no effect.

Power generation is modeled using a compact bottom-up activity analysis representation where discrete technologies produce a homogeneous electricity good by combining technology-specific capital with inputs of labor, fuel, and materials. The substitution elasticity between technology-specific capital and the composite inputs is chosen to match exogenous technology-specific price elasticities of supply. The national accounts provide data to calibrate production functions for electricity generating technologies that have been active in the base-year 2008: hydro power, nuclear power, power from renewables, and power from fossil fuels.

3.3.3 Government activity

A single government entity represents government activities at all levels (that is federal, cantonal, and communal) as well as part of the social security system. The government collects taxes to finance transfers and the provision of a public good. Besides value-added taxes, income taxes, corporate profit taxes and social security contributions, the model features industry-specific output taxes and subsidies as well as import and export levies. The public good is produced with commodities purchased at market prices. The economic impact assessment of different policy scenarios always involves revenue-neutral tax reforms in order to keep the provision of the public good constant. Thus, we can provide a meaningful welfare comparison without the need to trade off private and government (public) consumption. Revenue neutrality is achieved by endogenously setting aggregate amounts of lump-sum transfers between the government and households. The lump-sum transfers are allocated among households in proportion to base-year household consumption.

3.3.4 International trade and model closure

With the exception of crude oil, which is treated as a homogeneous good, domestic and imported varieties of the same good are differentiated following the Armington (1969) assumption (i.e. for each commodity, its total market supply is a CES composite of a domestically produced variety and an imported variety). In analogy to the import side, domestically produced goods are converted through a constant-elasticity-of-transformation function into goods destined for the domestic market and the export market, respectively.

In international trade, Switzerland is assumed to be small, implying that the levels of Swiss exports and imports do not affect world market prices. Switzerland holds its balance-of-payments (measured in foreign exchange) constant across policy scenarios and the exchange rate adjusts endogenously to reflect changes in terms of trade.

3.4 Computational strategy

Following Mathiesen (1985) and Rutherford (1995), we formulate the model as a mixed complementarity problem and represent the economic equilibrium through two classes of conditions: zero profit and market clearance. Numerically, we solve the model in GAMS using the PATH solver (Dirkse and Ferris, 1995). The calibration of the numerical model follows the standard procedure in applied general equilibrium modeling (see, for example, Harrison et al., 1997; Böhringer et al., 2016).

The main challenge for computing equilibria in a CGE model with a large number of households is dimensionality: the number of simultaneous variables and equations becomes large and may create numerical problems for solution algorithms. To overcome dimensionality restrictions, we employ a sequential recalibration algorithm as proposed by Rutherford and Tarr (2008). The algorithm decomposes the large-scale market equilibrium problem into two subproblems and employs an iterative procedure to find a consistent general equilibrium solution. The first subproblem solves a representative agent version by replacing the heterogeneous households by a single representative agent (RA). The second subproblem solves a partial equilibrium relaxation of the household side by evaluating household demand functions taking equilibrium prices from the first subproblem as given. Changes in households' quantity choices based on prices from the first subproblem will generally not coincide with aggregated demand as predicted by the RA model of the first subproblem and thus the solutions of the two subproblems are inconsistent. In a next iteration, the utility function of the RA in the first subproblem thus has to be recalibrated to the observed aggregate demands of the second subproblem. Solution of the first and then the second subproblem and recalibration of the first subproblem is iterated until the to subproblems have converged.[8]

4. SCENARIO DESIGN

This section describes the scenarios which underlie our numerical simulations for counterfactual policy analysis. We provide detail on our baseline assumptions as well as the different market-based and CaC policy measures.

4.1 Business-as-usual (BaU) scenario

Our analysis evaluates the economic effects of future policy measures compared to a "business-as-usual" (BaU) scenario, which assumes that already existing policies continue to be in place but that no new policies are introduced. To represent BaU conditions in 2030, social accounting and survey data from 2008 are calibrated forward employing estimates for trends of GDP, energy

8. See Rausch and Rutherford (2010, pp. 3–7) for a more comprehensive and technical description of the decomposition algorithm.

Table 2: Alternative business-as-usual trends until 2030

	Central case	Energy efficient high growth†	High growth†
BaU assumptions			
GDP (%Δ relative to 2008)	23.4	36.8	36.8
Energy demand (%Δ relative to 2008)			
Motor fuels	–24.3	–24.3	0
Coal	–30.3	–30.3	0
Electricity Distribution & Transmission	6.7	6.7	0
Natural Gas	5.2	5.2	0
Heating oil	–57.7	–57.7	0
Other mineral oil products	4.7	4.7	0
Energy-related CO_2 emissions (%Δ relative to 1990)	–29.5	–29.5	–3.0
Policy targets			
Energy-related CO_2 emissions (–40% relative to 1990) %Δ relative to BaU in 2030	–15.0	–15.0	–38.2
Electricity consumption (–3% relative to 2005) %Δ relative to BaU in 2030	–9.8	–9.8	–3.7

Notes: † The alternative business-as-usual trends *Energy efficient high growth* and *High growth* are used for the sensitivity analysis in Section 5.4.

demands, emissions, autonomous energy efficiency improvements (AEEI), technological change in the power sector, and changing fuel prices on the world market. In the model, GDP growth is achieved by inflating the supply of effective labor and capital. Trends in energy demand and efficiency improvements are reached by decreasing energy intensity of production and consumption while at the same time increasing the reliance on other inputs to keep per-unit expenditures of production sectors and consumers constant.[9]

Table 2 summarizes our assumptions about these trends for three different version of the BaU that differ with respect to projected energy demand and GDP growth. Our *Central case* scenario implies a reduction in the demand for most fuels by 2030 relative to 2008 and intermediate growth rates of GDP. The alternative business-as-usual trends *Efficient high growth* and *High growth* are discussed in the sensitivity analysis in Section 5.4. The BaU forward projection of energy demand determines CO_2 emissions and electricity consumption prevailing in 2030. The trends in energy demand and GDP in the BaU scenario are assumed to emerge under continuation of current climate and energy policy measure.

Table 3 shows the policies that are active in the BaU. We assume that by 2030 the Swiss ETS is coupled with the European Union's ETS assuming that industries requiring emissions permits under the ETS can trade them with the EU ETS at a price of 26.48 €/tCO_2.[10]

4.2 Policy scenarios

Environmental targets—Switzerland has set itself energy and climate policy targets for 2030 beyond what is achievable with currently installed policies: reducing CO_2 emissions by 40% relative to 1990 levels and reducing electricity consumption by 3% relative to 2005. The former is

9. Böhringer et al. (2009) use a similar forward calibration procedure and highlight the importance of alternative baseline assumptions for the appraisal of policy regulation. We carried out additional sensitivity analysis which abstains from the forward projection of the model and find that all of our key insights remain robust (see Appendix 6.3).

10. All prices are originally given is Swiss Francs (CHF) and converted to Euro (€) using the average annual exchange rate of our base year 2008 from the European Central Bank (2017).

Table 3: Overview of instruments in policy scenarios

	BaU	Steering	Promotion
Instruments targeting CO_2 emissions			
CO_2 tax on thermal fuels	52.95 €/ton CO_2	Endogenous†	BaU level
CO_2 tax on motor fuels	0 €/ton CO_2	Endogenous†	BaU level
Emissions standards for new passenger vehicles	Exogenous††	BaU level	20% below BaU
Subsidies for buildings program	189 million €	0	Endogenous
Emissions trading system	Exogenous	BaU level	BaU level
Instruments targeting electricity consumption			
Electricity tax	0.82 Cent/kWh	Endogenous	BaU level
Subsidies for open competitive bidding	32 million €	0	Endogenous
Efficiency standards for electrical appliances	Exogenous††	BaU level	20% below BaU

Notes: "Endogenous" means that the level of the instrument is determined endogenously within the model to meet the respective (emissions or electricity) target. † Following Landis et al. (2016), the tax on motor fuels is set to be 0.4 times the endogenous level of the tax rate on thermal fuels. †† The effects from efficiency standards are considered to the extent that they are reflected in the benchmark data, i.e. we do not employ an explicit instrument to represent these standards in the BaU.

in line with emission paths to reach Swiss climate policy targets for 2050, the latter reflects a desire to manage electricity consumption in light of the planned phase-out of nuclear power. Table 2 shows the reductions from BaU levels required to reach these targets.

Steering vs. Promotion—The design of our policy scenarios is chosen to reflect two fundamentally different paradigms of regulation for reducing energy use: a "steering" approach that rests on economic incentives arising from taxes on emissions and energy use and a "promotion" approach that builds on promoting and mandating measures for saving energy. The discussion of future climate and energy policy in Switzerland has also been focused on these two different approaches (Federal Council, 2015a,b). Table 3 summarizes our scenario assumptions:

- *Steering* represents a scenario predominantly following broad-based MBIs based on CO_2 and electricity taxes. While the emissions of firms in energy intensive sectors remain capped by the Swiss ETS, the CO_2 taxes on the fossil fuel demand of the remainder of the economy are set endogenously to meet the policy targets for CO_2 emissions. Similarly, electricity demand is taxed to meet the respective reduction target. Sector-specific subsidy programs targeting energy use in household heating and industrial sectors are abolished. CaC regulation (emissions standards for vehicles and efficiency standards for electrical appliances) are kept at their BaU levels.
- *Promotion* represents narrowly focused regulation which limits where-flexibility by the use of CaC instruments and increased reliance on subsidizing energy savings in specific sectors. CO_2 and electricity taxes (as well as the cap on emissions in the ETS) are kept at their BAU levels. The stringency of standards for vehicles and electricity appliances are increased by 20%, and policy targets for CO_2 and electricity are met by increasing subsidies in the sector-specific programs.

Note that while both scenarios involve the use of MBIs, their design in terms of sectoral coverage differs significantly. In light of policy relevance, we deem scenarios relying purely on either MBIs or CaC measures as unrealistic. First, even in light of a future shift toward more incentive-based regulation, it seems highly unlikely that emissions standards for vehicle and efficiency standard for electrical appliances would cease to exist. Second, existing taxes on CO_2 and electricity, if anything, are expected to increase making the case of a pure CaC regulation without taxes uninteresting from the perspective of real-world policy.

We next describe in more detail each regulatory instrument included in the *Steering* and *Promotion* scenarios.

4.2.1 Market-based instruments (MBIs)

Broad-based MBIs: taxes on CO_2 emissions and electricity—CO_2 taxes are levied in proportion to the CO_2 emissions intensity of fuels consumed by industrial and household sectors. In the BaU and the *Promotion* scenarios, electricity taxes and CO_2 taxes on thermal fuels are fixed and motor fuels are exempt from the tax. In the *Steering* scenario, the tax on motor fuels is 0.4 times the tax on thermal fuels.[11] Revenues from taxing CO_2 emissions associated with industrial energy use are returned to industries in proportion to the wage bills (through reductions on the social security bill). Revenues from taxing CO_2 emissions of households are returned to consumers by refunding each Swiss resident an equal lump-sum amount.

Electricity demand is taxed at the same rate throughout the economy and taxation revenue is returned according to the same rules as CO_2 tax revenues.

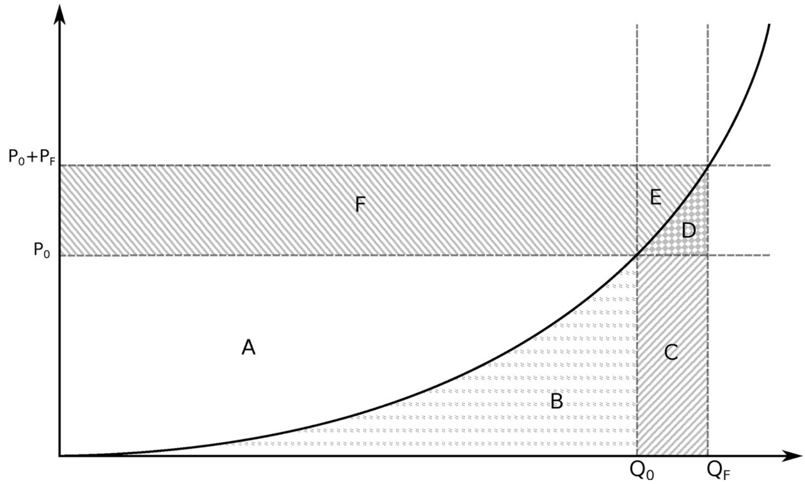
Sector-specific MBIs: Subsidies in the Buildings Program and the Open Competitive Bidding program—The Swiss government subsidizes investments in energy savings through two main programs: (1) the so-called Buildings Program ("Gebäudeprogramm") promotes the thermal insulation of residential buildings; (2) the so-called Open Competitive Bidding (OCB) program ("Wettbewerbliche Ausschreibungen") subsidizes measures that save electricity.

In order to represent potentials for energy savings by insulating buildings and reducing industrial electricity demand, the model employs specifically calibrated energy-savings activities. They trade off a fixed factor, representing the potential to save energy for a specific type of energy use, against capital investments in a CES function. The energy saving activities thus allow for variable levels of capital investments to yield variable levels of annual energy savings (provision of energy services without the consumption of physical energy) and the marginal cost of energy savings is determined by (the inverse of) the marginal productivity of capital in the CES function. The CES functions are calibrated using value shares of the fixed factors in energy saving from the benchmark and elasticities of substitution between fixed factors and capital.

A generic marginal cost curve as it results from the CES functions for the specific types of energy-savings activities is depicted in Figure 3. At any quantity Q of energy savings, it gives the marginal cost (annualized) in terms of capital investments for the last unit of energy saved. At the market price for energy P_0, energy savings up to Q_0 can be implemented without losses. The associated total implementation cost in terms of capital investment is given by the area B under the marginal cost curve. Given the zero-profit conditions in equilibrium and the constant returns to scale nature of CES functions, area A represents the implicit revenue generated by the fixed factor "energy savings potential". Under the buildings program, government support for investments with annualized value P_F is granted, and thus, energy savings up to Q_F can be implemented as the investors compare annualized investment costs with annual energy savings plus P_F. The buildings program helps financing further projects that would not be viable without support P_F, but also supports renovations that more than pay for themselves at existing energy prices (those up to Q_0). Thus, expenditures according to area D+E+F are made by the government, where F represents the support payments

11. Landis et al. (2016) find that for the Swiss climate policy context, cost-effective carbon pricing policies entail substantially lower taxes on motor fuels than on thermal fuels (by a factor of 0.1–0.6 if other externalities such as congestion or local air pollution, are ignored). This also reflects current Swiss policy discussions (Federal Council, 2015b) according to which high taxes on motor fuels are politically highly contentious.

Figure 3: Marginal cost curve for energy savings



going to renovation measures that would have been implemented even without government support (i.e. due to "free riding" behavior). If all free riding could be ruled out, the government would only subsidize new investments with project specific rates at a budgetary cost equal to the area D.

Under the buildings program, house owners who improve the insulation of their buildings receive support per area where insulation is improved.[12] The support rates differ for different renovation measures: window replacement, insulation of walls facing outside, insulation of roofs, and insulation of walls facing unheated rooms. Our model captures the variety of measures by modeling two technologies (*insulating windows or walls facing unheated rooms* and *insulating roofs or walls facing outside*) that can each save either of the two heating fuels (*natural gas* or *oil*). Each technology-fuel combination has a different ratio of annualized values of subsidies and saved energy (and thus a different marginal cost curve for energy savings).[13] Investments that would have been carried out even without the subsidy also receive support (i.e. "free-riding" effects), and the model's insulation cost functions are calibrated to the observation that, at current rates, about a third of investments that receive subsidies would have been cost-effective without them.[14] Rents on energy-saving capital, i.e. differences between energy savings and insulation cost for the cheapest insulation measures, accrue to households that own buildings (either directly or through investments in firms that own buildings).

Under the Open Competitive Bidding (OCB) program the Swiss government subsidizes investments in measures that save electricity. Investors apply for support through the OCB if they plan a project that will entail electricity savings. Only the most cost-effective projects (in terms of lifetime energy savings per unit of subsidy payment) are chosen until the budget of the OCB program is depleted. The program implements a stringent evaluation process to avoid free-riding be-

12. The buildings program also promotes measures for waste heat recovery, renewable energy supply, and the optimization of building utilities. Our analysis only includes insulation measures.

13. This view of the buildings program neglects the fact that within measures such as, for example, window replacements, different energy savings can be expected due to different pre-installed windows. By assuming the same support rate for all units of energy saving,r view of the program assumes that each unit of energy saving is achieved by insulating the same surface area. We partially address this by distinguishing between renovations of houses heated with gas or oil but are likely to not capture the full heterogeneity of renovation projects in this respect.

14. See "free riding" effects reported by EnDK (2014).

havior, i.e. the support of projects that would have already been profitable on their own. The model implements the electricity saving opportunities that may apply to the OCB by one cost function. The fact that free-riding can be ruled out in the OCB is mimicked by taxing the rents on the fixed factor such that the subsidies on the free-riding projects are recovered by the government.[15] The remaining rents from energy-saving opportunities (corresponds to area A in Figure 3) in the context of the OCB program still accrue to owners of the firms.

4.2.2 Command-and-control (CaC) measures

We consider two CaC measures that Switzerland has introduced (in line with corresponding EU legislation). First, CO_2 emissions standards for new passenger vehicles—mandating a minimum fuel efficiency that has to be met on average in the fleet of new cars. Second, efficiency standards for electrical appliances—mandating a minimum energy efficiency in delivering their services to consumers. Efficiency standards mandate producers to increase the efficiency of appliances such that households spend more on higher quality appliances but less on energy. It is herein assumed that they manage to do this cost-efficiently (e.g., using advertisement and price signals) and that competition between suppliers ensures that they sell equipment at prices such that average revenues reflect average cost.[16] At a given level of energy efficiency, final energy services are less expensive under energy use standards than in a situation where energy goods are taxed. This leads to higher consumption of energy services compared to the tax case.

In our model, energy services—vehicle kilometers traveled in case of emission standards and rooms lit, loads washed, etc. in the case of efficiency standards for appliances—are produced using the required appliances and energy.[17] Figure 11 in Appendix 7.2 depicts this production structure. When the Swiss government imposes efficiency standards on appliances providing a given energy service, it issues a limited number of virtual "energy use allowances" *per unit* of the service. These allowances are assumed to be traded among firms and factories inside the production sector at the shadow price of energy demand reduction. As allowance trade is purely internal to production sectors, no revenue enters or leaves those sectors.[18]

4.2.3 Revenue-neutrality: balancing the government budget

While energy and CO_2 tax revenue is recycled to industries and households, policy-induced changes in tax bases and financing of the subsidy programs will affect the government budget. As the provision of the public good, i.e. the government budget after transfer payments, has to remain constant in order to enable a meaningful welfare comparison across scenarios, the model needs a

15. Note that this tax does not effectively change the incentives to supply the fix factor to the energy savings activity, as the factor does not have another use in the economy and is in fixed supply.

16. When Fischer (2004) assumes that providers of equipment to which standards are applied have market power, she finds that consumers of low-end appliances may be provided with too inefficient and consumers of high-end appliances with too efficient products. Our model does not distinguish between different quality levels of equipment (neither for cars nor for electrical appliances) and thus misses to account for this detail.

17. Our model does not distinguish between different vintages in neither the car fleet nor the stock of electrical appliances but assumes that more stringent standards reduce the fuel (electricity) demand across the whole vehicle fleet (stock of appliances).

18. Our analysis abstracts from the administrative cost of implementing and monitoring both market-based and CaC policy instruments. As the parametrization of such cost is beyond the scope of this paper, we leave for future research to investigate the extent to which differences in administrative cost among various instruments may change the ranking of policies.

Table 4: Aggregate welfare effects (annual cost relative to *BaU*)

	in % †	in bill. €	in € per household
Steering	0.23	0.63	184
Promotion	1.19	3.31	976

Notes: † The aggregate welfare change, Γ, is computed as a Benthamite (utilitarian) social welfare function simply aggregating welfare changes across households without inequality aversion: $\Gamma = \sum_{h=1}^{H} \omega_h 100(u_h - 1)$, where h is the household index, H the total number of households in the sample, ω_h the sample weights for the survey data, and u_h the utility level under the policy situation (where the *BaU* utility level is normalized to unity).

means to balance the budget under policy scenarios. As the current political discussion does not provide any information on how extended subsidy schemes under the buildings program would be financed if the volume of subsidies exceeds the revenue from CO_2 taxation, we assume a budget balancing mechanism that impacts the income distribution among households as little as possible. Specifically, we use a uniform tax on household income from capital, labor, and government transfers after other taxes. The change in disposable income from this tax causes the same percentage change for all households, because the same rate applies to all households and it does not cause any changes in labor supply or capital endowment according to our model.

5. SIMULATION RESULTS

This section presents the main results from our counterfactual policy analysis. We first focus on comparing the aggregate economic costs and the effectiveness of policies to reduce CO_2 emissions and electricity consumption. We then present the distributional impacts of the various policy measures detailing how different socio-economic groups of households would be affected. To check to what extent our results depend on our baseline assumptions, we then conduct sensitivity analysis by employing alternative assumptions for those.

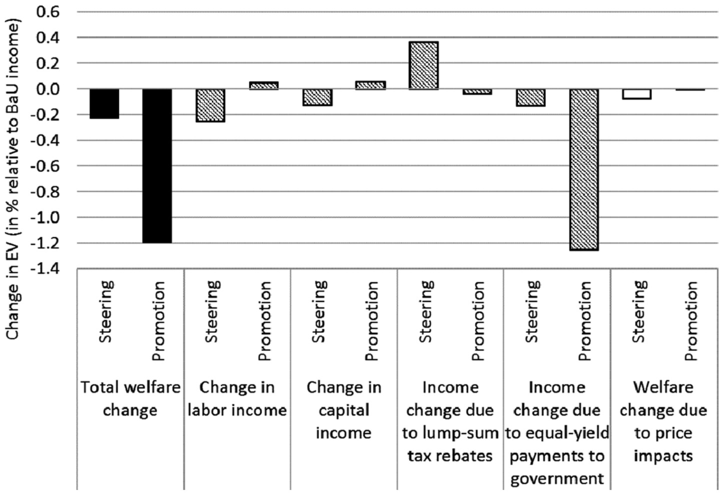
5.1 Aggregate efficiency cost

Table 4 reports the aggregate welfare costs for the two policy scenarios. Throughout, we measure economic costs (ignoring environmental damages or benefits) as the change in Hicksian equivalent variation relative to the BaU in 2030. A first important insight is that a sizeable decarbonization of the Swiss economy is possible at modest costs; the costs of reducing CO_2 emissions by 40% by 2030 (relative to 1990) range between 0.23% and 1.19% of annual consumption or about 0.62–3.31 € billion per year. For the average household the annual cost amount to 184–976 €.[19]

Importantly, however, the economic costs of such a decarbonization is shown to significantly depend on the choice of policy instruments. Achieving the same reductions in CO_2 emissions and electricity consumption is about five times less costly under the *Steering* compared to the *Promotion* scenario. The additional cost imposed by relying on promotion instruments such as the Buildings Program and the OCB rather than using broad-based taxes amounts to about 2.67 billion € per year for the Swiss economy. This corresponds to an excess burden of 792 € per year for an average Swiss household. The reasons that the *Promotion* scenario is faring worse in terms of economic cost are that the standards and subsidies target only fractions of energy demand in the

19. Note that when reporting money-metric welfare costs, we always refer to € in the base year.

Figure 4: Decomposition of welfare changes for *Steering* and *Promotion* policies.



economy and do not allow markets to equalize marginal costs of reducing demand for electricity and CO_2 emissions across sectors. Also energy services under the *Promotion* scenario are cheaper than under efficient taxes on electricity and CO_2 emissions at the same levels of energy efficiency. Thus, houses, cars, and appliances need to be more energy efficient than they have to be under the *Steering* scenario to reach the same targets.

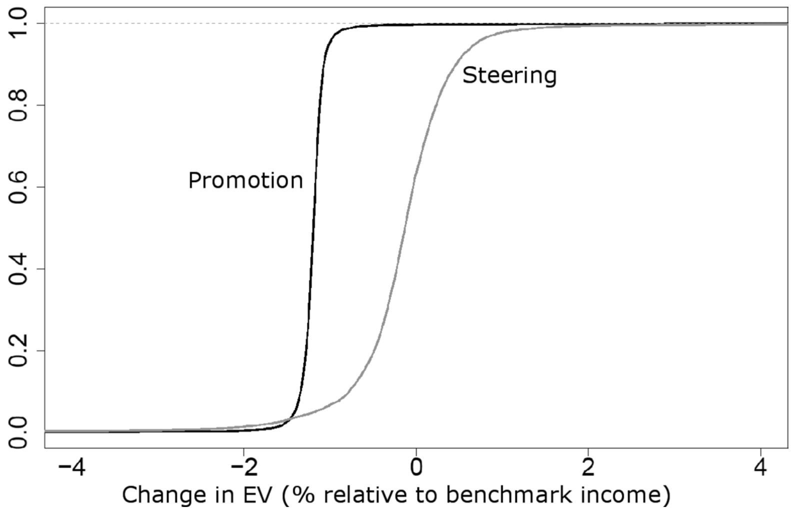
5.1.1 Decomposition of aggregate cost impacts

Figure 4 decomposes the total welfare change into the effects of the two incidence channels income and commodity prices. The welfare loss in the *Steering* scenario is to a large extent driven by a reduction in factor income whereas under the *Promotion* scenario welfare is much less affected by changes in capital and labor income. A positive income impact in the *Steering* stems from transfers received through recycling some of the CO_2 and electricity tax revenues to households.

Under the *Promotion* scenario, the effects on the sources of income side are negligibly small. The costs under the *Promotion* scenario largely materialize through the need to finance the subsidy instruments which is reflected by the need to hold the government budget neutral (i.e. income change due to equal-yield government payments). As the use of explicit tax instruments under the *Steering* policy package increase consumer prices, some of the welfare costs are due to price impacts whereas this effect is nearly zero under *Promotion* as consumer prices for energy are not much affected (see further discussion in the context of Table 5). The important insight is that the efficiency costs under a promotion-based policy are "hidden" from the consumption side. Looking merely at output and factor price changes would suggest that the costs under *Promotion* are smaller than under *Steering*. Only when considering the cost of providing the budget for the subsidy program, the higher efficiency costs of the *Promotion* policies become visible.[20]

20. While the focus of this paper is on assessing the household-level impacts, we want to briefly report on the sector-specific performance of the alternative approaches to regulation. Figure 10 shows the change in output by sector for the *Steering* and *Promotion* scenarios. Two insights emerge. First, the variation of sectoral impacts is substantially larger under *Promotion*. This is consistent with the previous observation that both factor and output prices are only minorly affected under *Promotion* relative to *Steering* (see Table 5). Second, while most sectors reduce their output under *Steering*, for some sectors the output slightly increases under *Promotion*. Based on sectoral output, it thus appears that *Promotion* is less costly

Figure 5: Cumulative distribution of household-level welfare impacts for *Steering* and *Promotion* policy scenarios



5.2 Incidence across households

5.2.1 Heterogeneity of household-level impacts

Figure 5 summarizes the distribution of welfare impacts across Swiss households for the two policy scenarios. Clearly, the two policies differ in how equally they distribute the economic burden associated with reaching the policy targets. And while all policies entail a welfare loss at the aggregate level, household-level welfare impacts can be negative or positive. As the size of the mean impact is smaller for *Steering* as compared to *Promotion* policies, the fraction of benefiting households is larger for the steering-based instruments: under the *Steering* policy about 36% of household would gain whereas nearly all households are worse off under the *Promotion* scenario (i.e. only 0.3% of households gain).

The result that the household-level impacts are more dispersed under *Steering* as compared to the *Promotion* scenario is driven by the different pattern of price changes induced by each policy scenario (see Table 5) and their impacts across household groups. Policies in the *Promotion* scenario lead to smaller changes in (tax-inclusive) consumer prices than do the taxes in the *Steering* scenario. The factor price change for capital (relative to the Consumer Price Index, CPI) is mostly driven by the change in the CPI as the price of capital is determined on the international capital market.[21] The relative price of capital thus declines relatively strongly under the *Steering* scenario whereas it is nearly not affected under *Promotion* scenario. The increase in the CPI under the *Steering* scenario also explains the decline in the wage rate (relative to the CPI). In the *Promotion* scenario, the wage rate slightly increases reflecting the increased marginal productivity of labor as the capital subsidies imply more capital-intensive production.

overall. The additional efficiency cost of *Promotion* relative to *Steering*, however, materialize through the costs of providing the budget for the subsidy program—as already discussed in the context of the welfare decomposition (see Figure 4) above.

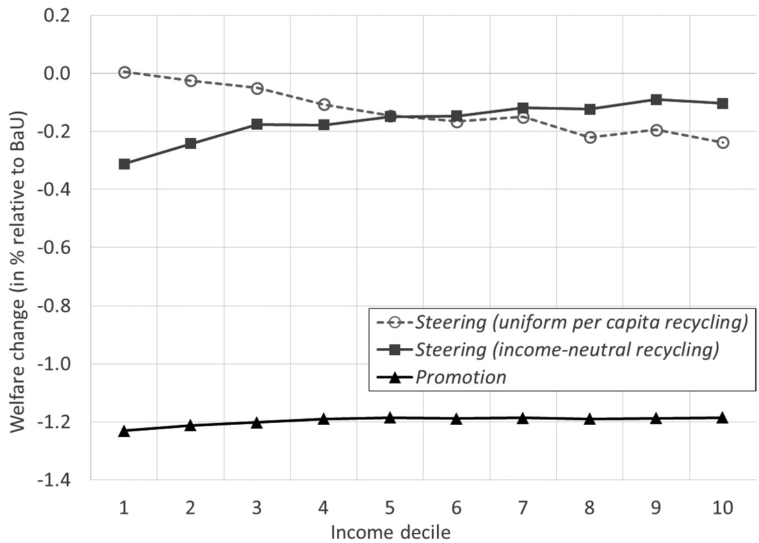
21. Recall that following the small open economy assumption for Switzerland, Swiss and foreign investors view investments inside or outside Switzerland as perfect substitutes which, in turn, implies that rents on capital are determined by the international interest rate.

Table 5: Price changes induced by the policy scenarios (in % relative to *BaU*)

		Consumer prices (tax-inclusive) for energy †				Factor prices†	
	CPI	Motor fuels	Electricity	Natural gas	Refined oil	Capital	Labor
Steering	0.7	14.1	5.8	24.7	35.6	–0.7	–0.6
Promotion	0.0	0.0	–2.4	0.0	0.0	0.0	0.1

Notes:† All changes refer to *relative* price changes where relative prices are obtained by dividing by the Consumer Price Index (CPI). The calculation of the CPI is based on BaU reference quantities (Laspeyres index) with foreign exchange normalized to 1.

Figure 6: Mean welfare impacts by income decile for steering- vs. promotion-based policies



Since both output prices for energy as well as factor prices do not change much under the *Promotion* scenario, the dispersion of welfare impacts is relatively small. In contrast, the relatively large price impacts for goods and factor prices under the *Steering* scenario means that households are differently affected, depending on their sources of income and their expenditure pattern.

5.2.2 Impacts by income decile

Figure 6 shows the mean welfare impacts by income decile for the two multiple-instrument scenarios. The *Promotion* scenario yields a roughly neutral incidence over income groups, i.e. household groups are affected equally. As the *Promotion* scenario does not much affect output and factor prices, the impacts are principally driven by the need of the government to finance subsidy programs and balance its budget. As subsidy payments are financed with a tax that is neutral across income, there are no differential effects among households. The incidence under the *Steering* scenario, on the other hand, is regressive on the expenditure side (as poorer households with higher energy expenditure shares are more affected by higher energy prices). On the income side the incidence depends on the ways in which the revenues from the CO_2 and electricity taxes are recycled. In our simulation analysis we assume that tax revenues are recycled to households on a per-capita basis (reflecting current policy practice). As a given amount of revenue has the higher relative impact on the income of low income households, the per-capita recycling yields a markedly progressive incidence pattern (i.e. low-income households benefits disproportionately more from the *Steering* policy). Hence, the progressivity on the income side overcompensates the regressive incidence on the expenditure side. Figure 6 shows results if we change the revenue recycling to the same distributionally neutral income tax change that finances the subsidies in the *Promotion* scenario. The difference between the income-neutral recycling and the results for the standard implementation of the *Steering* scenario illustrates clearly how the revenue recycling mechanism makes an otherwise regressive policy package progressive.

Figure 7 takes a more detailed look at the distribution of welfare impacts within and across income deciles for the *Promotion* and the *Steering* scenarios. The large heterogeneity in income and expenditure shares among households translates into a large dispersion of household-level welfare impacts. The main insight from the figure is that focusing on average welfare impact by income group obscures the substantial variation in impacts. In particular, the result that the *Steering* scenario causes small overall policy costs and distributes them in a progressive manner hides the fact that the households with the largest relative loss in consumption opportunities loose more under the *Steering* than under the *Promotion* scenario and that these households belong to the lowest income decile. While probably not a reason to reject the *Steering* scenario as a reasonable option to move toward meeting Swiss climate targets, this results should prepare policy makers to deal with hardship cases that might arise from increases in energy costs.

5.2.3 Impacts by socio-economic groups

Table 6 shows the mean welfare impacts by different socio-economic groups. Several insights emerge. For the *Promotion* scenario, the mean impacts for the various groups are relatively similar. This echoes the previous finding that *Promotion* policies yield a neutral incidence across income.

The *Steering* scenario yields larger disparities between the socio-economic household groups (also in line with the findings above). In particular, we find that (on average) house owners are more affected by *Steering* instruments than renters, which is due to their relatively higher expenditure shares on energy commodities. Differentiating households with respect to working age, we notice that the mean impact of the *Steering* scenario for retired households is slightly positive. This is because they do not suffer from large and negative impacts on the source-side of income: their labor income share is low and they get an average of 64% of their income from government transfers (including pension payments), which are indexed to inflation in our model. This insulates them from factor price changes. Overall the retired households gain as the benefit from per-capita recycling of the tax revenue more than offsets the negative factor income and energy price effects. With respect to the difference between urban, agglomeration and rural households we find that the group with the highest energy expenditure share—rural households—are more affected by higher energy prices in the *Steering* scenario than urban households.

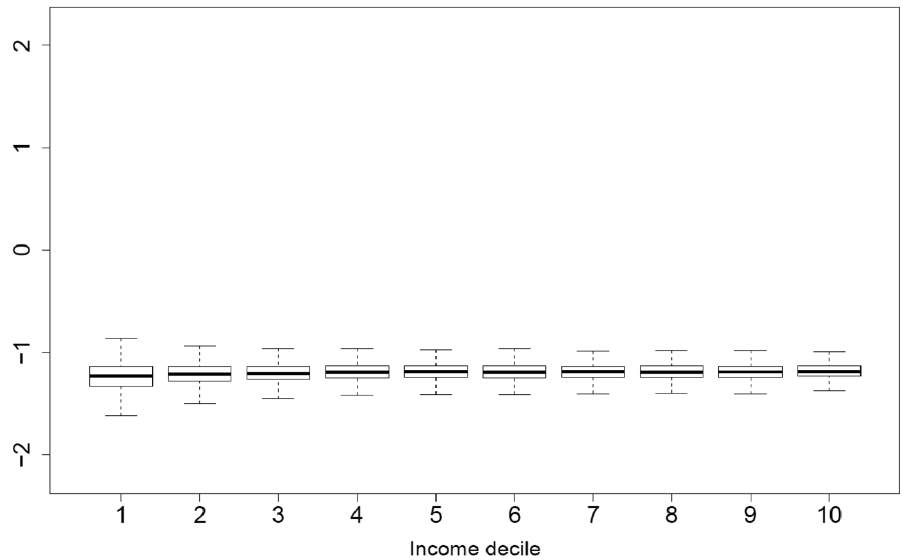
5.3 Promotion policies in single sectors

The *Promotion* scenario, inspired by currently enacted and proposed policies in Switzerland, analyzes a combination of different promotion-based instruments. We have argued that the efficiency costs of the *Promotion* scenario largely stems from the limited "where-flexibility". To examine this further, we consider two additional scenarios focused on regulating emissions from private transportation (labeled *Standards for passenger vehicles*) and domestic heating (labeled *Subsidies for buildings*) with the respective sector-specific promotion-based instrument.[22] To isolate the

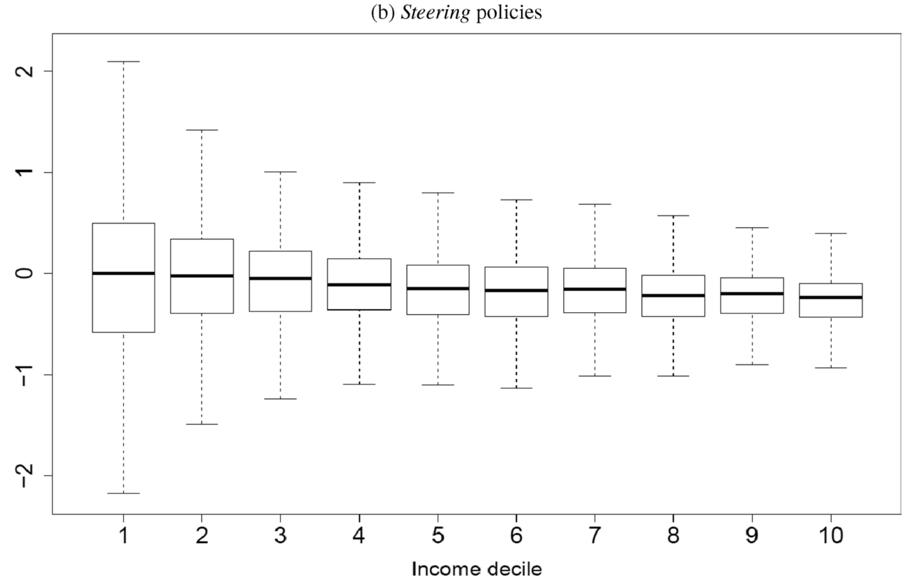
22. We do not report here the results from the promotion-based measures focused on electricity as their overall efficiency costs are comparatively small.

Figure 7: Within- and across-income decile distribution of welfare changes (in % relative to BaU) for multiple-instrument policies.

(a) *Promotion* policies



(b) *Steering* policies



Notes: Solid line shows mean welfare impact and box the interquartile (IQR) range. The "whiskers" show outlier values within 1.5 times the IQR of the nearest quartile.

Table 6: Mean welfare impacts by socio-economic groups (in % relative to *BaU*)

	Housing		Working age		Location		
	Owner	*Renter*	*Retired*	*Working*	*Agglo.*	*Rural*	*Urban*
Steering	–0.20	–0.07	0.00	–0.16	–0.14	–0.18	–0.08
Promotion	–1.17	–1.22	–1.19	–1.20	–1.20	–1.20	–1.19

Table 7: Sensitivity of aggregate welfare impacts (relative to BaU) for multiple-instrument policies

	in %†	in bill. €	in € per avg. household
Central case			
Steering	0.23	0.63	184
Promotion	1.19	3.31	976
High growth			
Steering	1.03	3.16	930
Promotion	4.84	14.89	4388
Efficient high growth			
Steering	0.20	0.61	181
Promotion	1.13	3.46	1019
High MAC			
Steering	0.26	0.71	210
Promotion	1.89	5.25	1547
Low MAC			
Steering	0.15	0.42	123
Promotion	0.79	2.20	648
Varying the stringency of standards under *Promotion*			
Low standards	1.35	3.75	1105
High standards	1.18	3.28	966
Promotion policies in single sectors (*Steering* + ...)			
Standard for passenger vehicles	0.22	0.62	183
Subsidies for buildings	0.67	1.86	549

Notes: † The aggregate welfare change, Γ, is computed as follows: $\Gamma = \sum_{h=1}^{H} \omega_h 100(u_h - 1)$, where h is the household index, H the total number of households in the sample, ω_h the sample weights for the survey data, and u_h the utility level under the policy situation (where the *BaU* utility level is normalized to unity).

impacts of these sectoral policies *and* to control for where-flexibility, we require that (1) outside these sectors all emissions are regulated with a CO_2 tax and that (2) the pattern of emissions and (3) the stringency of the sector-specific instrument is set such that the same level of sectoral emissions as under *Steering* is achieved.

Tables 7 and 8 (two bottom lines) report the results in terms of aggregate impacts as well as the variation in the incidence. The following insights emerge. First, even when choosing the emission reduction levels that are found to be efficient under a carbon tax, a promotion-based policy for reducing buildings-related emissions in the given context entails substantial efficiency costs. The reason is that the subsidy for energy-saving investments in buildings only provides an indirect signal to reduce CO_2 emissions and fails to appropriately incentivize carbon abatement through energy conservation due to lowering the price of building-related energy services. Second, using an emissions standard for vehicles to achieve the same level of transport-related emissions as under *Steering* does not create additional efficiency costs relative to a CO_2 tax. The potential inefficiency from lowering the price of transportation services is compensated by the efficiency loss of the CO_2 tax which stems from the adverse interaction with (high) pre-existing taxes on transportation fuels in Switzerland. The negative tax interaction effect is smaller under an emissions standard as the price for energy services increases only slightly while a CO_2 tax induces a comparatively larger price increase.[23] This suggests that most of the inefficiency of the promotion-based instrument for transportation is related to limiting where-flexibility, i.e. the transition from scenario *Subsidies for buildings* to *Promotion* induces an inefficiently high level of abatement in transportation through mandating

23. See Landis et al. (2017) for an analysis of carbon pricing and tax interactions with the taxes on motor fuels in Switzerland. Similarly, Goulder et al. (2016) find that an intensity standard on clean electricity is more cost-effective compared to a carbon tax on electricity due to pre-existing distortionary income taxes.

Table 8: Sensitivity of distribution of household-level welfare impacts (% change relative to BaU)

	Mean μ	Median	Standard deviation σ	CV $\sigma/\|\mu\|$	% of households with impacts >0	% of households with impacts within $\mu \pm \sigma$
Central case						
Steering	–0.23	–0.13	2.55	11.3	36.1	98.8
Promotion	–1.19	–1.20	0.54	0.5	0.3	98.3
High growth						
Steering	–1.03	–0.90	8.26	8.0	17.7	99.3
Promotion	–4.84	–5.06	3.49	0.7	0.7	98.5
Efficient high growth						
Steering	–0.20	–0.12	2.19	10.9	35.7	98.8
Promotion	–1.13	–1.13	0.51	0.4	0.3	98.3
High MAC						
Steering	–0.26	–0.13	3.56	13.9	40.2	98.8
Promotion	–1.89	–1.95	1.08	0.6	0.6	98.3
Low MAC						
Steering	–0.15	–0.11	1.20	8.0	25.7	99.1
Promotion	–0.79	–0.79	0.72	0.9	0.2	99.0
Varying the stringency of standards under *Promotion*						
Low standards	–1.35	–1.38	0.80	0.6	0.4	98.8
High standards	–1.18	–1.14	1.96	1.7	0.4	99.1
Promotion policies in single sectors (*Steering* + ...)						
Standard for passenger vehicles	–0.22	–0.14	2.13	9.5	29.1	98.7
Subsidies for buildings	0.67	0.62	1.30	1.9	2.4	98.9

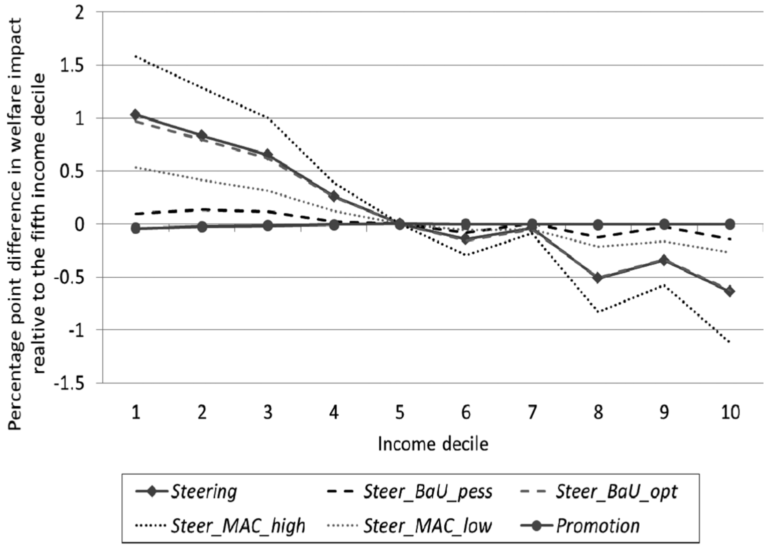
a substitution toward more fuel-efficient, but costly, passenger vehicles. Third, using an emissions standard for passenger vehicles somewhat decreases the variance of the household-level impacts relative to a pure *Steering* scenario. The reduction is, however, much smaller than with using a promotion-based instrument to lower buildings-related CO_2 emissions. The reason is that the emissions standard contains an implicit tax on CO_2 emissions which works against the price decrease due to subsidizing emissions-savings capital in passenger vehicles; in contrast, the buildings program only consists of a subsidy instrument, leaving the price of energy services largely unaffected. In line with the previous results, the smaller the price increase due to regulation, the less dispersed are the household-level welfare effects.

While the findings above are specific to the scenarios considered, our analysis of single policies illustrates the more fundamental point that the relative performance of promotion-based policies versus tax-based regulation crucially depends on aspects of instrument choice and design (e.g., subsidies vs. standards, sectoral coverage, policy stringency) as well as other factors (e.g., the structure of pre-existing tax distortions). Thus, while single promotion-based policies may have the potential to get close to outcomes obtained under steering-based policy, the enhanced reliance of CaC policies and subsidies increases the risk that falsely designed environmental regulation brings about substantial efficiency costs (as evidenced by our main policy scenarios *Promotion* versus *Steering*).

5.4 Sensitivity analysis

To check for the robustness of our results, we carry out sensitivity analyses along three dimensions. First, we examine the impact of alternative *BaU* assumptions about baseline GDP and energy demand growth. Comparing *Central case* and *Efficient high growth* allows us to examine the implications of high GDP growth (without increase of energy demand), while comparing the

Figure 8: Percentage point difference in welfare impact relative to the 5th income decile (for selected sensitivity cases).



Central case and *High growth* allows for considering the effects of higher GDP growth rates if they also entail higher energy demand. Second, as the ratio of compliance cost between the *Steering* and the *Promotion* scenario hinges crucially on the parametrization of marginal abatement costs, we consider two additional cases reflecting low and high costs relative to our central case. More specifically, we calculate for each technology the given level of abatement in the *Promotion* scenario and the corresponding level of the subsidy. We then assume for the *Low* case that the same amount of abatement could have been reached with half the amount of the subsidy. For the *High* case, we double the subsidy amount required to reach the same level of abatement. Third, as the level of the command and control (CaC) instruments is set exogenously in the *Promotion* scenario, we want to check how our findings are affected by the assumed level of stringency for each CaC instrument. An optimistic (pessimistic) case assumes that standards are 10% more (10% less) stringent than in the central case.

Our qualitative results with regards to cost-effectiveness and distributional impacts are confirmed throughout the sensitivity analysis. Table 7 shows the aggregate welfare effects for the above-described sensitivity cases. Our key finding that the *Promotion* scenario achieves the same policy targets at considerably higher cost compared to the *Steering* package is robust with respect to these sensitivities. We find that the annual average welfare cost under *Promotion* exceed those under *Steering* by a factor of four to eight. Table 8 reports summary statistics for the distribution of household-level welfare impacts for the above-described sensitivity cases. Importantly, Table 8 bears out our finding that the dispersion of household-level impacts is significantly larger for the *Steering* as compared to the *Promotion* scenario: it can be reproduced using varying assumptions about GDP and energy demand growth in the *BaU*, about the marginal abatement costs of promotion instruments, and about the stringency of the CaC instruments. Our sensitivity analysis confirms the finding of a neutral incidence pattern of average impacts across income deciles under the *Promotion* scenario. For the *Steering* scenarios, the distributional incidence across income deciles changes but remains non-regressive (see Figure 8). Relative to the central case, we find that in the case where opportunities for insulating buildings and saving electricity are more (less) expensive, the welfare impacts become more (less) progressive (comparing *Steering* scenarios low and high MAC, *Steer_MAC_high* and *Steer_MAC_low* to the central case). Regarding the sensitivity of our results with respect to varying baseline assumptions, we find that the *efficient high growth* (*Steer_BaU_opt*) baseline produces almost the same distributional impacts across income deciles as does the central case BaU. But for the *high growth* (*Steer_BaU_pess*) baseline the distributional impacts almost vanish and the impacts across income deciles are close together: in order to reach the very stringent reduction targets, the prices on energy significantly increase and the regressive nature of the expenditure side channel of incidence becomes more important.

6. CONCLUDING REMARKS

Should energy use be lowered using broad-based taxes or through promoting and mandating energy savings through command-and-control measures and targeted subsidies? This paper has examined the efficiency and equity effects of alternative regulatory approaches to environmental policy, using the case of Swiss energy and climate policy as an example. We have developed a quantitative framework that combines a numerical general equilibrium model with micro-simulation analysis at the household level. The advantage of this combination is that we can analyze implications for economy-wide cost-effectiveness of policy reforms while providing at the same time a detailed perspective on household responses to and incidence of regulatory measures. The integrated modeling framework does not only feature a rich representation of household heterogeneity (based on a representative sample of 9,734 households of the Swiss population), but also accounts for the inter-sectoral linkages and price-dependent market feedbacks across the whole economy. In particular, applying our framework enables us to contribute to the scarce literature in environmental economics on assessing the distributional impacts of non market-based regulation.

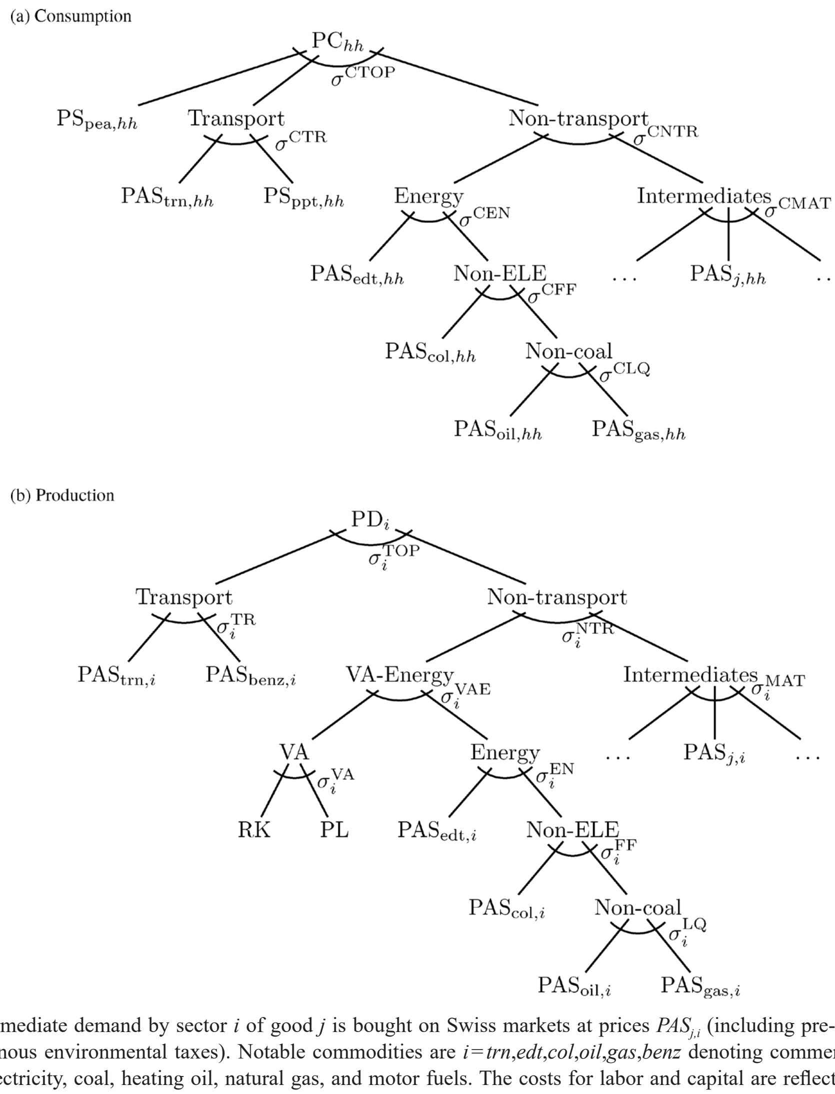
We have scrutinized the impacts of two alternative policy paradigms for regulation: a "steering-based" approach relies on comprehensive market-based regulation using economy-wide taxes on CO_2 and electricity consumption; a "promotion-based" approach employs narrowly focused regulation which limits where-flexibility by the use of CaC instruments (emissions standards for new passenger cars and efficiency standards for electrical appliances) and subsidies for investments in energy-savings capital in specific sectors (open competitive bidding for industrial electricity use and residential buildings programs). At the economy-wide level, we find that taxing energy is about five times more cost-effective than promoting energy savings. Tax-based regulation leads to a substantial variation in household-level impacts whereas different household types are similarly affected under a promotion-based approach. A large fraction of households (about 36%) gain under tax-based regulation (with rebating of carbon tax revenues) while almost all households are worse off under a promotion-based policy. We show that the cost of promotion-based regulation, which largely materializes through the need to finance energy subsidies, is "hidden" to the extent that consumer price impacts are small. Our analysis thus points to important trade-offs between efficiency and equity for environmental policy design.

The welfare measure used throughout this study focuses on economic cost only. We therefore abstract from any environmental benefits due to, for example, averted climate impacts or changes in local air pollution (we keep CO_2 emissions constant across scenarios anyway). Also, our welfare calculations do not take into account the effects from reducing non-environmental externalities such as, for example, congestion due to changes in the demand for transportation services. There is evidence in the literature that the co-benefits from energy and climate policies aimed at reducing fossil fuel use can be substantial. While this paper has deliberately focused on providing a "conventional" cost-effectiveness analysis, future research is needed to provide a careful context-specific evaluation of the presence and likely magnitude of relevant external effects which may asymmetrically affects the welfare costs of different regulatory approaches. Findings from the co-benefits literature (see, for example, Thompson et al., 2014, for an analysis of the co-benefits of climate policy from averted local air pollution) suggests, however, that our welfare estimates should be best viewed as providing an upper bound for the cost of environmental regulation.

APPENDIX

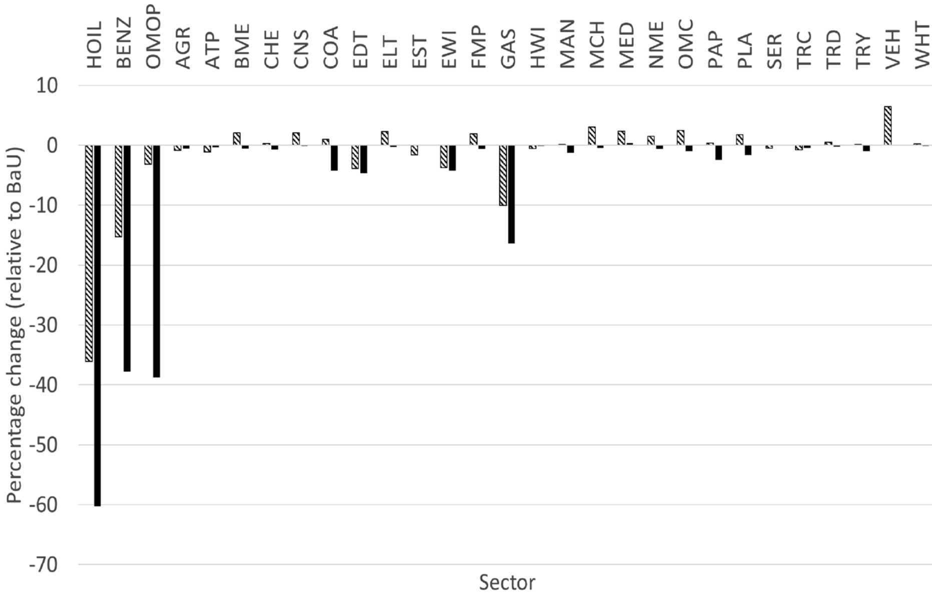
A.1 Additional figures and tables

Figure 9: Nesting of constant-elasticity-of-substitution (CES) functions in production and consumption.



Notes: Intermediate demand by sector *i* of good *j* is bought on Swiss markets at prices $PAS_{j,i}$ (including pre-existing taxes and endogenous environmental taxes). Notable commodities are $i = trn, edt, col, oil, gas, benz$ denoting commercial transport services, electricity, coal, heating oil, natural gas, and motor fuels. The costs for labor and capital are reflected by *PL* and *PK*. Sectoral output is priced at PD_i and household consumption is valued at PC_{hh}. $PAS_{i,hh}$ are the prices of commodities i purchased on national markets by households. PS_{pea} (Private electric appliances) and PS_{ppt} (Private passenger transport) refer to the energy services derived from electrical appliances and cars using energy (see Appendix 6.2.2 for more details on their composition).

Figure 10: Impacts on sectoral outputs (for acronyms of sectors see Table 1)



A.2 Modeling the policy instruments in the *Promotion* framework

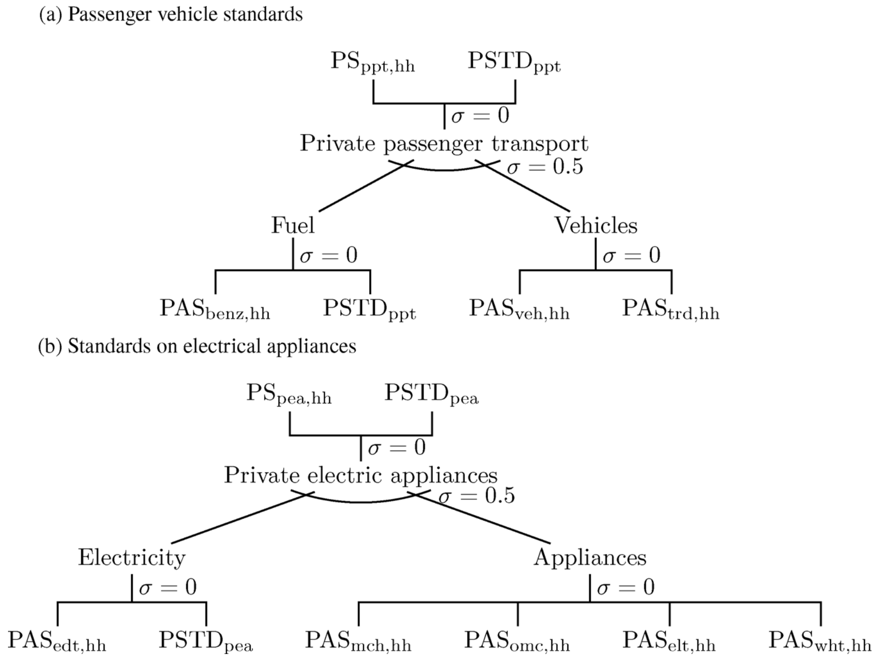
A.2.1 Subsidy programs

The CES functions are calibrated using value shares of fixed factors in the BaU case and elasticities of substitution between fixed factors and capital. Table 9 shows the parametrization of the CES aggregates that describe these marginal costs of energy savings in the base case under the *high* and *low* assumptions for sensitivity analysis in Section 5.4.

Table 9: Values of elasticity of substitution σ and benchmark input share θ for calibration of the cost curves of energy saving measures.

	Central case	Low	High
Building program			
$\sigma^{GP}_{\text{Windows/Floors,oil}}$	0.95	1.10	0.85
$\sigma^{GP}_{\text{Windows/Floors,gas}}$	0.95	1.10	0.85
$\sigma^{GP}_{\text{Roof/Walls,oil}}$	0.95	1.20	0.83
$\sigma^{GP}_{\text{Roof/Walls,gas}}$	0.95	1.25	0.82
$\theta^{GP}_{\text{Windows/Floors,oil}}$	0.90	0.90	0.90
$\theta^{GP}_{\text{Windows/Floors,gas}}$	0.93	0.93	0.93
$\theta^{GP}_{\text{Roof/Walls,oil}}$	0.73	0.73	0.73
$\theta^{GP}_{\text{Roof/Walls,gas}}$	0.80	0.80	0.80
Open competitive bidding			
σ^{WA}	0.07	0.08	0.06
θ^{WA}	0.89	0.89	0.89

Figure 11: Standards on vehicles for private passenger transport ppt (a) and electrical appliances pea (b).



Notes: $PSTD_{ppt}$ and $PSTD_{pea}$ denote the shadow values of emission allowances that are generated in proportion to generated energy services, which are valued at $PS_{ppt,hh}$ and $PS_{pea,hh}$ by households. In order to generate energy services, energy (priced at $PAS_{benz,hh}$ and $PAS_{edt,hh}$) and devices (priced at $PAS_{veh,hh}$ and $PAS_{trd,hh}$ for vehicles and at $PAS_{mch,hh}$, $PAS_{omc,hh}$, $PAS_{elt,hh}$, and $PAS_{wht,hh}$ for electric appliances) are required. The energy and non-energy inputs are complements and can substitute for each other according to the elasticity of substitution σ=0.5.

A.2.2 Efficiency standards

Figure 11 depicts the production structure of private transportation (part (a), ppt) and the energy services derived from private electrical appliances (part (b), pea). Fuel and electricity demand can be substituted by higher expenditures on durables like vehicles (requiring the purchase of vehicles [veh] and repair services [trd]) or electric appliances (including machinery and equipment [mch], office machinery and computers [omc], radio, TV and communication equipment [elt], trade and repair [wht]). When the government lowers the amount of energy demand allowed for generating energy services, the shadow values $PSTD_{ppt}$ and $PSTD_{ppt}$ of energy use allowances increase, making the cost-minimizing generation of energy service rely on more efficient appliances and thus reducing energy demand. While the value of the energy services to households ($PS_{ppt,hh}$ and $PS_{pea,hh}$) cover the costs for the energy demand (benz or edt) as well as costs of vehicles (veh, trd) or appliances (mch, omc, elt, and wht), the implicit sales and purchases of energy demand allowances within the production of energy services cancel each other out.

A.3 Sensitivity analysis: no forward calibration from 2008

We analyzed yet another baseline scenario: keeping GDP, energy efficiency levels and pre-existing policies at 2008 levels and implementing the policy targets for 2030 in that economic environment. As the energy efficiency gains of the *Central case* business-as-usual scenario are not given here, the costs of the policies are similar to what we observe in the *High growth* business-as-usual scenario, where similar energy demands and emissions are postulated (albeit at higher GDP levels). The corresponding entries that would belong in Tables 7 and 8 are given in Tables 10 and 11 below along with the numbers for the *High growth* business-as-usual for comparison.

Table 10: Sensitivity of aggregate welfare impacts (relative to BaU) for multiple-instrument policies

	in%†	in bill. €	in € per avg. household
No forward calibration			
Steering	0.93	2.86	843
Promotion	4.06	12.51	3686
High growth			
Steering	1.03	3.16	930
Promotion	4.84	14.89	4388

Notes: † The aggregate welfare change, Γ, is computed as follows: $\Gamma = \sum_{h=1}^{H} \omega_h 100(u_h - 1)$, where h is the household index, H the total number of households in the sample, ω_h the sample weights for the survey data, and u_h the utility level under the policy situation (where the *BaU* utility level is normalized to unity).

Table 11: Sensitivity of distribution of household-level welfare impacts (% change relative to BaU)

	Mean μ	Median	Standard deviation σ	CV $\sigma/\lvert\mu\rvert$	% of households with impacts	
					>0	within $\mu \pm \sigma$
No forward calibration						
Steering	–0.93	–0.75	6.7	7.21	22.7	98.7
Promotion	–4.06	–4.11	1.57	0.39	0.3	98.3
High growth						
Steering	–1.03	–0.90	8.26	8.0	17.7	99.3
Promotion	–4.84	–5.06	3.49	0.7	0.7	98.5

A.4 Online appendix

The online appendix provides a complete algebraic description of the model's equilibrium conditions. It can be accessed at https://www.ethz.ch/content/dam/ethz/special-interest/mtec/cer-eth/economics-energy-economics-dam/documents/people/srausch/online_appendix_EJ_efficient_equitable_policydesign.pdf.

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REFERENCES

Armington, P. (1969). "A theory of demand for products distinguished by place of production." *International Monetary Fund Staff Papers 16*, 159–76. https://doi.org/10.2307/3866403.

Bento, A.M., L.H. Goulder, M.R. Jacobsen, and R.H. von Haefen (2009). "Distributional and efficiency impacts of increased U.S. gasoline taxes." *American Economic Review 99*(3): 667–699. https://doi.org/10.1257/aer.99.3.667.

Bethlehem, J., F. Cobben, Schouten, and W. Barry (2011). *Handbook of Nonresponse in Household Surveys*. John Wiley & Sons, Inc. https://doi.org/10.1002/9780470891056.

BFS (2012a). "Haushaltsbudgeterhebung 2009." BFS Aktuell.

BFS (2012b). "Haushaltsbudgeterhebung 2010."

BFS (2013). "Haushaltsbudgeterhebung 2011."

BFS (2014). "Steckbrief Haushaltserhebung. Neues Gewichtungsmodell, Resultate 2000-2003 und Studie zur Altersvorsorge." BFS Aktuell. Available at: http://www.bfs.admin.ch/bfs/portal/de/index/infothek/erhebungen__quellen/blank/blank/habe/01.html (visited on 04.02.2015).

Böhringer, C., A. Löschel, U. Moslener, and T.F. Rutherford (2009). "EU climate policy up to 2020: An economic impact assessment." *Energy Economics* 31, Supplement 2, S295–S305. https://doi.org/10.1016/j.eneco.2009.09.009.

Böhringer, C., J. C. Carbone, and T. Rutherford (2016). "Embodied carbon tariffs." *Scandinavian Journal of Economics*. Forthcoming.

Bovenberg, A.L., L.H. Goulder, and D.J. Gurney (2005). "Efficiency costs of meeting industry-distributional constraints under environmental permits and taxes." *RAND Journal of Economics* 36(4): 951–971.

Cornali Schweingruber, A., R. Epple, U. Oetliker, and S. Rochat (2007). "Die Einkommens- und Verbrauchserhebung mit neuer Methode." Technical report, Bundesamt für Statistik.

Dirkse, S.P. and M.C. Ferris (1995). "The PATH solver: a non-monontone stabilization scheme for mixed complementarity problems." *Optimization Methods and Software* 5: 123–156. https://doi.org/10.1080/10556789508805606.

EnDK (2014). "Energieverbrauch von Gebäuden". https://www.endk.ch/de/ablage/endk-1/20140828-factsheet.pdf, retreived 16 January 2018.

European Central Bank (2017). "Eurosystem policy and exchange rates." www.ecb.europa.eu/stats/policy_and_exchange_rates/euro_reference_exchange_rates/html/eurofxref-graph-chf.en.html.

Federal Council, B. (2015a). "Botschaft des Bundesrates." https://www.newsd.admin.ch/newsd/message/attachments/41483.pdf.

Federal Council, B. (2015b, March). "Erläuternder Bericht zum Vorentwurf. Vernehmlassung für ein Klima- und Energielenkungssystem." http://www.news.admin.ch/NSBSubscriber/message/attachments/38702.pdf.

Fischer, C. (2004). "Who Pays for Energy Efficiency Standards?" Discussion Paper DFF DP 04-11, Resources For the Future.

Fullerton, D. and H. Monti (2013). "Can pollution tax rebates protect low-wage earners?" *Journal of Environmental Economics and Management* 66(3): 539–553. https://doi.org/10.1016/j.jeem.2013.09.001.

Fullerton, D. and E. Muehlegger (2017). "Who bear the economic costs of environmental regulations?" NBER Working Paper No. 23677.

Goulder, L. and I. W. Parry (2008). "Instrument choice in environmental policy." *Review of Environmental Economics and Policy* 2(2): 152–174. https://doi.org/10.1093/reep/ren005.

Goulder, L.H. (1995). "Environmental taxation and the "double dividend": A reader's guide." *International Tax and Public Finance* 2(2): 157–183. https://doi.org/10.1007/BF00877495.

Goulder, L.H., M.A.C. Hafstead, and R.C. Williams III (2016). "General equilibrium impacts of federal clean energy standards." *American Economic Journal: Economic Policy* 8(2): 186–218. https://doi.org/10.1257/pol.20140011.

Harrison, G.W., T.F. Rutherford, and D.G. Tarr (1997). "Quantifying the Uruguay round." *The Economic Journal* 107(444): 1405–1430. https://doi.org/10.1111/j.1468-0297.1997.tb00055.x.

Hasset, K., A. Mathur, and G.E. Metcalf (2011). "Fuel taxes and the poor: the distributional effects of gasoline taxation and their implications for climate policy," Chapter The consumer burden of a carbon tax on gasoline. *Environment for Development*. Resources for the Future Press.

Holland, S.P., J.E. Hughes, and C.R. Knittel (2009). "Greenhouse gas reductions under low carbon fuel standards?" *American Economic Journal: Economic Policy* 1(1): 106–146. https://doi.org/10.1257/pol.1.1.106.

Landis, F., S. Rausch, and M. Kosch (2016). "Is a uniform carbon tax a good idea? The case of Switzerland." SCCER-CREST Working Paper. Available at: http://www.sccer-crest.ch/fileadmin/user_upload/Landis_Rausch_Kosch_2016_Uniform_Carbon_Tax.pdfhttp://www.sccer-crest.ch/fileadmin/user_upload/Landis_Rausch_Kosch_2016_Uniform_Carbon_Tax.pdf.

Landis, F., S. Rausch, and M. Kosch (2017). "Differentiated Carbon Prices and the Economic Cost of Decarbonization." *Environmental and Resource Economics* March: 1–34.

Mathiesen, L. (1985). "Computation of economic equilibria by a sequence of linear complementarity problems." *Mathematical Programming Study* 23: 144–162. https://doi.org/10.1007/BFb0121030.

Metcalf, G.E. (2009). “Market-based policy options to control U.S. greenhouse gas emissions.” *Journal of Economic Perspectives* 23: 5–27. https://doi.org/10.1257/jep.23.2.5.

Nathani, C., D. Sutter, R. van Nieuwkoop, S. Kraner, M. Peter, and R. Zandonella (2013). “Energiebezogene Differenzierung der Schweizerischen Input-Output-Tabelle 2008.” Schlussbericht an das Bundesamt für Energie, rütter und partner/infras/modelworks, Rüschlikon/Zürich/Thun.

Poterba, J.M. (1989). “Lifetime incidence and the distributional burden of excise taxes.” *American Economic Review Papers and Proceedings* 79(2): 325–330. https://doi.org/10.3386/w2833.

Rausch, S., G. Metcalf, and J. Reilly (2011). “Distributional impacts of carbon pricing: A general equilibrium approach with micro-data for households.” *Energy Economics* 33(1): S20–S33. https://doi.org/10.1016/j.eneco.2011.07.023.

Rausch, S., G.E. Metcalf, J.M. Reilly, and S. Paltsev (2010). “Distributional implications of alternative U.S. greenhouse gas control measures.” *The B.E. Journal of Economic Analysis & Policy* 10(2). Symposium. https://doi.org/10.2202/1935-1682.2537.

Rausch, S. and T.F. Rutherford (2010). “Computation of equilibria in OLG models with many heterogeneous households.” *Computational Economics* 36(2): 71–189. https://doi.org/10.1007/s10614-010-9229-8.

Rausch, S. and G. Schwarz (2016). “Household Heterogeneity, Aggregation, and Distributional Impacts of Environmental Taxes.” *Journal of Public Economics* 38: 43–57. https://doi.org/10.1016/j.jpubeco.2016.04.004.

Rubin, D.B. (1987). *Multiple imputation for nonresponse in surveys*. John Wiley & Sons, Inc. https://doi.org/10.1002/9780470316696.

Rutherford, T.F. (1995). “Extension of GAMS for complementarity problems arising in applied economics.” *Journal of Economic Dynamics and Control* 19(8): 1299–1324. https://doi.org/10.1016/0165-1889(94)00831-2.

Rutherford, T.F. and D. Tarr (2008). “Poverty effects of Russia’s WTO accession: modeling “real” households with endogenous productivity effects.” *Journal of International Economics* 75(1): 131–150. https://doi.org/10.1016/j.jinteco.2007.09.004.

Sterner, T. (Ed.) (2012). “Fuel Taxes and the Poor: The Distributional Effects of Gasoline Taxation and Their Implications for Climate Policy.” *Environment for Development*. New York: Resources for the Future Press. https://doi.org/10.4324/9781936331925.

Thompson, T., S. Rausch, R. Saari, and N. Selin (2014). “A systems approach to evaluating the air quality co-benefits of U.S. carbon policies.” *Nature Climate Change* 4: 917–923. https://doi.org/10.1038/nclimate2342.