Public acceptability of carbon taxation: a model of political support with income and urban-rural inequality

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Abstract

Carbon taxation is a flagship climate policy aimed at efficiently reducing greenhouse gas emissions. Yet, it fails to garner sufficient political support in many countries. This paper investigates the role of urban-rural inequalities in this lack of domestic support. I develop a model of household support for carbon taxation at a national level, with income inequality and heterogeneous Stone-Geary utility. Rural households need to consume more necessary energy goods than urban households. I characterize the conditions for the existence of a majority voting equilibrium and perform a calibration of the model with budget survey data for twenty European countries.

I find that the majority voting tax may be at a higher rate than the optimal carbon tax. However, the calibration suggests that the optimal rate tends to exceed the majority voting rate by a few percent. I demonstrate that political support among rural households is always below that of urban households. The numerical exercise reveals a gap between 15 and 45 %, at the median income. I show that recycling the revenues from carbon taxation as lump-sum or means-tested transfers renders the tax and rebate scheme progressive, but has only a limited effect on political support.

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1 Introduction

Keeping global temperature increase under 2°C compared to pre-industrial levels, as stated in the Paris Agreement, requires timely and ambitious policies to reduce greenhouse gas emissions. Carbon pricing is a flagship climate policy put forth by economists for its cost-effectiveness. Yet, implementation of carbon prices, in the form of carbon taxation, emissions trading systems, and even reductions in fossil fuel subsidies, has been slow. The main reason for this is the fact that carbon taxes are widely unpopular among citizens. For instance, carbon taxation has failed to achieve a majority in votes in many countries, such as in Switzerland in 2015. It has also resulted in protests, such as in France with the yellow vests movement. Political constraints limit the feasibility of carbon taxes because governments and political parties need political support and wish to avoid voiced opposition from a segment of the electorate.

Concerns about fairness and distributive impacts of carbon pricing play a key role in the acceptability of carbon taxation (see Maestre-Andrés et al. (2019) for a review of the literature). Carbon taxation results in two types of distributional impacts. First, households with different levels of income face different tax burdens, in proportion to their income. In high-income countries, the consumption of emission-intensive goods increases with income, while each additional unit of income tends to emit less, i.e., the income elasticity of polluting goods is less than one. Thus, richer households tend to consume more emission-intensive goods in absolute value, but less in proportion to their income. As a result, carbon taxation is usually regressive in high-income countries (Ohlendorf et al., 2021). Second, there is significant variation in tax burdens for households at the same income level (e.g., Gill and Moeller 2018; Cronin et al. 2019; Douenne 2020; Tomás et al. 2020 for respectively Germany, the US, France, and Spain). A particularly salient source of this variation is location-based, as rural households may consume more fuel and energy to meet their transport and housing needs than urban households. Distributional impacts of carbon taxation hinge upon income inequality as well as urban-rural inequality, i.e., *vertical* and *horizontal* inequalities.

Optimal taxation frameworks focusing on energy and greenhouse gas emissions taxation have recently included horizontal inequality (Fischer and Pizer, 2019; Hänsel et al., 2022). Efficient policies that result in heterogeneous costs and benefits can create losers with costs that are not compensated (Sallee, 2019). This, in turn, may lead to political opposition from losers. In the survey literature, location and dependence on fossil fuels have a stronger impact on acceptability than income. Households that live in rural areas, have less efficient heating, or are more car-dependent tend to oppose carbon taxes more strongly (Umit and Schaffer 2020; Douenne and Fabre 2020; Boyer et al. 2020).

The literature on the political economy of carbon taxation studies political support using voting models. It was first developed by Cremer et al. (2004), who explore the double dividend hypothesis with a majority voting model. They find that recycling tax revenues as income tax reduction enhances the political feasibility of carbon taxation. Aidt (2010) shows how a polluter lobby may favor refunding tax revenues to voters if it results in larger environmental tax cuts. Habla and Roeder (2013) combine majority voting with an overlapping generations model to study the effect of aging on the voted tax.

This paper makes a novel contribution to this literature by including urban-rural inequality in a majority voting framework. The political feasibility of carbon taxation is proxied by the level of carbon tax achieved under majority voting. I capture heterogeneity within income groups in the cost of carbon taxation by modeling households that differ in the quantity of carbon-intensive goods they are constrained to consume. I consider urban households living in high-density areas and rural households living in less dense areas. Rural households have higher subsistence consumption of the emission-intensive good than urban households, reflecting their higher energy needs for transport and housing. I evaluate the extent to which the intersecting income and urban-rural inequalities can limit political support for carbon taxation, and whether countries with higher levels of urban-rural inequality face tighter political constraints. To achieve further insights, I perform a numerical calibration of the model using household budget survey data for twenty European countries.

I find that urban-rural inequality results in lower political support for the carbon tax among rural households than among urban households. The numerical exercise reveals a gap in the accepted carbon tax rate across the median urban and rural households of up to 45%. I determine the conditions for the existence of a majority voting equilibrium over the carbon tax and show that a very large urban-rural inequality can lead to polarization of political support. That is to say, a majority voting equilibrium in which there are no urban and rural households with the same level of supported carbon tax, and in which the median voter is urban or rural depending on which group is in majority in the population. My findings highlight that horizontal inequality could imply equity-efficiency-acceptability trade-offs in the design of carbon tax schemes.

Second, I show that the effect of income on political support for carbon taxation in the model depends on the relative strength of the environmental concern and the preference for consuming carbon-intensive goods. A rise in household income increases the level of politically supported carbon taxation if the willingness to mitigate greenhouse gas emissions, scaled by the effectiveness of mitigation, is greater than the marginal budget share of the carbon-intensive good. In addition, an increase in income is more likely to positively affect support for carbon taxation for households with a larger budget share devoted to constrained consumption of carbon-intensive goods. This reflects how relaxing the budgetary constraint due to the necessary consumption of carbon-intensive goods can make room for more climate mitigation efforts.

Third, I compare the majority voting carbon tax to the optimal carbon tax, i.e., the carbon tax chosen by a social planner taking into account both vertical and horizontal inequality. My results show that the majority voting tax rate can be at a higher or lower level than the optimal tax rate. The social planner takes into account the tax burden of every household and hence incorporates the equity-efficiency trade-off. The median voter, on the other hand, only factors in their own tax burden. If the median voter is an urban household with a low carbon tax burden, the majority voting tax rate can thus be higher than that of the social planner. However, in the numerical exercise, I find that the tax resulting from majority voting is lower than the tax chosen by the social planner in every country. This occurs although the social planner and every household share the same level of environmental preference by assumption.

Lastly, I study the effect of recycling the revenue generated by a carbon tax. Rebates have been put forth as a means of improving the progressivity of carbon taxation (e.g., Cronin et al., 2019; Ravigné et al., 2022). For instance, the European Union *Fit for 55* policy package includes a Social Climate Fund that is set up to provide "temporary direct income support for vulnerable households" (European Commission, 2021). I analyze whether transfers are sufficient to overcome the regressive distributional impacts of the tax and whether this is likely to increase political support for the carbon tax. I examine the effects of three types of transfers: lump-sum, targeted at households with an income below the median, and targeted to rural households.

I find that recycling the tax revenues as a lump-sum or means-tested transfer renders the tax scheme progressive. However, lump-sum or means-tested transfers result in heterogeneity across households in the net impact, with rural households benefiting less than urban households. The distributive impact of transfers targeted to rural households depends on the distribution of income across the urban and rural populations in each country. When households are myopic to the rebound effect of transfers on emissions, an increase in income has two effects. On the one hand, it raises the marginal willingness to mitigate greenhouse emissions. On the other hand, it increases the demand for carbon-intensive goods. Thus, transfers raise the acceptability of carbon taxation only if the pro-mitigation effect is stronger than the increased demand effect. The numerical calibration reveals that the impact of transfers on the carbon tax rate chosen by majority voting is positive but weak, with an increase of a few percent. The results also suggest that no transfer type is a one-size-fits-all, as the impact of each transfer structure—lump-sum, means-tested, or targeted at rural households—is different across countries.

The layout of the paper is as follows. In section 2, I present a model of carbon taxation with income and urban-rural inequality, and derive the optimal carbon tax. Section 3 shows the existence of a median voter determining the result of majority voting and describes its characteristics. Section 4 presents the results from a calibration of the model to European countries using household budget survey data. Section 5 concludes.

2 Carbon taxation in a model with vertical and horizontal inequality

2.1 The economy

The economy comprises households consuming a polluting—or carbon-intensive—good x, and a non-polluting good c. The size of the population and the price of non-polluting good c are normalized to one. The price of the polluting good x is p. Aggregate consumption of the carbon-intensive good, X, produces emissions that result in climate change damages.

Households differ in two aspects. First, they differ with respect to the amount of polluting good they are constrained to consume. A rural household, of type $h = r$, needs to consume a larger amount of carbon-intensive good than an urban household, of type $h = u$. The share of urbans in the population is $0 \leq \alpha \leq 1$. Second, households differ by their level of income. Household i earns income y_i^h which is distributed over $[y^-, y^+] \subset \mathbb{R}^+$. In addition, median income $\tilde{y}$ is assumed to be below average income $\bar{y}$.

2.1.1 Consumption preferences

I follow the optimal carbon taxation literature and use Stone-Geary preferences (Klenert and Mattauch, 2016; Aubert and Chiroleu-Assouline, 2019; Jacobs and van der Ploeg, 2019). This choice is made to model in the most straight-forward way a demand for the polluting good which both increases in income and results in an income elasticity that is below one (Pottier, 2022). I assume that preferences over the carbon-intensive good are heterogeneous (as in Hänsel et al. (2022)), and differ according to the type of the household, rural or urban. The constrained consumption parameter, which determines the minimum amount that must be consumed in order to achieve positive utility, is larger for a rural household than an urban household. For a household i of type $h = \{u, r\}$, sub-utility corresponding to consumption is

$$u(c_i, x_i) = c_i^{1-\gamma-\beta}(x_i - x_0^h)^\gamma$$

with $x_0^r \geq x_0^u$ and $\gamma + \beta < 1$. u_c is defined only if the household consumes at least an amount x_0^h of the polluting good.

The demand derived from the maximization of $u(c_i, x_i)$ subject to the budget constraint $y_i = c + px$ is

$$x_i^* = \frac{1}{(1-\beta)}\left(\frac{\gamma}{p}y_i + (1-\gamma-\beta)x_0^h\right). \tag{1}$$

In turn, the following income elasticity can be derived from the demand for the polluting good

$$\frac{\partial x_i}{\partial y_i}\frac{y_i}{x_i} = \frac{1}{1 + \frac{(1-\gamma-\beta)}{\gamma}\frac{px_0^h}{y_i}} < 1.$$

The income elasticity of demand for the carbon-intensive good thus decreases towards zero as constrained consumption x_0^h increases. It increases towards one as income y_i increases. In other words, a larger amount of subsistence consumption renders demand for the polluting good more inelastic, while the reverse is true for higher levels of income.

Finally, aggregate demand for the carbon-intensive good, with a population comprised of a share α of urbans and $(1-\alpha)$ of rurals, writes

$$
\begin{aligned}
X &= \int_{y^-}^{y^+} (\alpha x_i^{u*} + (1-\alpha) x_i^{r*})\, dF(y_i) \\
&= \frac{1}{(1-\beta)} \left(\frac{\gamma}{q} \bar{y} + (1-\gamma-\beta) \bar{x}_0 \right)
\end{aligned}
$$

with $\bar{x}_0 \coloneqq (\alpha x_0^u + (1-\alpha) x_0^r)$ the average amount of subsistence consumption in the population.

2.1.2 Environmental preferences

Aggregate consumption of the carbon-intensive good results in emissions that lead to climate change, thus degrading environmental quality $E(X)$ (with $E(X) \geq 0$ and $\frac{\partial E}{\partial X} < 0$). Households do not take into account the externality resulting from their consumption of the carbon-intensive good in their consumption choice, but have a preference over the economy's mitigation performance, i.e. environmental quality. The literature on optimal carbon taxation and on the political economy of carbon taxation usually models additive environmental damages (e.g.,Aubert and Chiroleu-Assouline 2019; Jacobs and van der Ploeg 2019; Habla and Roeder 2013), which leads to a negative relationship between income (or expenditure) and support for environmental taxation. This feature is explained by the larger tax payments of richer households, in *absolute value*. Yet, it is at odds with the survey literature, and with the carbon tax incidence literature which uses *relative* tax burden to study regressivity and fairness issues. Surveys on the determinants of political support find that income has a positive or non-significant effect on tax support (e.g. Levi 2021; Bergquist et al. 2022). I depart from this assumption by using CES preferences over consumption and environmental quality. As will be shown in (3.1.1), this specification results in a more flexible relationship between income and support for the carbon tax. Total utility then writes:

$$
U(c_i, x_i, E) = c_i^{1-\gamma-\beta} (x_i - x_0^h)^{\gamma} E(X)^{\beta}.
$$

Non-additive utility from environmental quality means that the willingness to pay for mitigation increases when basic needs are met. For instance, compare the amount of polluting good consumption x that a household is willing to forego for an additional unit of environmental quality E in this specification relative to the additive case[1]. In the additive case, the amount of carbon-intensive good that the household will forego decreases with consumption of the non-polluting good and does not depend on environmental quality. With the CES specification, the household will forego more consumption of the carbon-intensive good when environmental damages are larger, irrespective of the level of non-polluting good consumption.

2.1.3 Carbon taxation

The polluting good is taxed at a rate τ to mitigate emissions and avoid climate damages. This results in a consumer price for the carbon-intensive good of $q = p + \tau$. Aggregate polluting good consumption decreases with the carbon tax. The proceeding of the tax can be rebated through a lump-sum transfer, T, that adds up to income y_i.

I analyze how the intersecting vertical and horizontal inequalities affect support for the carbon tax. Individual support is modeled as the preferred tax rate of a household, given their income and urban-rural characteristics. Following the literature studying majority voting over an environmental tax, political support is captured by the median voter's preferred tax rate if preferences are single-peaked (Cremer et al., 2004; Habla and Roeder, 2013). The tax supported by the median voter can then be compared to the optimal tax benchmark.

To find the household's preferred tax level, indirect utility is maximized over the tax rate. In the case without transfer, it writes

$$V(q, y_i, x_0^h) \quad = \quad \frac{a}{q^\gamma}(y_i - qx_0^h)^{(1-\beta)} E(X)^\beta,$$

with $a = \frac{(1-\gamma-\beta)^{(1-\gamma-\beta)}\gamma^\gamma}{(1-\beta)^{(1-\beta)}}$. Defining $v(q, y_i, x_0^h) := \frac{a}{q^\gamma}(y_i - qx_0^h)^{(1-\beta)}$, this can be rewritten as

$$V(q, y_i, x_0^h) = v(q, y_i, x_0^h) E(X(q))^\beta,$$

with $v(\cdot)$ indirect utility from consumption and $E(\cdot)^\beta$ from the environmental quality.

[1]The marginal rate of substitution between environmental quality and the emission-intensive good is $MRS_{E,x} = \frac{\frac{\partial U}{\partial E}}{\frac{\partial U}{\partial x}} = \frac{\beta}{\gamma}\frac{(x_i - x_0^h)}{E}$. The marginal rate of substitution with environmental quality entering utility additively, such that $U^{add} = c_i^{1-\gamma}(x_i - x_0^h)^\gamma + E(X)$, is $MRS_{E,x}^{add} = \frac{1}{\gamma}\left(\frac{x_i - x_0^h}{c_i}\right)^{1-\gamma}$.

2.2 Social planner tax rate

I characterize the pigouvian tax, chosen by a social planner maximizing the weighted sum of indirect utilities over the carbon tax, in the absence of lump-sum transfers. The social planner solves

$$\max W = \theta \int_{y^-}^{y^+} V(q, y_i, x_0^u) dF(y_i^u) + (1-\theta) \int_{y^-}^{y^+} V(q, y_i, x_0^r) dF(y_i^r)$$

with $\theta = \frac{\alpha\omega^u}{\alpha\omega^u + (1-\alpha)\omega^r}$ the generalized weight of urbans and ω^h the social weight associated to households of type h.

After some algebra (see Appendix A.1), the first order condition for the social planner results in the following implicit optimal tax rate

$$\tau_{sp} = \frac{\beta \varepsilon_{E,\tau}}{\frac{\gamma}{q_{sp}} + (1-\beta)\left(\frac{\theta x_0^u \mathbb{E}\left[(y_i - q_{sp}x_0^u)^{-\beta}\right] + (1-\theta) x_0^r \mathbb{E}\left[(y_i - q_{sp}x_0^r)^{-\beta}\right]}{\theta \mathbb{E}\left[(y_i - q_{sp}x_0^u)^{(1-\beta)}\right] + (1-\theta)\mathbb{E}\left[(y_i - q_{sp}x_0^r)^{(1-\beta)}\right]}\right)}, \tag{2}$$

with $\varepsilon_{E,\tau} \coloneqq \frac{\partial E}{\partial \tau}\frac{\tau}{E(X)}$ the tax elasticity of environmental quality. The optimal carbon tax rate equalizes the social marginal costs and benefits. The costs reflect the welfare loss from a more expensive carbon-intensive good, which depends on the demand shift towards non-polluting consumption and the subsistence amount of emission-intensive consumption that cannot be substituted. The social planner weights the losses of rural and urbans with their share in the population α as well as the equity weights ω. The benefits stem from the reduction in emissions which are determined by the tax-elasticity of environmental quality.

3 Support for carbon taxation and median voter tax

3.1 Characteristics of household support for carbon taxation

Next, I characterize the preferred tax rate of each household, with respect to their income and urban-rural type. The program for a household with income y_i and type $h = \{u, r\}$ is

$$\max_{\tau} V(q, y_i, x_0^h) = v(q, y_i, x_0^h) E(X(q))^{\beta}.$$

Applying Roy's identity to consumption sub-utility $v(q, y_i, x_0^h)$, i.e. $\frac{\partial v()}{\partial \tau} = -\frac{\partial v()}{\partial y_i} x_i^*$, the first-order condition of the household is

$$\frac{\partial V()}{\partial \tau} = -\frac{\partial v}{\partial y_i} x_i^* E(X(q))^\beta + v(q, y_i, x_0^h) \frac{\partial E(X(q))^\beta}{\partial \tau} = 0. \tag{3}$$

After some algebra and using $\varepsilon_{E,\tau} = \frac{\partial E}{\partial \tau} \frac{\tau}{E(X)}$, the tax elasticity of environmental quality, the preferred tax rate τ of household i of type h can be written implicitly as

$$\tau^h(y_i) = \frac{\beta \varepsilon_{E,\tau}}{\frac{\gamma}{q} + (1-\beta)\frac{x_0^h}{y_i - q x_0^h}}.$$

Compared with equation (2), the household takes into account the same benefits from mitigating climate change, but only considers their own cost, which depends on their income and constrained consumption of the carbon intensive good. It appears that income increases the preferred level of tax, while constrained consumption decreases it. Because this equation only implicitly defines the preferred level of tax, I derive these relationships more robustly in what follows.

3.1.1 Effect of income household preferred tax rate

I assume that the environmental utility function $E()$ is such that preferences are single-peaked (locally concave, as shown in Appendix A.2). The voter's preferred tax rate is defined implicitly by equation (3) so the comparative statics needed to characterize the median voter must be derived by implicit differentiation. Let

$$\begin{aligned} G(\tau^h(y_i), y_i) &= -\frac{\partial v(\tau^h(y_i), y_i, x_0^h)}{\partial y_i} x_i^*(\tau^h(y_i), y_i) E(X(\tau^h(y_i)))^\beta \\ &\quad + v(\tau^h(y_i), y_i, x_0^h) \frac{\partial E(X(\tau^h(y_i)))^\beta}{\partial \tau}, \end{aligned}$$

with $\tau^h(y_i)$ the solution to the problem of a voter of type h with income y_i and $G(\tau(y_i), y_i) = 0$. The effect of income on preferred tax rate is

$$\frac{\partial \tau^h(y_i)}{\partial y_i} = -\frac{\frac{\partial}{\partial y_i} G(\tau^h(y_i), y_i)}{\frac{\partial}{\partial \tau} G(\tau^h(y_i), y_i)}$$

with $\frac{\partial G(\tau^h(y_i),y_i)}{\partial \tau} = \frac{\partial^2 V(\tau^h(y_i))}{\partial \tau^2} < 0$ by local concavity (Appendix A.2). Using short notation,

$$\text{sign}\left(\frac{\partial \tau^h(y_i)}{\partial y_i}\right) = \text{sign}\left(-\frac{\partial v}{\partial y_i}\frac{\partial x_i^*}{\partial y_i}E^\beta - \frac{\partial^2 v}{\partial y_i^2}x_i^* E^\beta + \frac{\partial v}{\partial y_i}\frac{\partial E^\beta}{\partial \tau}\right).$$

There are two opposing effects. On the one hand, an increase in income raises the demand for carbon-intensive consumption and increases the indirect utility cost of the tax. On the other hand, an increase in income reduces the marginal utility of consuming the carbon-intensive good and increases the benefits of mitigation. Either effect can dominate depending on the trade-offs between carbon-intensive consumption and environmental quality, as described in the following proposition:

Proposition 1. *When carbon-intensive subsistence expenditure is strictly positive and strictly below income* ($0 < \frac{qx_0^h}{y_i} < 1$)*, the preferred tax rate of a household of type* h *and income* y_i *increases weakly with income if and only if*

$$\varepsilon_{E,q} + \frac{1}{\left(\frac{qx_0^h}{y_i}\right)^{-1} - 1} \geq \frac{\gamma}{\beta}.$$

Proof: Appendix A.4.

The left-hand side captures the effect of marginal income on willingness to mitigate. The first term, the price elasticity of environmental quality $\varepsilon_{E,q}$, reflects how effectively a higher carbon tax reduces emissions. The second term captures the effect of carbon-intensive subsistence consumption. A larger budget share of subsistence consumption $\frac{qx_0^h}{y_i}$ makes mitigation less affordable and increases the impact of marginal income on willingness to mitigate. The right-hand side is the ratio of the marginal budget share of carbon-intensive consumption γ (before rescaling by environmental concerns) to the environmental quality preference parameter β.

Proposition 2. *(Corner cases)*

When carbon-intensive subsistence expenditure is zero, the preferred tax rate increases weakly with income if and only if $\beta\varepsilon_{E,q} \geq \gamma$.

When carbon-intensive subsistence expenditure equals income, an increase in income always results in a (weakly) increase in preferred tax.

Proof: Appendix A.4.

3.1.2 Effect of urban-rural type on household preferred tax rate

Next, I compare the preferred tax rate of a rural and an urban household with the same level of income. To do so, I consider the difference in the first derivative of the indirect utility of an urban and a rural household, given the same tax rate. I then evaluate this difference at the preferred tax of an urban household with the given income, and characterize the gap in preferred tax rates[2]. The subtraction of equation (3) for both types, evaluated at the same income y and at the preferred tax rate of the urban τ^u, writes

$$\frac{\partial}{\partial \tau} V_i^r \left(\tau^u(y), y\right)\Big|_y = \frac{\partial V^r}{\partial \tau}(\tau^u(y), y) - \frac{\partial}{\partial \tau} V^u(\tau^u(y), y) < 0$$

Proposition 3. *For a same level of income, a rural household prefers a strictly lower tax rate than an urban household.*

Proof: Appendix A.5.

This reflects the cost of the larger subsistence consumption of carbon-intensive good by the rural household.

3.2 Majority voting

I now turn to country level results. Majority voting captures political support at the aggregate level. This can be thought of as the outcome of a referendum, such as the Swiss cantonal *votations*, or as the opinion of the domestic constituency which is taken into account by the ruling government.

The preferred tax rate of a household is

i) a unique global maximum (single-peaked preferences) if $\frac{\partial}{\partial q}\varepsilon_{E,q} \leq 0$, with $\varepsilon_{E,q}$ the price-elasticity of environmental quality
(*Proof: Appendix A.3*)

ii) weakly increasing with income iff $\varepsilon_{E,q} + \frac{1}{\left(\frac{q x_0^h}{y_i}\right)^{-1} - 1} \geq \frac{\gamma}{\beta}$

iii) lower for a rural household than an urban household, all other things equal.

The result of majority voting can thus be characterized by the tax rate chosen by the median voter (Kramer, 1972) in the whole population. I start by studying the

[2]This can be done because $\frac{\partial}{\partial \tau} V^u \left(\tau^u(y_i), y_i\right) = 0$ by definition of $\tau^u(y_i)$ (solution of the first order condition), and all other parameters in $V()$ are fixed exogenously.

median voter in the urban and rural population separately, then move on to the study of the median voter when all voters are pooled.

3.2.1 Majority voting in the urban and rural populations

Let $\tilde{y}^h$ denote the income of the median voter of type $h = \{u, r\}$, when voters are separated according to their type, along the urban-rural divide. By definition, the income of the median voter inside a type population, $\tilde{y}^h$, is the income such that $F(\tilde{y}^h) = \frac{1}{2}$, with $F^h(\cdot)$ the cumulative distribution of income of households of type h over $[y^-, y^+]$. If income has the same distribution inside the rural and urban populations, the income of the median voter is identical for both populations, i.e. $\tilde{y}^u = \tilde{y}^r$.

A rural household always prefers a strictly lower tax rate than an urban household for a same level of income. Thus, the tax rate chosen by majority voting inside the rural population only is lower than the tax rate inside the urban population only when $\tilde{y}^u = \tilde{y}^r$.

$$\tau^u(\tilde{y}^u) > \tau^r(\tilde{y}^r).$$

3.2.2 Majority voting in the whole population

I now turn to the result of majority voting in the total population, comprised of a proportion α of urbans and $(1 - \alpha)$ of rurals.

At a given level of tax, the cumulative distribution of votes is the sum of the urban and rural distributions, weighted by the proportion of each type in the population. By the median voter theorem, the majority voting tax rate in the whole population is the median voter tax rate τ_{mv} such that

$$\alpha F^u(y^u(\tau_{mv})) + (1 - \alpha)F^r(y^r(\tau_{mv})) = \frac{1}{2},$$

with $y^h(\tau_{mv})$ the income of a voter of type h whose preferred tax rate is τ_{mv}. In the following, let $y^h_{mv} = y^h(\tau_{mv})$ denote the income of the median voter of type h in the total population majority voting.

Under some conditions on the ordering of voters along preferred tax levels, the median voter can be characterized further:

Proposition 4. *If* $\varepsilon_{E,q} + \left(\left(\frac{qx_0^h}{y_i}\right)^{-1} - 1\right)^{-1} \geq \frac{\gamma}{\beta}$ *for all* $y_i \in [y^-, y^+]$ *and* $h = \{u, r\}$, *and if there is no overlap between the preferred tax rates of urbans and rurals (i.e.*

$\tau^r(y^+) < \tau^u(y^-)$), then the median voter is

i) an urban household poorer than the median household when urbans are in majority ($\alpha > \frac{1}{2}$)

ii) a rural household richer than the median household when rurals are in majority ($\alpha < \frac{1}{2}$)

If on the contrary $\varepsilon_{E,q} + \left(\left(\frac{qx_0^h}{y_i}\right)^{-1} - 1\right)^{-1} \geq \frac{\gamma}{\beta}$ for all $y_i \in [y^-, y^+]$ and $h = \{u, r\}$, and if there is no overlap between the preferred tax rates of urbans and rurals (i.e. $\tau^r(y^-) < \tau^u(y^+)$), then the median voter is

i) an urban household richer than the median household when urbans are in majority ($\alpha > \frac{1}{2}$)

ii) a rural household poorer than the median household when rurals are in majority ($\alpha < \frac{1}{2}$)

Under either of these two sets of conditions, the urban-rural inequality in subsistence carbon-intensive consumption is sufficiently large to lead to a polarization of votes along the urban-rural divide. The polarization means that no household from the group (urban or rural) in minority supports the majority voting tax.

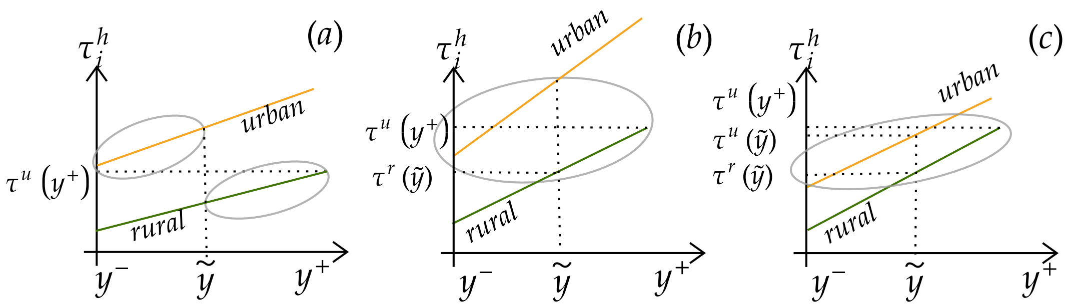
When these conditions do not hold, the median voter can be either an urban, a rural, or both an urban and a rural household with different incomes. The different cases are illustrated in Figure 1.

3.2.3 How does the majority voting tax rate compare to the social planner rate?

The majority voting tax rate can now be compared to the social planner benchmark to analyze whether income and urban-rural inequalities lead to insufficient political support for the socially optimal carbon tax. I evaluate the first order condition of the social planner at the majority voting tax rate. A strictly positive value of the evaluated social planner first order condition implies that the majority voting tax rate is lower than the pigouvian rate.

Proposition 5. *Denoting $q_{mv} = p + \tau_{mv}$ the carbon-intensive good price at the majority voting tax rate and y^h_{mv} the income of the median voter of type h, the majority voting tax rate τ_{mv} is strictly lower than the social planner tax rate τ_{sp} if*

Figure 1: Majority voting tax rate when $\frac{\partial \tau^h(y_i)}{\partial y_i} \geq 0$



Note: The graph shows how the preferred tax rate changes with income between minimum income y^- and maximum income y^+, for urban and rural households. The gray circles represent the possible location of the median voter in terms of income and urban-rural dimensions.
Panel (a) displays the case in which there is no overlap between the tax rates of the rural and the urban, which leads to a polarized majority vote. In panel (b), the median voter can be either a rural, an urban household, or both. In panel (c), the median voter tax rate is always the preferred tax rate of both an urban and a rural.

and only if

$$(\beta\varepsilon_{E,q} - \gamma)\left(\sum_{j=\{u,r\}}\left(\theta^j \mathbb{E}\left[(y_i - q_{mv}x_0^j)^{1-\beta}\right]\right) - (y_{mv}^h - q_{mv}x_0^h)^{1-\beta}\right)$$
$$-(1-\beta)\left(\sum_{j=\{u,r\}}\left(\theta^j \frac{q_{mv}x_0^j}{\mathbb{E}\left[(y_i - q_{mv}x_0^j)^{\beta}\right]}\right) - \frac{q_{mv}x_0^h}{(y_{mv}^h - q_{mv}x_0^h)^{\beta}}\right) > 0 \qquad (4)$$

with $\theta^u = \theta$ and $\theta^r = 1-\theta$ the generalized welfare weight.

Proof: Appendix A.6.

Whether τ_{mv} is smaller or larger than is socially optimal depends on how the individual costs of the median voter compare to the social evaluation of the cost for the whole population. The first term corresponds to the relative strength of preference for mitigation versus carbon-intensive consumption. When the marginal willingness to pay to improve environmental quality ($\beta\varepsilon_{E,q}$) is larger than the adjusted marginal budget share for the polluting good (γ), the preferred tax rate increases with income (Proposition 1). The social planner takes into account a socially weighted income, net of type-specific subsistence expenditure and aggregated over the whole distribution. If this socially weighted net income is larger than the net of subsistence expenditure income of the median voter, and if, in addition, the tax rate increases with income, then the social planner carbon tax tends to be larger than the majority voting tax.

The second term captures the additional cost of the tax from the constrained consumption of the carbon-intensive good. The median voter only takes into account their own subsistence expenditure, which is larger if the median voter household is rural rather than urban. On the other hand, the social planner considers a socially weighted average of the cost for both urban and rural households. Thus having a rural median voter tends to push the majority voted tax to a lower level than the social planner tax.

To get further insights into the role of income and urban-rural inequality, this result can be contrasted with the special case in which there is no subsistence consumption, i.e. $x_0^h = 0$ for urban and rural households. In this case, the necessary and sufficient condition for the majority voting tax rate to be strictly lower than the social planner rate is

$$(\beta\varepsilon_{E,q} - \gamma)\left(\mathbb{E}\left[{y_i}^{1-\beta}\right] - \left(y_{mv}^h\right)^{1-\beta}\right) > 0$$

The second term in equation (4) disappears since it reflected horizontal heterogeneity, and only the term capturing the relative preference for mitigation and polluting consumption remains. In the absence of any urban-rural inequality, the median voter will earn the population's median income, i.e. $y_{mv}^h = \tilde{y}$. When the preferred tax rises with income ($\beta\varepsilon_{E,q} - \gamma > 0$), the skew of the income distribution towards higher income leads the majority tax rate to be lower than the social planner tax.

3.2.4 Impact of transfers on majority voting carbon tax

The government can recycle the revenues generated by the carbon tax to the households. Transfers can be lump-sum or targeted on demographic variables, such as to urban or rural households or to households with income lower than a given threshold.

Households do not anticipate the effect of the tax on the transfer amount they will individually receive; which implies that transfers are treated by households as additional income.

Furthermore, keeping the same level of carbon tax, redistribution is likely to increase the level of greenhouse gas emissions in aggregate. This rebound effect is due to the increase in income for part or all of the population that partly translates into increased consumption of the carbon-intensive good. I assume that households are myopic about the rebound effect. The government, on the other hand, factors in the change in aggregate emissions due to the transfer. The government budget constraint is thus

$$nT = \tau X\left(q, \bar{y}, T\right),$$

with n the proportion of the population receiving the transfer.

Replacing the expression for aggregate emissions and solving for the transfer yields

$$T = \frac{\tau}{n\left((1-\beta) - \gamma\frac{\tau}{q}\right)}\left[\frac{\gamma}{q}\bar{y} + (1-\gamma-\beta)\bar{x}_0\right].$$

Transfers reduce the absolute cost of the tax for the households receiving them. However, they do not necessarily result in political support for higher carbon tax rates. Transfers can increase this political support only if the marginal income they bring translates into more demand for mitigation than for carbon-intensive consumption. This leads to the following condition:

Proposition 6. *Transfers to households increase the carbon tax rate which is supported by majority voting if* $\varepsilon_{E,q} + \frac{1}{\left(\frac{qx_0^h}{y_i}\right)^{-1} - 1} \geq \frac{\gamma}{\beta}$ *for all* y_i.

Proof: Transfers enter the household budget as additional income. Proposition 1 gives the condition for an increase in income to result in a higher preferred tax rate.

Because the tax chosen by majority voting can only be characterized implicitly, I perform numerical simulations to shed light on the magnitudes of the political support effects captured in the model. The next section illustrates the majority voting results and provides further insights into the potential of different transfer schemes to improve equity and political support for carbon taxation.

4 Calibration of the model to European countries

The model is calibrated with European data. I use fuels and domestic energy expenditures as a proxy for carbon-intensive consumption. These consumption categories correspond to the notion of a heterogeneous subsistence consumption, with consumers constrained in the short-term. In addition, price shifts due to a carbon tax tend to have a large pass-through (e.g., Harju et al., 2022 on gasoline) and be salient for these categories of goods. Because households and the social planner factor in the post-tax price only, I set the pre-tax relative price to 1 to make interpretation more straightforward.

4.1 Parameter calibration

I use the latest round of the Eurostat Household Budget Survey (Eurostat, 2015). Variables are harmonized across countries which facilitates cross country comparisons.

4.1.1 Income and share of urbans and rurals

The income distribution $F(\cdot)$ is calibrated for each country and separately for urbans and rurals, by assuming a truncated log-normal distribution $Lognormal(\mu_h, \sigma_h^2)$, with $\mu_h = \ln(\tilde{y}_h)$ and $\sigma^2 = 2(\ln(\bar{y}_h) - \mu_h)$. Mean and median income $\bar{y}_h$ and $\tilde{y}_h$ are calibrated using total consumption expenditure[3] per adult from the Household Budget Survey. For the minimum and maximum income, y^- and y^+, I use the 1st and 99th percentile of the consumption expenditure distribution.

For the horizontal inequality, i.e. the urban-rural type, I use the population density level variable. It can take three values: Densely populated (at least 500 inhabitants/km2), Intermediate (between 100 and 499 inhabitants/km2) and Sparsely populated (less than 100 inhabitants/km2). I use the share of households living in densely populated areas as the share of urbans α, and the share in either intermediate or sparsely populated areas as the share of rurals $(1 - \alpha)$.

4.1.2 Estimation of the demand for carbon-intensive goods

To calibrate the subsistence amount of the carbon-intensive good x_0^h, I estimate a demand system using the Household Budget Survey. I drop the countries for which the necessary data (fuels, energy expenditure and density of population) is not available or of bad quality.

The linear expenditure system (LES) (Pollak and Wales, 1969) is the demand system derived from a Stone-Geary specification. From the demand equation (1),

[3] Total consumption expenditure fits better to the notion of income used in this paper. The expenditure-elasticity of emissions is closer to 1 than the total income elasticity, due to different propensities to save across income groups.

expenditure can be rewritten as

$$qx_i = qx_0^h + \frac{\gamma}{1-\beta}\left(y_i - qx_0^h\right).$$

This results in an Engel curve for the carbon-intensive good which is linear in income with origin qx_0^h. As a preliminary check of whether this specification is a good enough fit to the data, I compute for each country the mean expenditure by quintile of total expenditure, for urbans and rurals. As shown in Figures 4 and 5 in Appendix B, a linear Engel curve for fuel and energy expenditure appears to be a reasonable approximation. Horizontal inequality, i.e. the difference in mean expenditure between urban and rurals, appears to be large in some countries and negligible in others.

The assumption of linearity in estimating the Linear Expenditure System parameters involves estimating a system of equations for J goods such that

$$p_j x_j = p_j x_{0j} + \lambda_j \left(y_i - \sum_m p_m x_{0m} \right)$$

with $p_j x_j$ the overall expenditure on good j, $p_j x_{0j}$ the subsistence expenditure on good j, λ_j the marginal budget share of good j, and y_i total expenditure. I construct the polluting good expenditure by aggregating the COICOP categories "Electricity, gas and other fuels" under Housing and "Fuels and lubricants" under Transport.

The difference in subsistence consumption due to the urban-rural divide can be estimated either by estimating the demand system separately on the rural and the urban subpopulations, or by a translation procedure (Pollak and Wales, 1978). The translation procedure specifies that the subsistence amounts depends on the demographic variable. Finally, assuming no subsistence consumption for the rest of expenditure to avoid singularity, I estimate for each country

$$p_i x_i = (\chi_{0,1} + \mathbb{1}_{h=r}\chi_{0,2}) + \gamma y_i$$

with $p_i x_i$ the expenditure in good i, $\chi_{0,1} = px_0^u$ the constrained expenditure of an urban, and $\chi_{0,2} = px_0^r - px_0^u$ the additional constrained consumption of a rural household with respect to that of an urban household.

4.1.3 Environment

I chose the environmental quality function to be

$$E(X) = 1 - \frac{X(q)}{X(p)}.$$

$E(X)$ is positive when emissions are reduced with respect to the baseline case without carbon taxation, and negative if they increase. The choice of pre-tax emissions $X(p)$ as the baseline and the CES type elasticity imply that a positive tax rate will always be chosen.

The parameter that determines preference over the environment, β, cannot be directly calibrated given the data. I find the value β which leads to a fixed and pre-defined optimal emissions reduction. This is as if an emission reduction target was fixed, which reveals the preference for mitigation of the social planner given the other model parameters. I choose a 10% emissions reduction in each country, i.e. $E(X) = 0.1$. This corresponds to a short-term and relatively strong reduction. For instance, the Fit for 55 package adopted by the European Commission in 2021 sets a target to reduce emissions by 55% by 2030, relative to 1990 emissions levels. Given that emissions have already decreased by around 25% between 1990 and 2020, an average reduction of around 5% per year between 2020 and 2030 is needed to reach the 55% reduction goal.

4.2 Results

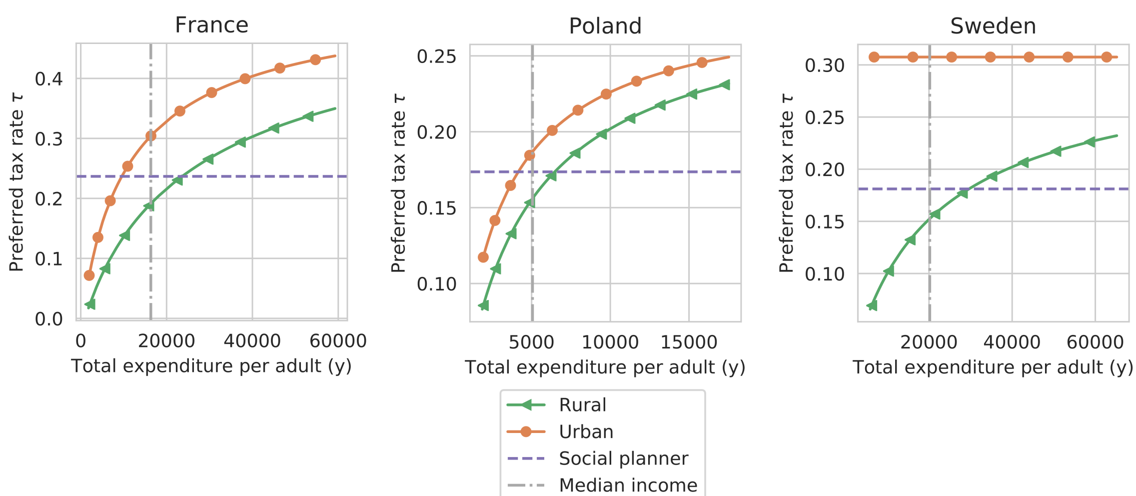
The results of the empirical estimation are shown in Figures (6) and (7), with the detail in Table 2. I solve numerically for the tax rate which maximizes indirect utility of the household of type $h = \{u, r\}$ and income y_i. The median voter tax rate in the urban population only (resp. rural only) is the tax rate preferred by the urban (resp. rural) household with median income, $\tau^u(\tilde{y})$ (resp. $\tau^r(\tilde{y})$). The majority voting tax rate is the tax such that $\alpha F(y^u_{mv}(\tau_{mv})) + (1-\alpha)F(y^r_{mv}(\tau_{mv})) = 0.5$, with $y^h \sim \text{Lognormal}(\mu^h, (\sigma^h)^2)$ on the support $[y^-, y^+]$. The optimal tax solves the social planner program, with equal weight on the urban and rural households, $\omega^r = \omega^u = 1$.

I analyze political support for carbon taxation, the role of urban-rural inequality and the distributive and support impacts of redistribution of the tax revenues. In what follows, I show graphical representation of the calibration results for selected countries. The graphs for all countries can be found in Appendix (B.3).

4.2.1 Impact of income and urban-rural type on political support

For all the calibrated countries, I find a (weakly) positive effect of income and preferred tax rate. For Finland, Hungary and Sweden (cf. Figure (8)) the effect of income on the preferred tax rate of the urbans is null. This is because the estimate of subsistence expenditure for the urban was non-significant or slightly negative, which results in no subsistence expenditure for the urban households in these case. The effect of income on the level of preferred tax rates is larger at lower levels of income. In addition, the gap between the preferred tax rate of urban and rural households with the same level of income decreases with income. This concavity reflects the loosening of the constraint from subsistence consumption of the carbon-intensive good. These findings are illustrated in Figure 2 for France, Poland and Sweden.

Figure 2: Effect of income and urban-rural type on calibrated preferred tax rates



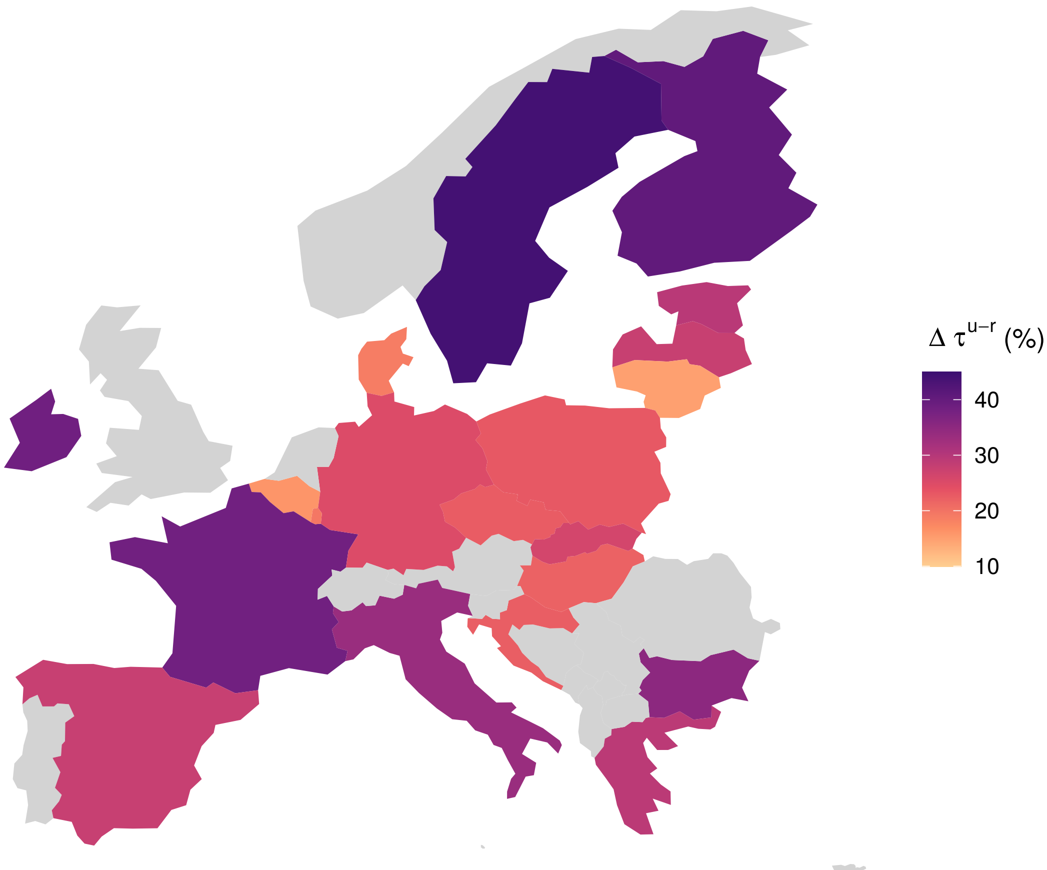
More precisely, the impact of the higher subsistence consumption of the carbon-intensive good of rurals on the political support for carbon taxation can be captured by comparing the tax rate of the median voter inside the urban and rural populations separately. I compare the tax preferred by an urban household earning the median income, to the one preferred by a rural household earning the median income, dividing by the urban's tax to capture the gap as a proportion :

$$\Delta\tau^{u-r}(\tilde{y}) = \frac{\tau^u(\tilde{y}) - \tau^r(\tilde{y})}{\tau^u(\tilde{y})}.$$

Figure 3 displays this gap for all the calibrated countries, in percentage. It shows that the tax rate of a household with the median income is between 10 and 40%

lower for a rural than an urban household. Sweden, France, Finland and Ireland are found to be the countries with the larger gap.

Figure 3: Gap between the median voter tax rates in the urban vs rural population, as a share of median voter tax rate in the urban population, in %



Note: $\Delta\tau^{u-r} = \frac{\tau^u(\tilde{y})-\tau^r(\tilde{y})}{\tau^u(\tilde{y})}$.

Turning to the difference between the social planner tax rate τ_{sp}, with equal weights on rural and urban households, and the majority voting tax rate τ_{mv}, I find that the majority voting tax rate is lower than the social planner's in every country. As shown in Table 1, the difference is between 1 and 7.8 %. The gap is smaller than between urban's and rural's median households tax rates. This indicates that although the optimal tax rate is close to achieving support from half of the population, this support is polarized along the urban-rural dimension. The optimal tax rate also takes into account the heterogeneity in tax burden and additional cost for the rurals. If social weights are skewed towards urban households' welfare, the gap between optimal and majority voting rates increases.

Table 1: Calibration results, without transfers

Country	τ_{sp}	τ_{mv}	$\Delta\tau_{sp/mv}(\%)$	$\Delta\tau^{u/r}(\%)$
Belgium	0.425	0.397	6.7	16
Bulgaria	0.146	0.140	4.3	35.1
Czech Republic	0.226	0.221	2.1	22.6
Germany	0.249	0.238	4.2	25
Denmark	0.189	0.182	3.9	18.8
Estonia	0.207	0.193	6.8	29.5
Greece	0.203	0.192	5.2	29.3
Spain	0.168	0.166	1	27.8
Finland	0.166	0.153	7.7	40.4
France	0.237	0.228	3.7	38.4
Croatia	0.147	0.143	3	22.5
Hungary	0.131	0.124	5.7	22
Ireland	0.215	0.213	1.1	38.5
Italy	0.188	0.180	4.3	33.5
Lithuania	0.128	0.126	1.5	14.9
Luxembourg	0.258	0.246	4.9	19.5
Latvia	0.162	0.155	4.5	27.7
Poland	0.174	0.166	4.5	23
Sweden	0.181	0.167	7.8	43.9
Slovakia	0.257	0.245	4.4	26.2

4.2.2 Distributional and political support impacts of lump-sum transfers

Next, I focus on the impact of redistributing the revenues generated by the carbon tax through transfers. I analyze three transfer options: lump-sum, targeted at households with income below the median and targeted at rural households.

The transfer amount is computed from the majority voting tax rate in the absence of transfers, i.e.,

$$T = \frac{\tau_{mv}}{n\left((1-\beta)-\gamma\frac{\tau_{mv}}{p+\tau_{mv}}\right)}\left[\frac{\gamma}{p+\tau_{mv}}\bar{y}+(1-\gamma-\beta)\bar{x}_0\right],$$

with $n = 1$ if transfers are lump-sum, $n = \alpha F^u(\tilde{y}) + (1-\alpha)F^r(\tilde{y})$ if transfers are income-based and $n = (1-\alpha)$ if transfers are targeted to the rural households.

Before redistribution, carbon taxation is regressive due to subsistence consumption. Regressivity is stronger inside the rural population, due to the larger amount of subsistence consumption. Lump-sum transfers render the tax and rebate scheme progressive overall, but leaves the urban households better than the rural households. Carbon tax and lump-sum transfers thus result in horizontal distributional effects, between rural and urban households. Income-based transfers result in even stronger progressivity of revenue recycling, but only below the median income. Finally, rural targeted transfers reverse the regressivity of the tax carbon, but for rural households only. Focusing on the first income quintile in each country, Figure (10) demonstrates that urban households benefits the most from income-based transfers. Urban households gain up to 5% of their income in net from the carbon tax and rebate scheme. As shown in Figure (9), rural households in the first quintile benefit the most from either income-based or rural-only transfers, depending on the country. In many countries, income-based transfers tend to have a better incidence at the bottom of the distribution than income-based transfers, with rural households in the first quintile gaining up to 6% of their income in net.

I analyze the effect of redistribution on political support and urban-rural support polarization, looking at the induced change in the majority voting tax rate. Figure (12) shows that transfers targeted at households below the median income or targeted at rural households tend to result in a larger decrease in the urban-rural gap in political support, compared to lump-sum transfers. However, this is not the case for countries where the rural population is richer on average than the urban population (Belgium, Germany, Finland, and Luxembourg, c.f. Table (3)). Additionally, income-based transfers tend to reduce urban-rural polarization more than transfers targeted at rural households in eastern European countries such as Poland, the Czech Republic, or Estonia. These countries tend to have a high marginal propensity to consume carbon-intensive goods and a spatial income distribution in which poor households live in rural areas.

Lastly, Figure (11) displays the impact of transfers on the majority voting carbon tax, compared with the benchmark social planner tax. The social planner tax increases by 5%-18%, in part due to the rebound effect in greenhouse gas emissions that the households do not consider. Transfers increase the majority voting tax rate by a small percentage. This increase can be interpreted as the "pure" effect of changes in the tax incidence, without factoring in the rebound effect nor the relationship between the tax rate and transfer amount, and when households have the same preferences for the environment as the social planner. As Figure (11) shows, no transfer type stands out in terms of its effect on political support. Transfers directed at rural households do not appear to improve carbon tax acceptability more than lump-sum transfers. These transfers, which pose informational and efficiency issues, are thus not justified on grounds of acceptability.

4.2.3 Robustness checks

I test the robustness of the results to the level of the emission reduction target. I set the emissions reduction target at 5% instead of 10%. As shown by comparing Figures (13)-(16) in Appendix B.4.1 to Figures (9)-(12) in Appendix B.3, a less stringent climate target changes the magnitude but not the direction and overall pattern of the results.

5 Conclusion

I have analyzed political support for carbon taxation and the impact of horizontal distributive effects. Political support is captured through a majority voting model in which households differ with respect to the minimum amount of emission-intensive good they are constrained to consume, as well as the income they earn. According to the theoretical model, income can have a positive or negative effect on household's preferred tax rate, depending on the relationship between the price-elasticity of environmental quality, the preference over carbon-intensive consumption and mitigation, and the level of expenditure for subsistence carbon-intensive goods. Income and urban-rural inequalities jointly determine the majority voting tax rate and the corresponding median voter.

I then calibrate the model to twenty European countries and a ten percent emission reduction. I find that the political support of households increases with income and for urban households with respect to rural households. That is to say, political support increase when the budget constraint from the subsistence consumption of the carbon-intensive good slackens. The results show that the majority voting tax is 1-8% lower than the optimal carbon tax. However, the gap in accepted carbon tax between the median urban household and the median rural household is larger, with the median rural household's preferred tax up to 16-44% lower than the median urban household's preferred tax. I find that redistributing the revenues of the carbon tax as a lump-sum transfer renders the regressive tax scheme progressive.

However, lump-sum redistribution does not correct for the horizontal inequality and has limited, albeit positive, impact on political support.

These results yield mixed policy implications. Recycling the revenues generated by a carbon tax has the potential to greatly improve its distributional impact and fairness. However, lump-sum redistribution of tax revenues might not be sufficient to significantly improve political feasibility, especially if a large portion of households remains dependent on carbon-intensive consumption.

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Appendix

A Proofs

A.1 Social planner

The social planner's welfare function can be re-written as

$$W = \left(\theta \int_{y-}^{y^+} v(q, y_i, x_0^h) dF(y_i) + (1-\theta) \int_{y-}^{y^+} v(q, y_i, x_0^h) dF(y_i) \right) E(X)^\beta,$$

which leads to the following first-order condition

$$\begin{aligned} \frac{\partial W}{\partial \tau} = & \left(\theta \int_{y-}^{y^+} \frac{\partial}{\partial \tau} v(q, y_i, x_0^h) dF(y_i) + \theta \omega^r \int_{y-}^{y^+} \frac{\partial}{\partial \tau} v(q, y_i, x_0^h) dF(y_i) \right) E(X)^\beta \\ & + \left(\theta \int_{y-}^{y^+} v(q, y_i, x_0^h) dF(y_i) + (1-\theta) \omega^r \int_{y-}^{y^+} v(q, y_i, x_0^h) dF(y_i) \right) \frac{\partial E(X)^\beta}{\partial \tau} = 0. \end{aligned} \tag{5}$$

Plugging in the indirect utilities and their derivatives with respect to the tax and using LOTUS:

$$\begin{aligned} \frac{\partial W}{\partial \tau} = & -\frac{\gamma}{q} \left(\theta \mathbb{E} \left[(y_i - q x_0^u)^{(1-\beta)} \right] + (1-\theta) \mathbb{E} \left[(y_i - q x_0^r)^{(1-\beta)} \right] \right) E(X)^\beta \\ & -(1-\beta) \left(\theta x_0^u \mathbb{E} \left[(y_i - q x_0^u)^{-\beta} \right] + (1-\theta) x_0^r \mathbb{E} \left[(y_i - q x_0^r)^{-\beta} \right] \right) E(X)^\beta \\ & + \left(\theta \mathbb{E} \left[(y_i - q x_0^u)^{(1-\beta)} \right] + (1-\theta) \mathbb{E} \left[(y_i - q x_0^r)^{(1-\beta)} \right] \right) \beta E(X)^{\beta-1} \frac{\partial E}{\partial \tau} = 0. \end{aligned}$$

Re-ordering finally results in equation 2.

A.2 Local concavity of household's indirect utility

Denote $v(\tau) := \frac{a}{q^\gamma}(y_i - q x_0^h)^{(1-\beta)}$ and $h(\tau) := (E(X(q)))^\beta$, such that $V(\tau) = v(\tau)h(\tau)$. Let $\tau^* = \tau^h(y_i)$ such that $\frac{\partial V(\tau^*)}{\partial \tau} = 0$. The goal is to determine the sign of $\frac{\partial^2 V(\tau^*)}{\partial \tau^2} := V''(\tau^*)$. Dropping τ^* for convenience,

$$V' = v'h + vh' = 0$$

(by the first order condition), and

$$V'' = v''h + 2v'h' + vh''.$$

Next, rewrite

$$\begin{aligned} v' &= -\frac{a}{q^{*\gamma}}(y_i - q^* x_0^h)^{(1-\beta)}\left(\frac{\gamma}{q^*} + (1-\beta)x_0^h(y_i - q^* x_0^h)^{-1}\right) \\ &= -vg \end{aligned}$$

with $q^* := p + \tau^*$ and $g := \frac{\gamma}{q^*} + (1-\beta)x_0^h(y_i - q^* x_0^h)^{-1}$. Hence,

$$\begin{aligned} V'' &= (v'g + vg')\,h + 2(-vg)h' + vh'' \\ &= -gV' - vg'h - vgh' + vh''. \end{aligned}$$

Using the first order condition, i.e. $V' = 0$, results in

$$V'' = -v(g'h + gh' - h'').$$

So $\frac{\partial^2 V(\tau^*)}{\partial \tau^2} < 0$ if $g'h + gh' - h'' > 0$, i.e.

$$\beta(1-\beta)\varepsilon_{E,q}^2 + (2+\gamma)\,\beta\varepsilon_{E,q} - \gamma + (1-\beta)\frac{q^* x_0^h}{y_i - q^* x_0^h}\left(\beta\varepsilon_{E,q} + \frac{q^* x_0^h}{y_i - q^* x_0^h}\right) > 0.$$

In the special case without subsistence consumption of the carbon-intensive good ($x_0^h = 0$), $(g'h + gh' - h'' > 0)$ reduces to $\beta(1-\beta)\varepsilon_{E,q}^2 + (2+\gamma)\,\beta\varepsilon_{E,q} - \gamma > 0$. A sufficient condition for local concavity when $x_0^h = 0$ is for the environmental quality function $E()$ to be such that

$$\varepsilon_{E,q} > \frac{\left((1+\frac{\gamma}{2})^2 + \frac{1-\beta}{\beta}\gamma\right)^{\frac{1}{2}} - \left(1+\frac{\gamma}{2}\right)}{(1-\beta)}.$$

In addition, for $x_0^h > 0$, $(g'h + gh' - h'' > 0)$ also holds when $\beta(1-\beta)\varepsilon_{E,q}^2 + (2+\gamma)\,\beta\varepsilon_{E,q} - \gamma > 0$. Hence, $\varepsilon_{E,q} > \frac{\left((1+\frac{\gamma}{2})^2 + \frac{1-\beta}{\beta}\gamma\right)^{\frac{1}{2}} - \left(1+\frac{\gamma}{2}\right)}{(1-\beta)}$ is a sufficient condition for local concavity $\forall x_0^h$.

A second sufficient condition for local concavity when $x_0^h > 0$, for any environmental function such that $E > 0$ for $\tau \geq 0$ and $\frac{\partial E}{\partial \tau} > 0$ is that the budget share of subsistence consumption is sufficiently large, i.e.

$$\frac{q^* x_0^h}{y_i} > \frac{1}{1 + \left(\frac{1-\beta}{\gamma}\right)^{\frac{1}{2}}}.$$

A.3 Single-peakedness of indirect utility

Suppose that the environmental function $E()$ is such that $\frac{\partial^2 V(\tau^*)}{\partial \tau^2} < 0 \; \forall \tau^*$ such that $V(\tau^*) = 0$ (Appendix A.2). Under this condition, all optima are local maxima. Given that the program is continuous on the domain and the maximization is on one variable only, the absence of any local minimum implies that there is only one optimum. Thus the optimum τ^* is a global maximum.

Next, consider $\grave{q}$ in the neighborhood of q^*, with $\grave{q} > q^*$. By local strict concavity, $\frac{\partial V(\grave{q})}{\partial \grave{q}} < 0$, i.e.

$$\beta(y_i - \grave{q} x_0^h)\varepsilon_{E,q}(\grave{q}) < \gamma y_i + (1 - \gamma - \beta)\grave{q} x_0^h.$$

Now consider $\hat{q}$ arbitrarily far from $\grave{q}$ (i.e. not necessarily in the neighborhood) such that $\hat{q} > \grave{q}$. Then

$$\gamma y_i + (1 - \gamma - \beta)\hat{q} x_0^h > \gamma y_i + (1 - \gamma - \beta)\grave{q} x_0^h$$

and

$$\beta(y_i - \hat{q} x_0^h)\varepsilon_{E,q}(\hat{q}) < \beta(y_i - \grave{q} x_0^h)\varepsilon_{E,q}(\grave{q})$$

under the condition that $\frac{\partial}{\partial q}\varepsilon_{E,q}(q) \leq 0$, which reflects the fact that an increase in the tax has a stronger impact on environmental quality at lower than higher initial prices. Finally, $\hat{q} > \grave{q}$ implies

$$\beta(y_i - \hat{q} x_0^h)\varepsilon_{E,q}(\hat{q}) < \beta(y_i - \grave{q} x_0^h)\varepsilon_{E,q}(\grave{q}) < \gamma y_i + (1 - \gamma - \beta)\grave{q} x_0^h < \gamma y_i + (1 - \gamma - \beta)\hat{q} x_0^h,$$

i.e. $\frac{\partial V(\hat{q})}{\partial \hat{q}} < 0$. Thus, for all $q > q^*$, the indirect utility function $V()$ is strictly decreasing.

Symmetrically, it can be shown that for all $q < q^*$, $V()$ is strictly increase if $\frac{\partial}{\partial q}\varepsilon_{E,q}(q) \leq 0$. Hence, $V()$ is strictly quasi-concave under the condition for local concavity (Appendix A.2) and $\frac{\partial}{\partial q}\varepsilon_{E,q}(q) \leq 0$.

A.4 Effect of income on preferred tax rate

The sign of $A = \left(-\frac{\partial v}{\partial y_i}\frac{\partial x_i^*}{\partial y_i}E^\beta - \frac{\partial^2 v}{\partial y_i^2}x_i^* E^\beta + \frac{\partial v}{\partial y_i}\frac{\partial E^\beta}{\partial \tau}\right)$ needs to be determined. Developing each term yields

$$
\begin{aligned}
A &= \frac{a}{q^\gamma}(y_i - qx_0^h)^{-\beta-1}E^\beta\left(-\frac{\gamma}{q}(y_i - qx_0^h) + \beta\left(\frac{\gamma}{q}y_i + (1-\gamma-\beta)x_0^h\right) - (1-\beta)\left(y_i - qx_0^h\right)\beta\frac{\frac{\partial E}{\partial \tau}}{E}\right) \\
&= \frac{a}{q^\gamma}(1-\beta)(y_i - qx_0^h)^{-\beta-1}E^\beta\left(-\left(\frac{\gamma}{q} - \beta\frac{\frac{\partial E}{\partial \tau}}{E}\right)y_i + \left(\gamma + \beta\left(1 - \frac{\frac{\partial E}{\partial \tau}}{\frac{E}{q}}\right)\right)x_0^h\right)
\end{aligned}
$$

Using the fact $\frac{\partial E}{\partial \tau} = \frac{\partial E}{\partial q}$ for $q = p + \tau$ with p fixed,

$$
A = \frac{a}{q^{1+\gamma}}(1-\beta)(y_i - qx_0^h)^{-\beta-1}E^\beta\left(-\left(\gamma - \beta\varepsilon_{E,q}\right)y_i + \left(\gamma + \beta(1-\varepsilon_{E,q})\right)qx_0^h\right)
$$

with $\varepsilon_{E,q}$ the price elasticity of environmental quality. Hence, a necessary and sufficient condition for $A \geq 0$, i.e. preferred tax weakly increase with income, is

$$
\left(\gamma + \beta(1-\varepsilon_{E,q})\right)qx_0^h \geq \left(\gamma - \beta\varepsilon_{E,q}\right)y_i.
$$

When $0 < x_0^h < y_i$, the condition can be rewritten as

$$
\varepsilon_{E,q} + \frac{1}{\left(\frac{qx_0^h}{y_i}\right)^{-1} - 1} \geq \frac{\gamma}{\beta}.
$$

In the case with no carbon-intensive subsistence consumption, $x_0^h = 0$, the condition reduces to $\beta\varepsilon_{E,q} > \gamma$. Finally, when $qx_0^h = y_i$, the condition boils down to $\beta \geq 0$ which is true by assumption.

A.5 Effect of rural-urban type on preferred tax

The sign of $\left(\frac{\partial}{\partial \tau}V_i^r(\tau_u, y)\Big|_y\right)$, is

$$
\text{sign}\left(-\left(\frac{\partial v_r(\tau_u)}{\partial y_i}x_{ir}^*(\tau_u) - \frac{\partial v_u(\tau_u)}{\partial y_i}x_{iu}^*(\tau_u)\right)E((\tau_u))^\beta + (v_r(\tau_u) - v_u(\tau_u))\frac{\partial E((\tau_u))^\beta}{\partial \tau}\right).
$$

Starting with the first term, $B = -\left(\frac{\partial v_r(\tau_u)}{\partial y_i} x^*_{ir}(\tau_u) - \frac{\partial v_u(\tau_u)}{\partial y_i} x^*_{iu}(\tau_u)\right) E((\tau_u))^\beta$, it can be rewritten as

$$B = -\frac{a}{q(\tau_u)^\gamma} \left(\frac{\frac{\gamma}{q(\tau_u)} y_i + (1-\gamma-\beta) x_0^r}{(y_i - q(\tau_u) x_0^r)^\beta} - \frac{\frac{\gamma}{q(\tau_u)} y_i + (1-\gamma-\beta) x_0^u}{(y_i - q(\tau_u) x_0^u)^\beta} \right) E((\tau_u))^\beta.$$

Given that $x_0^r > x_0^u$, it can be shown that

$$\frac{\gamma}{q(\tau_u)} y_i + (1-\gamma-\beta) x_0^r > \frac{\gamma}{q(\tau_u)} y_i + (1-\gamma-\beta) x_0^u$$

and

$$(y_i - q(\tau_u) x_0^r)^{-\beta} > (y_i - q(\tau_u) x_0^u)^{-\beta}.$$

Hence,

$$\frac{\frac{\gamma}{q(\tau_u)} y_i + (1-\gamma-\beta) x_0^r}{(y_i - q(\tau_u) x_0^r)^\beta} - \frac{\frac{\gamma}{q(\tau_u)} y_i + (1-\gamma-\beta) x_0^u}{(y_i - q(\tau_u) x_0^u)^\beta} > 0$$

and $B < 0$.

Next, the second term $C = (v_r(\tau_u) - v_u(\tau_u)) \frac{\partial E((\tau_u))^\beta}{\partial \tau}$ can be rewritten as

$$C = \frac{a}{q(\tau_u)^\gamma} \left((y_i - q(\tau_u) x_0^r)^{(1-\beta)} - (y_i - q(\tau_u) x_0^u)^{(1-\beta)} \right) \frac{\partial E((\tau_u))^\beta}{\partial \tau}.$$

Using once again the fact that $x_0^r > x_0^u$, it can be shown that

$$(y_i - q(\tau_u) x_0^r)^{(1-\beta)} - (y_i - q(\tau_u) x_0^u)^{(1-\beta)} < 0$$

and as a result, $C < 0$.

Finally

$$\left. \frac{\partial}{\partial \tau} V_i^r (\tau_u, y) \right|_y = B + C < 0.$$

A.6 Comparison of majority voting and social planner tax rate

Subtracting the median voter first order condition to the social planner first order condition evaluated at the majority voting tax rate, $\frac{\partial}{\partial \tau} W(\tilde{\tau}) - \frac{\partial}{\partial} V(\tilde{\tau}, y^h_{mv})$, yields

$$
\frac{a}{\tilde{q}^{\gamma+1}}\left[-\gamma\sum_{j=\{u,r\}}\left(\theta^j\mathbb{E}\left[(y_i-\tilde{q}x_0^j)^{1-\beta}\right]\right)-(1-\beta)\sum_{j=\{u,r\}}\left(\theta^j\frac{\tilde{q}x_0^j}{\mathbb{E}\left[(y_i-\tilde{q}x_0^j)^{\beta}\right]}\right)\right.
$$
$$
\left.+\sum_{j=\{u,r\}}\left(\theta^j\mathbb{E}\left[(y_i-\tilde{q}x_0^j)^{1-\beta}\right]\right)\beta\varepsilon_{E,q}\right]E(X(\tilde{q}))^{\beta}
$$
$$
-\frac{a}{\tilde{q}^{\gamma+1}}\left[-\gamma(y_{mv}^h-\tilde{q}x_0^h)^{1-\beta}-(1-\beta)\tilde{q}x_0^h(y_{mv}^h-\tilde{q}x_0^h)^{-\beta}+(y_{mv}^h-x_0^h)^{(1-\beta)}\beta\varepsilon_{E,q}\right]E(X(\tilde{q}))^{\beta}
$$

with $\theta^u=\theta=\frac{\alpha\omega^u}{\alpha\omega^u+(1-\alpha)\omega^r}$ and $\theta^r=1-\theta$. Re-ordering the terms,

$$
\frac{\partial}{\partial\tau}W(\tilde{\tau})-\frac{\partial}{\partial\tau}V(\tilde{\tau},y_{mv}^h)>0
$$

is equivalent to

$$
\frac{a}{\tilde{q}^{\gamma+1}}E(X(\tilde{q}))^{\beta}\left[(\beta\varepsilon_{E,q}-\gamma)\left(\sum_{j=\{u,r\}}\left(\theta^j\mathbb{E}\left[(y_i-\tilde{q}x_0^j)^{1-\beta}\right]\right)-(y_{mv}^h-\tilde{q}x_0^h)^{1-\beta}\right)\right.
$$
$$
\left.-(1-\beta)\left(\sum_{j=\{u,r\}}\left(\theta^j\frac{\tilde{q}x_0^j}{\mathbb{E}\left[(y_i-\tilde{q}x_0^j)^{\beta}\right]}\right)-\frac{\tilde{q}x_0^h}{(y_{mv}^h-\tilde{q}x_0^h)^{\beta}}\right)\right]>0,
$$

resulting in equation (4).

B Calibration

B.1 Engel curves

Figure 4: Mean per adult energy expenditure, by expenditure quintile and density, 2015
Group of countries with higher mean expenditure

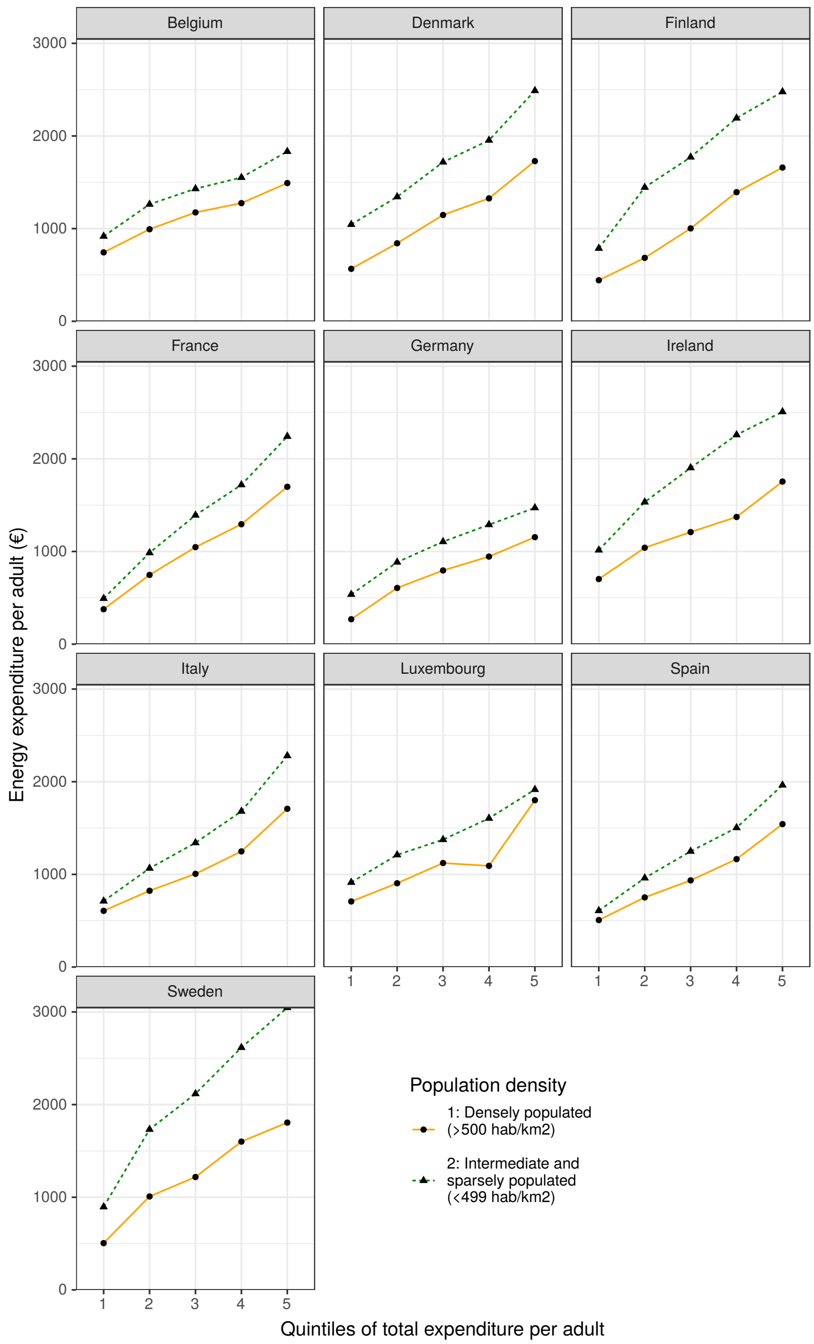
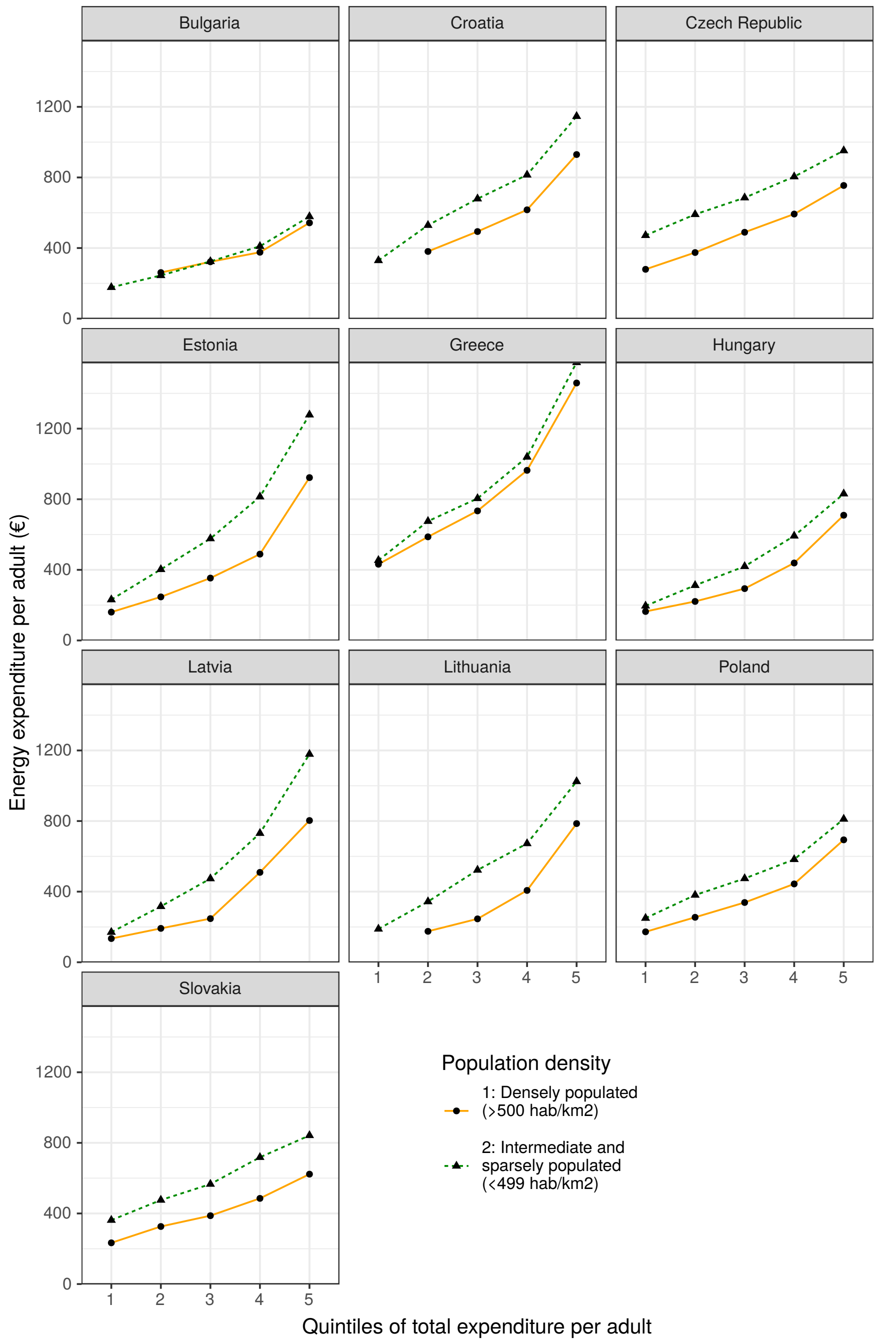
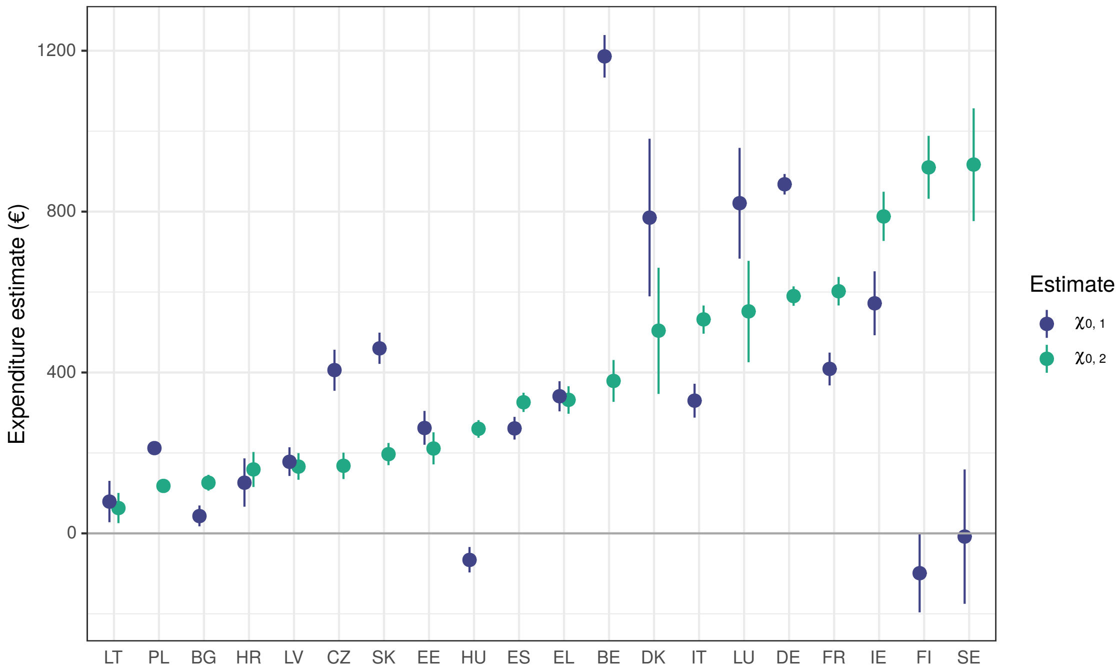


Figure 5: Mean per adult energy expenditure, by expenditure quintile and density, 2015
Group of countries with lower mean expenditure



B.2 Estimation results

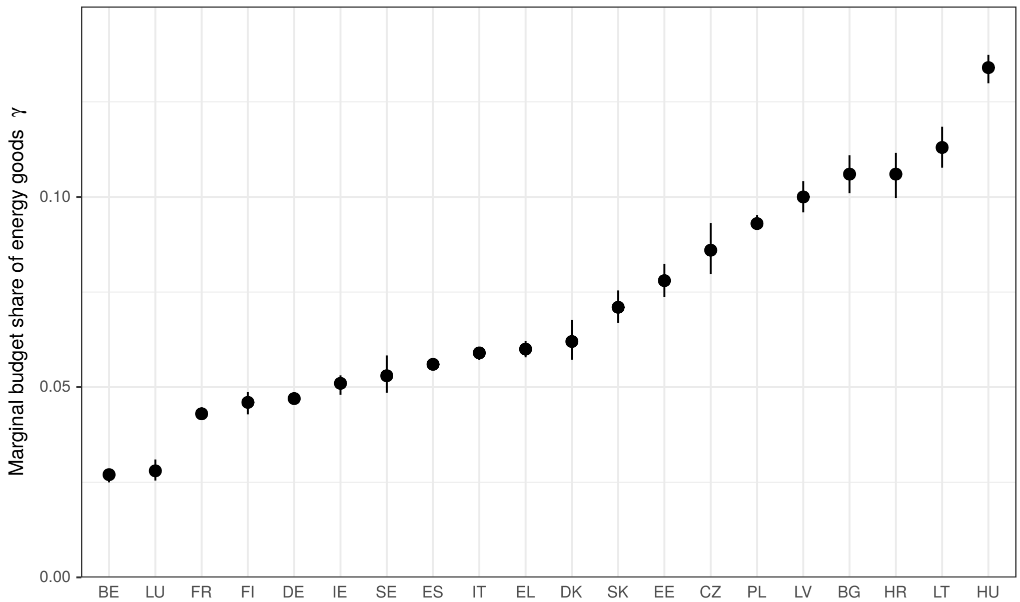
Figure 6: Estimates of subsistence expenditure of energy and fuels



Note: Coefficients with 95%CI for the intercept in the regression of energy and fuels expenditure on total expenditure, $p_i x_i = (\chi_{0,1} + \mathbb{1}_{h=r}\chi_{0,2}) + \gamma y_i$. $\chi_{0,2}$ *is the estimated additional expenditure of rurals (households in intermediate and less populated areas, with less than* 499 *hab/km²).*

BE: Belgium, BG: Bulgaria, CZ: Czech Republic, DE: Germany, EE: Estonia, EL: Greece, ES:Spain, FI: Finland, FR: France, HU: Hungary, HR: Croatia, IE: Ireland, IT: Italy, LU:Luxembourg, LT: Lithuania, LV: Latvia, PL: Poland, SE: Sweden, SK: Slovakia.

Figure 7: Estimates of marginal budget share for fuel and energy



Note: Coefficients with 95%CI for total expenditure in the regression of energy and fuels expenditure on total expenditure, $p_i x_i = (\chi_{0,1} + \mathbb{1}_{h=r}\chi_{0,2}) + \gamma y_i$.
BE: Belgium, BG: Bulgaria, CZ: Czech Republic, DE: Germany, EE: Estonia, EL: Greece, ES:Spain, FI: Finland, FR: France, HU: Hungary, HR: Croatia, IE: Ireland, IT: Italy, LU:Luxembourg, LT: Lithuania, LV: Latvia, PL: Poland, SE: Sweden, SK: Slovakia.

Table 2: Linear Expenditure System estimation for fuel and energy expenditures, 2015

Country	$\chi_{0,1}$	$\chi_{0,2}$	γ
Belgium	1186***	379***	0.027***
	(27)	(26.5)	(0.001)
Bulgaria	43***	126***	0.106***
	(13.2)	(10)	(0.003)
Czech Republic	406***	168***	0.086***
	(26)	(16.7)	(0.003)
Germany	868***	590***	0.047***
	(13)	(12.3)	(0)
Denmark	785***	504***	0.062***
	(99.9)	(80)	(0.003)
Estonia	262***	211***	0.078***
	(21.4)	(20.4)	(0.002)
Greece	341***	332***	0.06***
	(19.1)	(17.4)	(0.001)
Spain	261***	326***	0.056***
	(14.4)	(12.2)	(0.001)
Finland	-99**	910***	0.046***
	(49.8)	(39.9)	(0.001)
France	409***	602***	0.043***
	(20.8)	(18.1)	(0.001)
Croatia	126***	159***	0.106***
	(30.6)	(22.2)	(0.003)
Hungary	-66***	260***	0.134***
	(16.1)	(11.2)	(0.002)
Ireland	572***	788***	0.051***
	(40.5)	(31.2)	(0.001)
Italy	330***	532***	0.059***
	(21.5)	(17.9)	(0.001)
Lithuania	79**	63***	0.113***
	(26.2)	(19.1)	(0.003)
Luxembourg	821***	552***	0.028***
	(70.2)	(64.3)	(0.001)
Latvia	178***	166***	0.1***
	(18.2)	(16.9)	(0.002)
Poland	212***	118***	0.093***
	(8.2)	(6.8)	(0.001)
Sweden	-8	917***	0.053***
	(85.2)	(71.5)	(0.002)
Slovakia	460***	197***	0.071***
	(19.8)	(14.1)	(0.002)

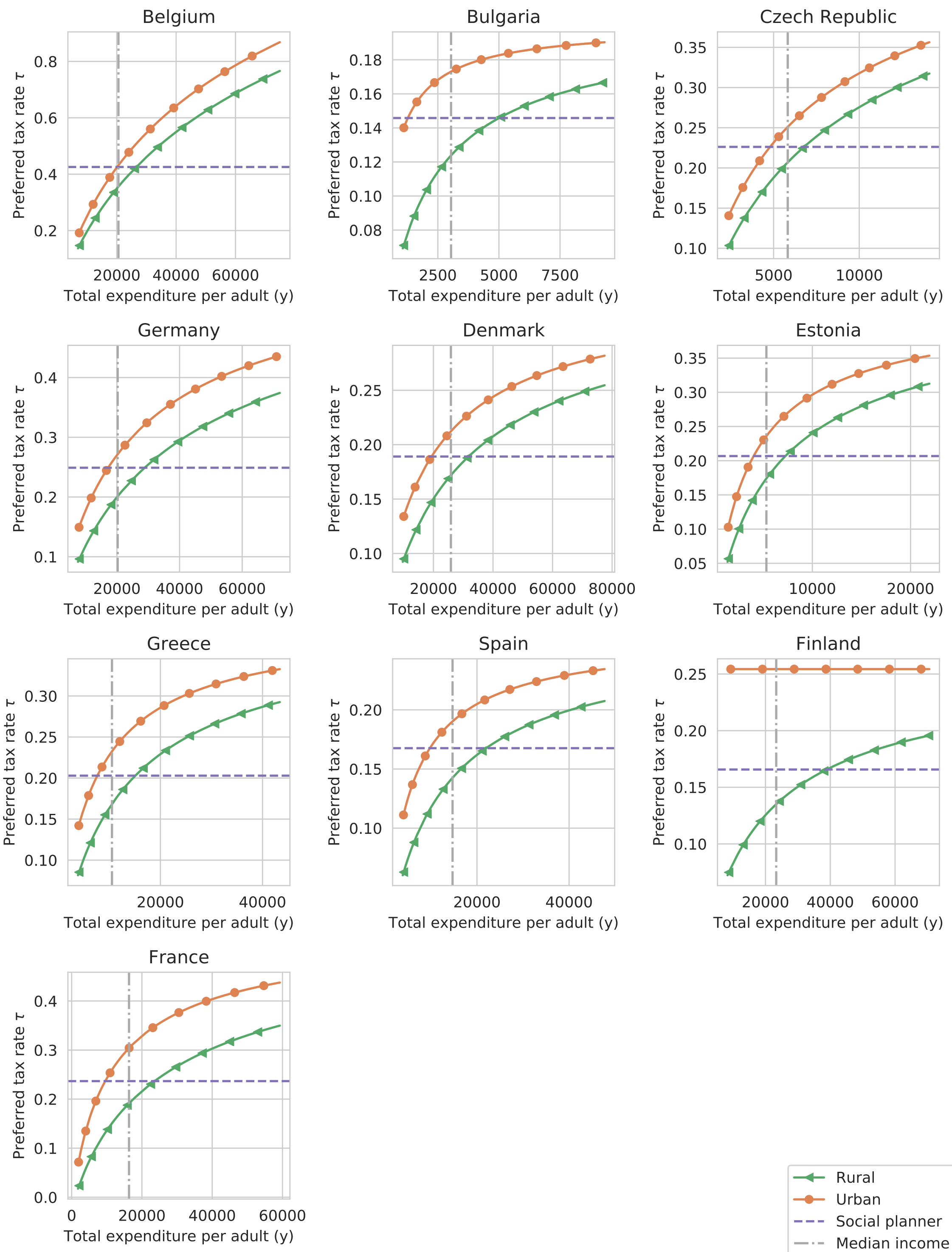
*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$.

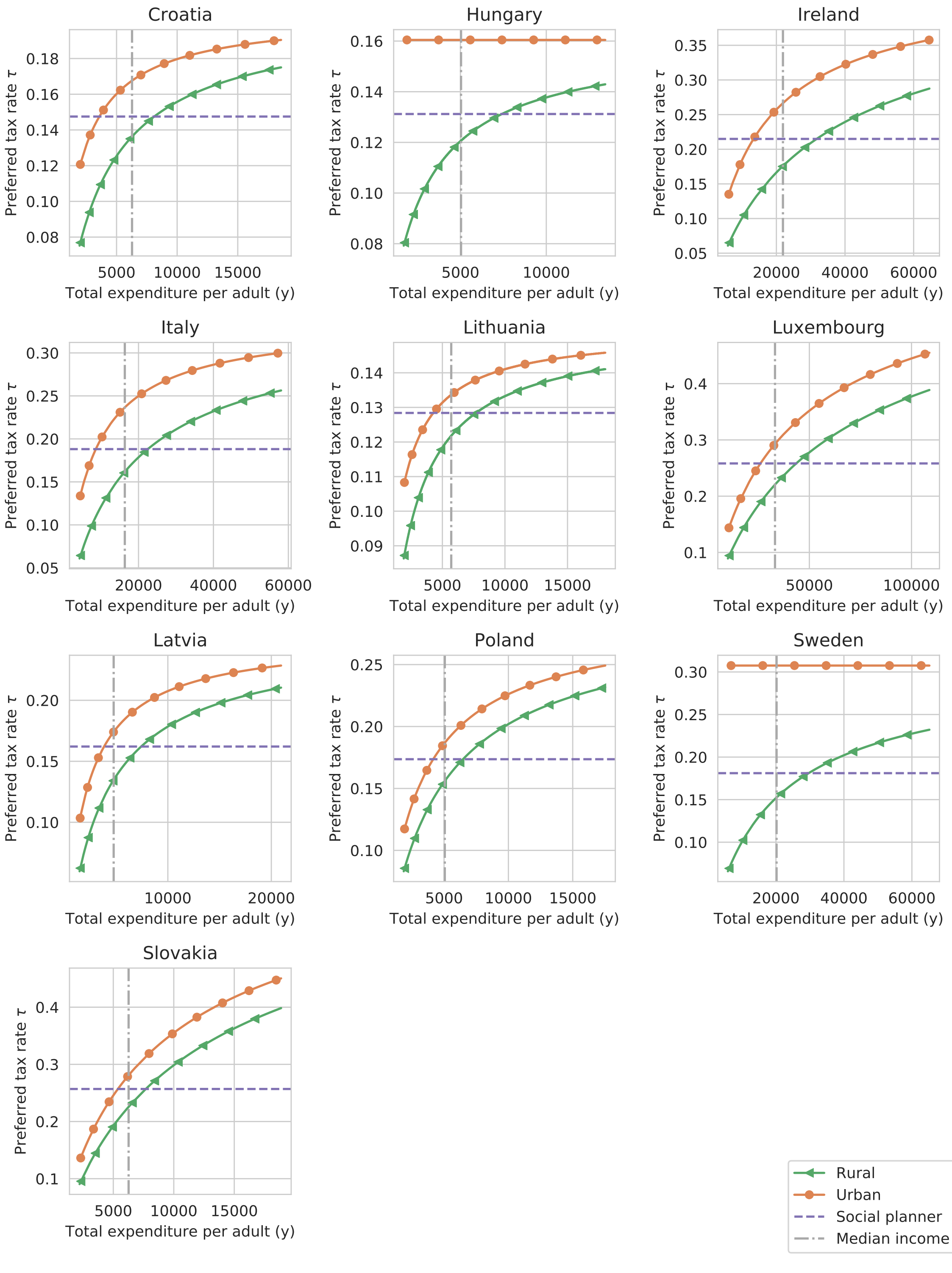
B.3 Calibration results for all countries

Table 3: Calibrated parameter values

Country	α	γ	β	x_0^u	x_0^r	y^-	y^+	$\tilde{y}^u$	$\tilde{y}^r$	$\bar{y}^u$	$\bar{y}^r$
Belgium	0.55	0.03	0.05	1186	1565	6938	74946	20149	20687	23117	23770
Bulgaria	0.44	0.11	0.02	43	169	1065	9325	3886	2539	4294	2777
Czech Republic	0.33	0.09	0.04	406	574	2310	14093	6297	5572	6644	5995
Germany	0.54	0.05	0.03	868	1458	7564	72031	19746	20260	22455	22748
Denmark	0.27	0.06	0.02	785	1289	9690	77483	25479	25767	29475	28600
Estonia	0.33	0.08	0.03	262	473	1360	21918	5696	5137	6992	6168
Greece	0.39	0.06	0.02	341	673	3862	43394	10554	9995	12716	11761
Spain	0.47	0.06	0.01	261	587	3882	47717	15598	13993	17509	15810
Finland	0.34	0.05	0.01	0	811	8291	70589	24136	22829	27252	25462
France	0.39	0.04	0.02	409	1011	1809	59250	16861	16096	19267	17979
Croatia	0.28	0.11	0.02	126	285	1948	18575	7404	5896	8142	6529
Hungary	0.27	0.13	0.02	0	194	1700	13432	6377	4662	6891	5010
Ireland	0.44	0.05	0.02	572	1360	5869	64594	23891	20499	25990	22458
Italy	0.29	0.06	0.02	330	862	4262	58059	17392	15981	20183	18496
Lithuania	0.40	0.11	0.02	79	142	1911	18015	7425	4625	8129	5242
Luxembourg	0.38	0.03	0.02	821	1373	10122	108766	30430	34750	35249	39143
Latvia	0.50	0.10	0.03	178	344	1471	20943	5178	4274	6408	5104
Poland	0.34	0.09	0.03	212	330	1865	17528	5847	4617	6703	5250
Sweden	0.25	0.05	0.02	0	909	5863	65152	21124	19877	23205	22372
Slovakia	0.40	0.07	0.05	460	657	2212	18871	6861	5921	7564	6429

Figure 8: Effect of income and urban-rural type on calibrated preferred tax rates



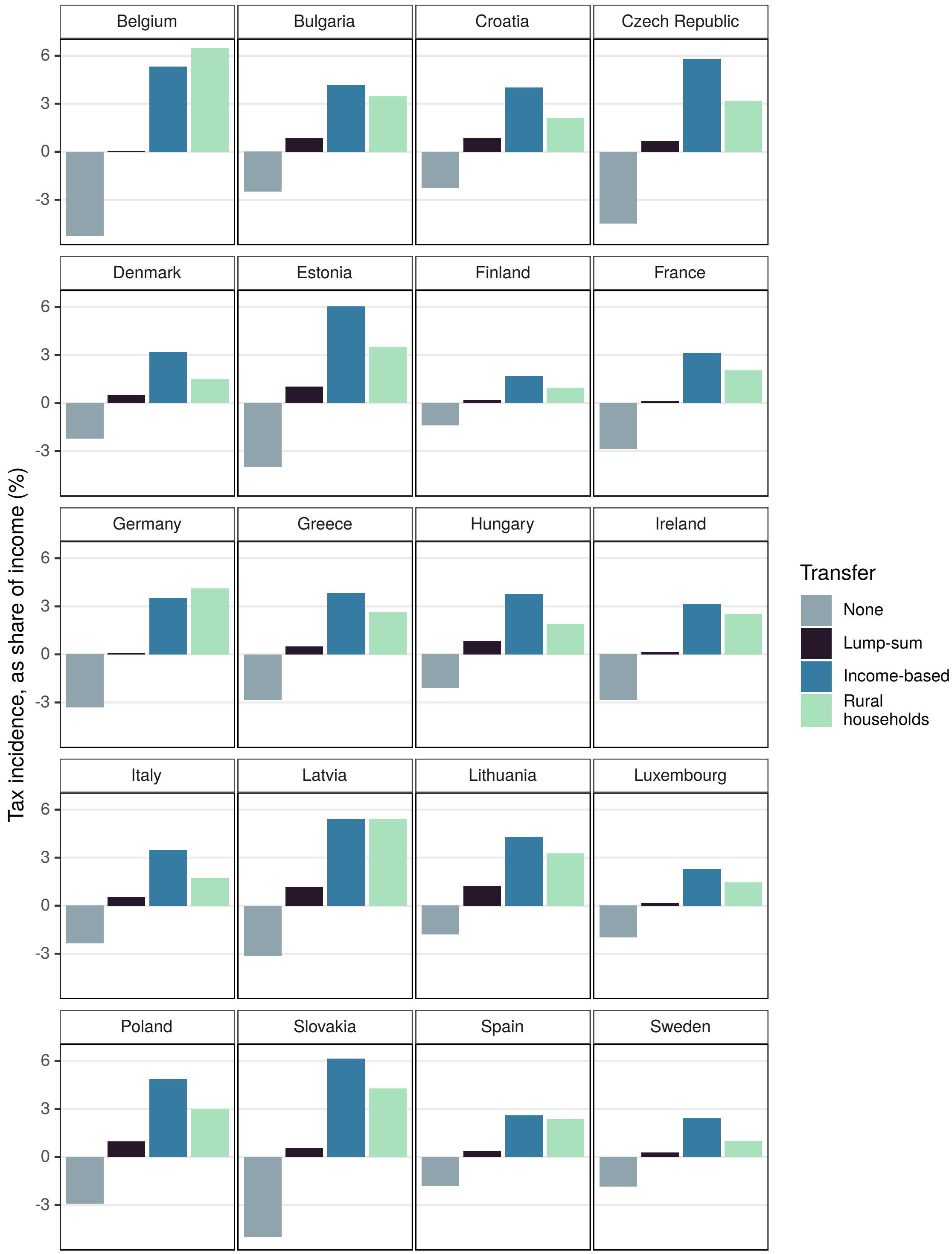


Croatia
Hungary
Ireland
Italy
Lithuania
Luxembourg
Latvia
Poland
Sweden
Slovakia
Preferred tax rate τ
Total expenditure per adult (y)
Rural
Urban
Social planner
Median income

B.4 Robustness checks

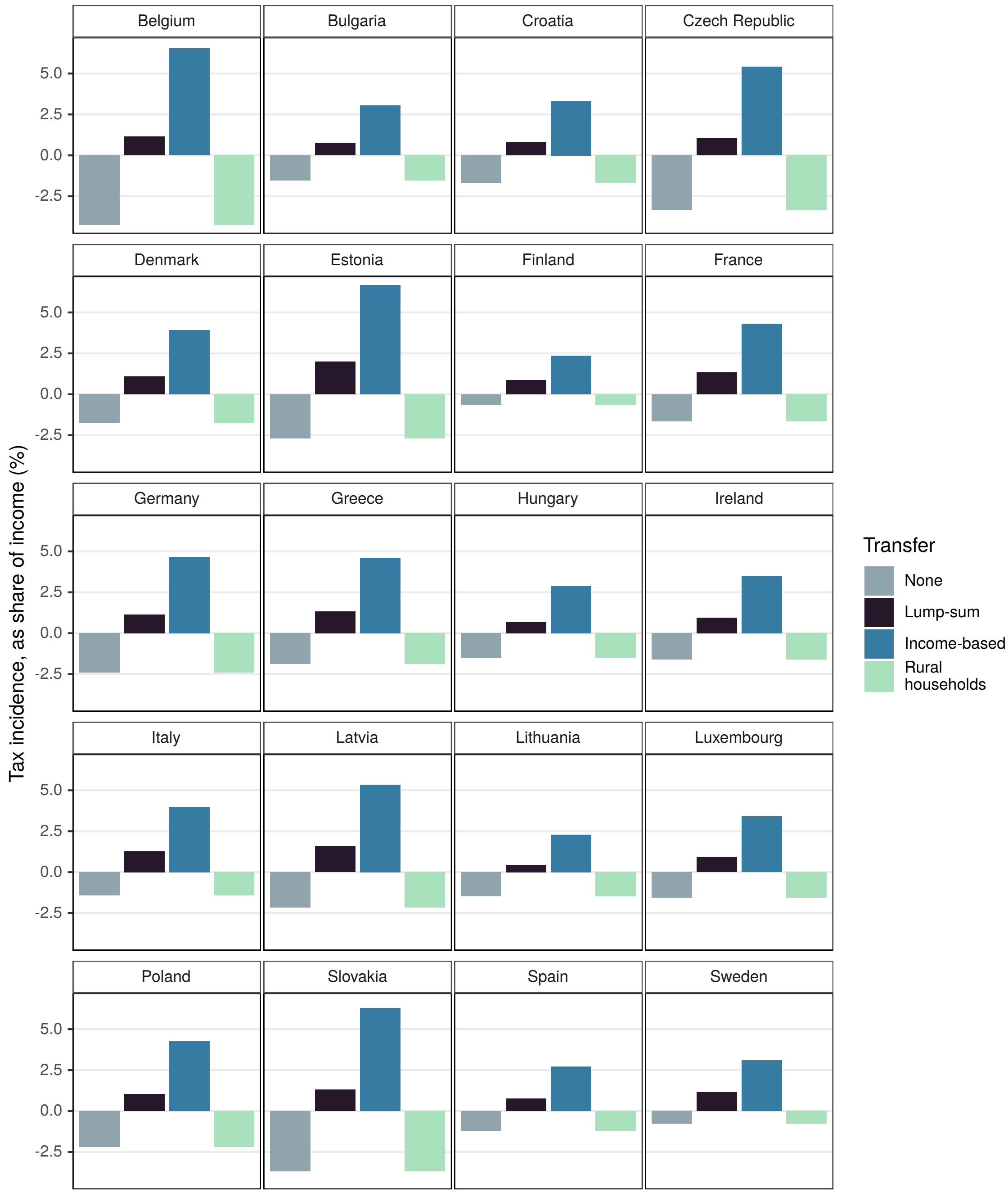
B.4.1 Emissions reduction target to 5%

Figure 9: Tax incidence for rural households in the first quintile, as proportion of income (%)



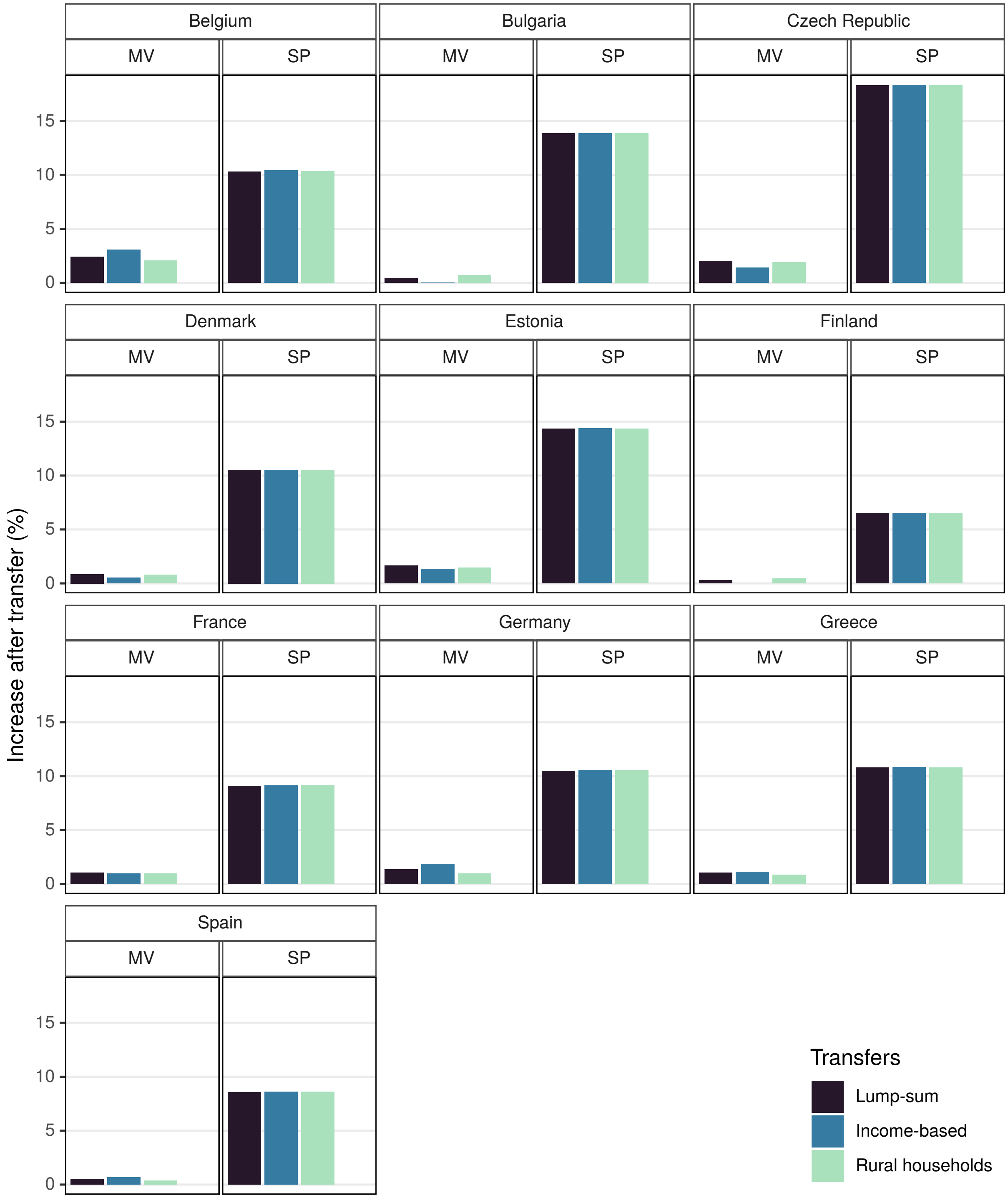
Note: negative values indicate net tax payments, positive values net tax rebates.

Figure 10: Tax incidence for urban households in the first quintile, as proportion of income (%)



Note: negative values indicate net tax payments, positive values net tax rebates.

Figure 11: Change in the median voter (mv) and the social planner (sp) carbon tax rates, (%)



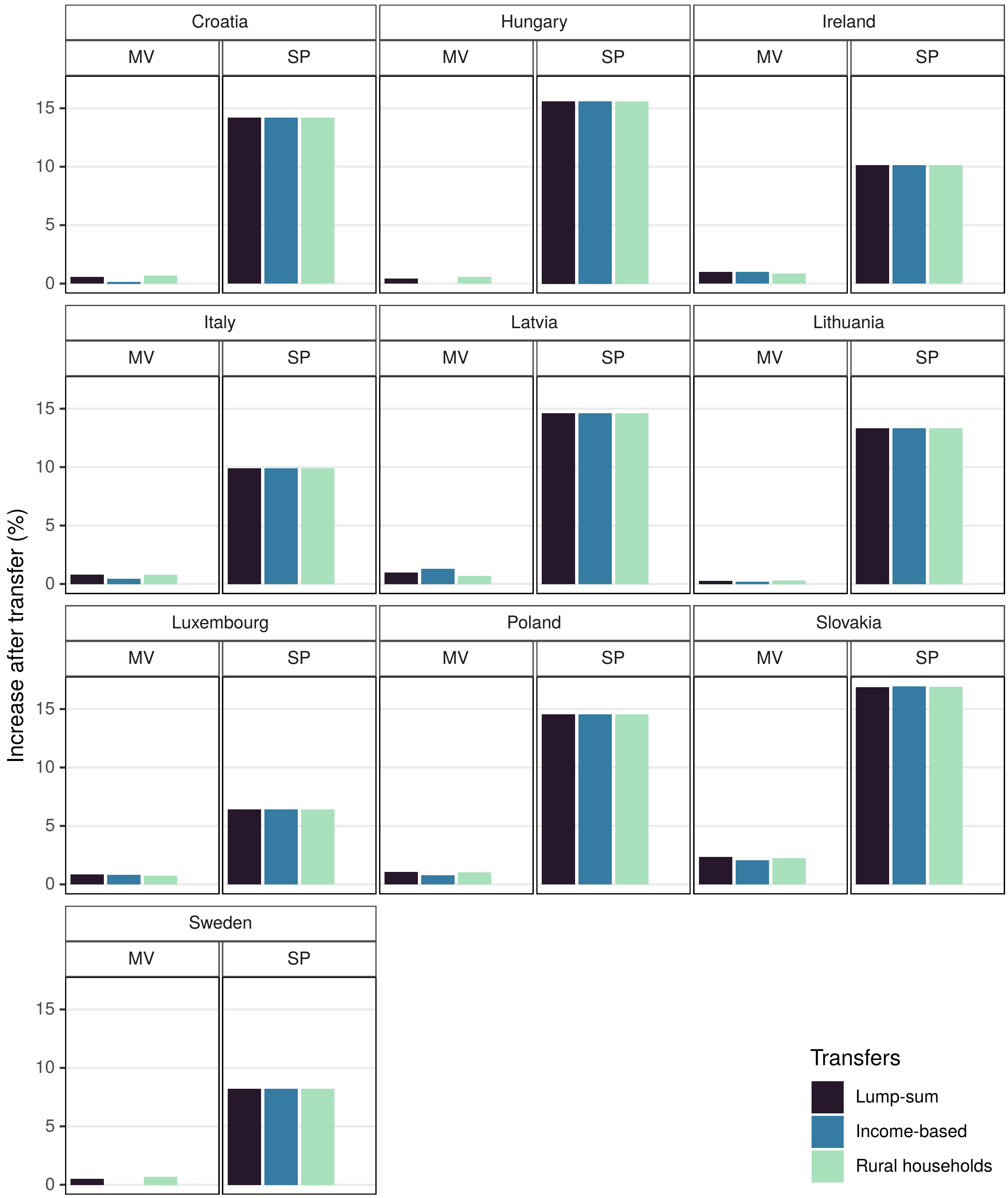

Croatia
Hungary
Ireland
Italy
Latvia
Lithuania
Luxembourg
Poland
Slovakia
Sweden
MV
SP
0
5
10
15
Increase after transfer (%)
Transfers
Lump-sum
Income-based
Rural households

Figure 12: Gap between the median voter tax rates in the urban vs rural population, as a share of median voter tax rate in the urban population (%), for different transfer schemes.

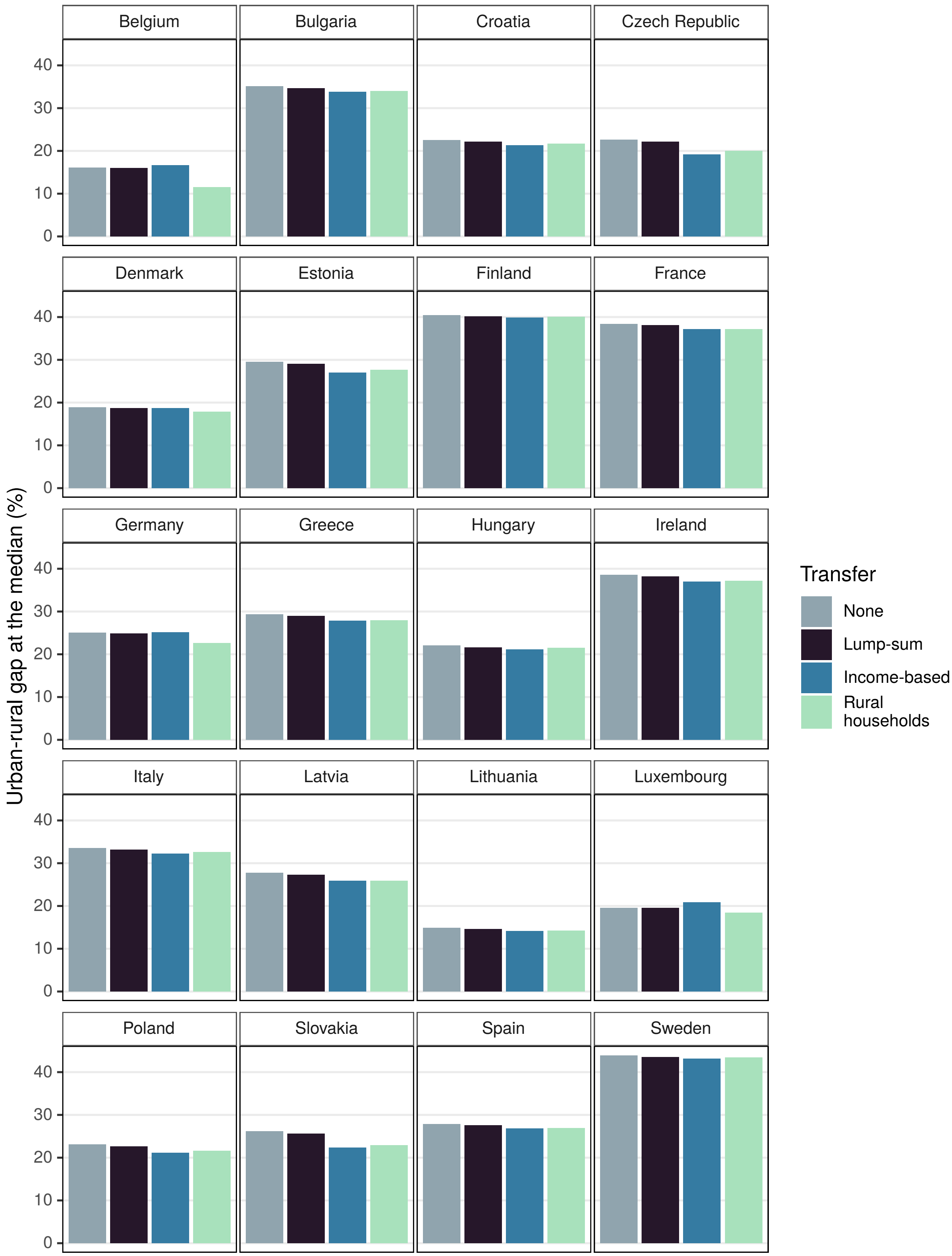
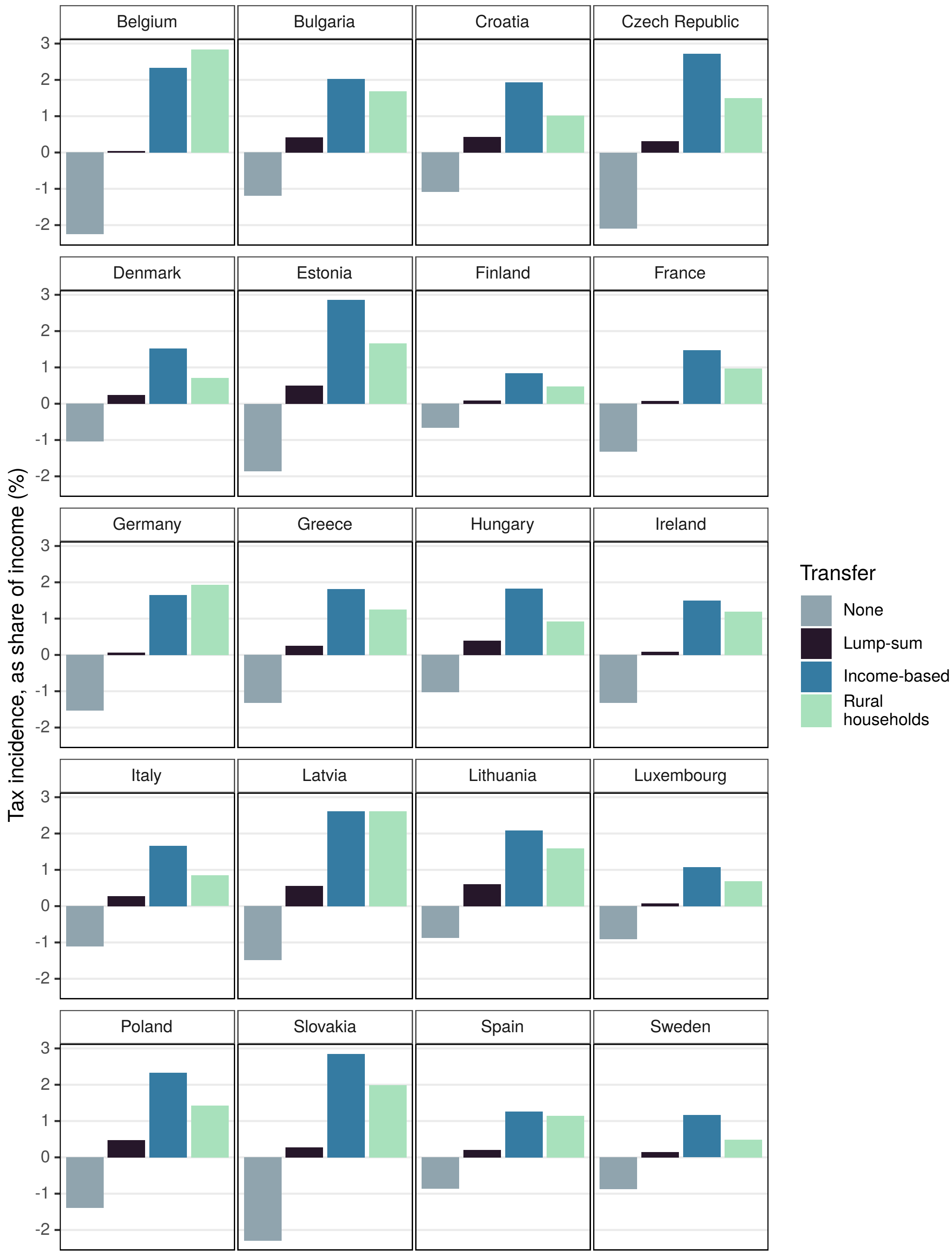
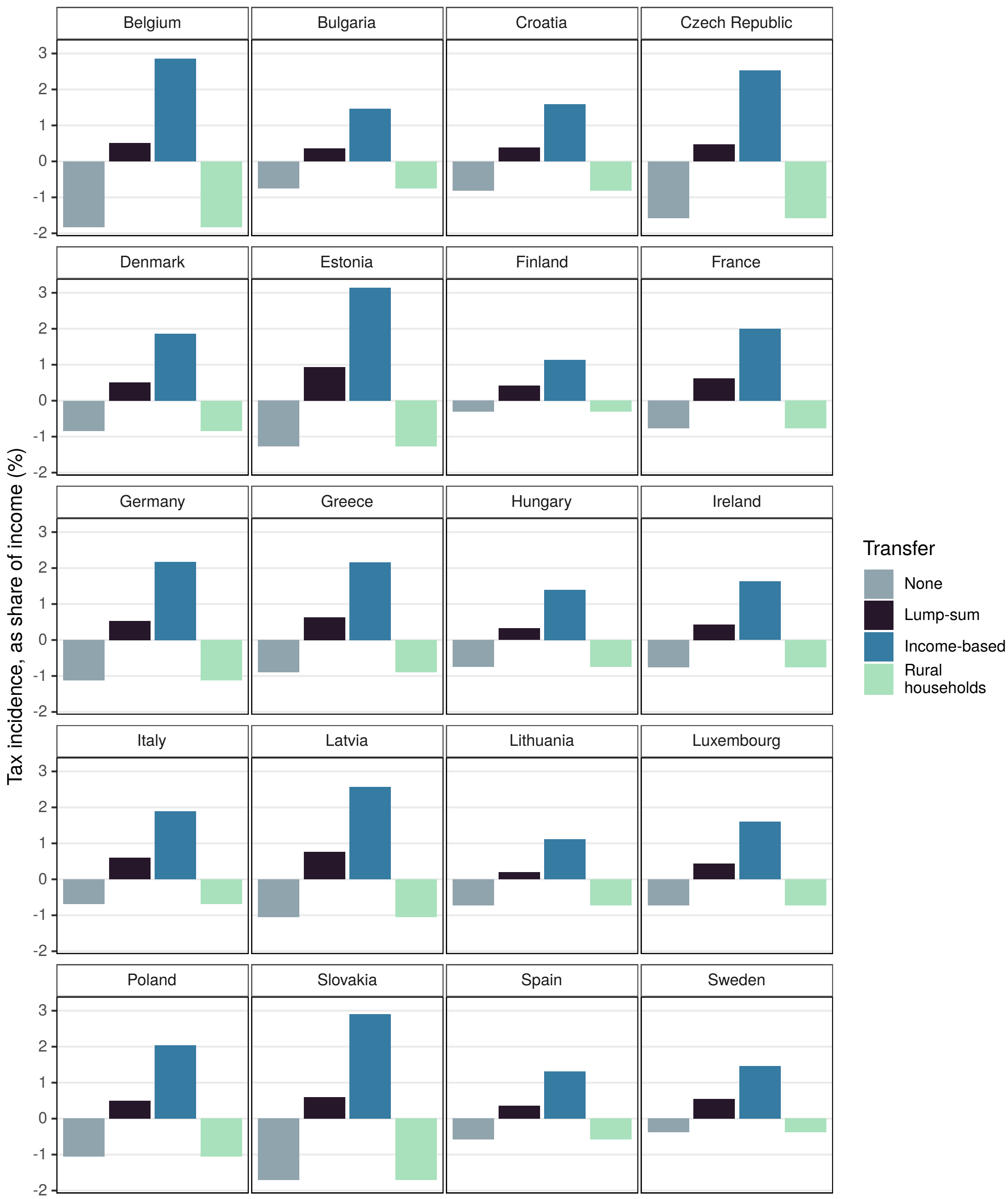


Figure 13: Tax incidence for rural households in the first quintile, as proportion of income (%)



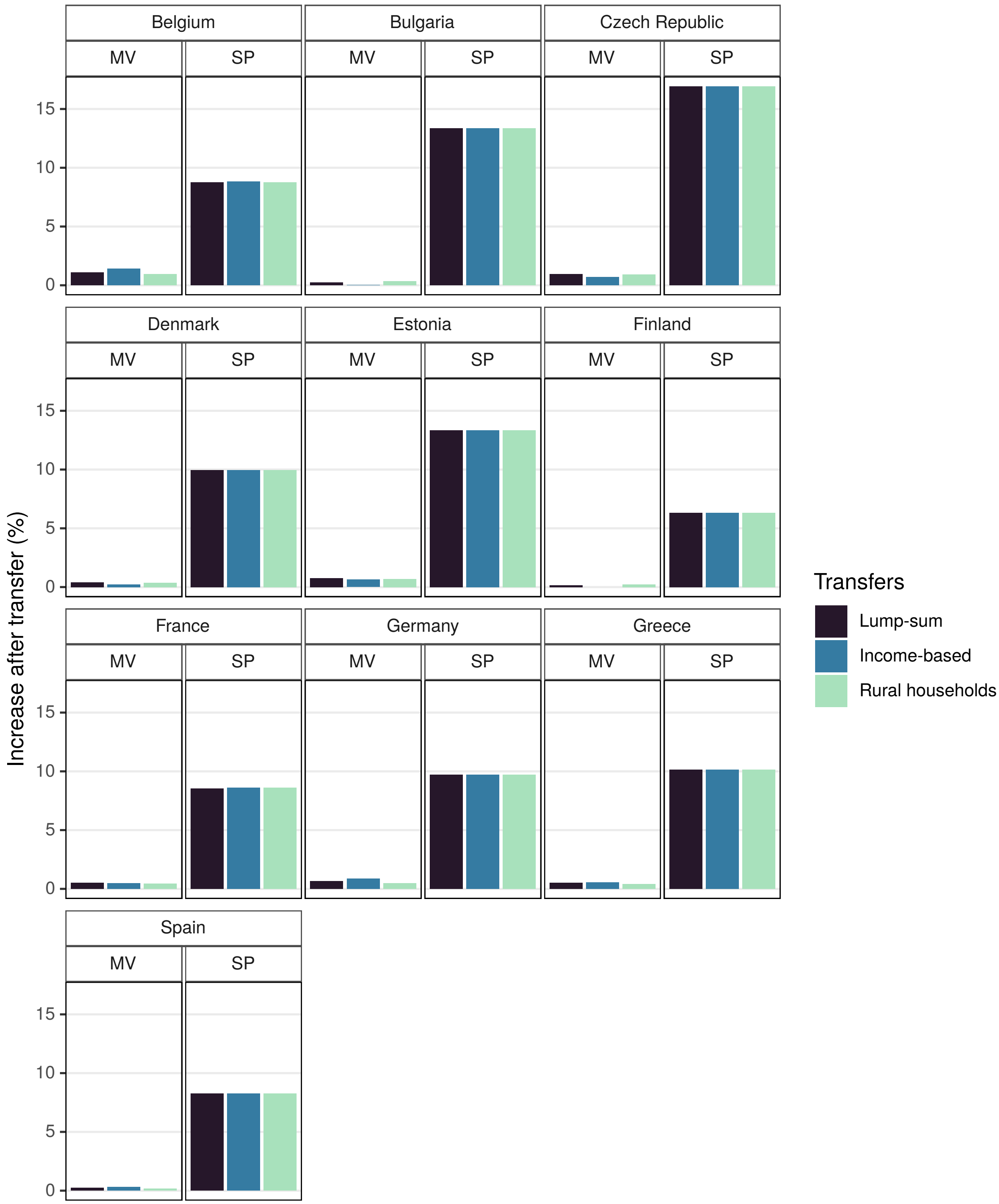
Note: negative values indicate net tax payments, positive values net tax rebates. Emissions reduction target of 5%

Figure 14: Tax incidence for urban households in the first quintile, as proportion of income (%)

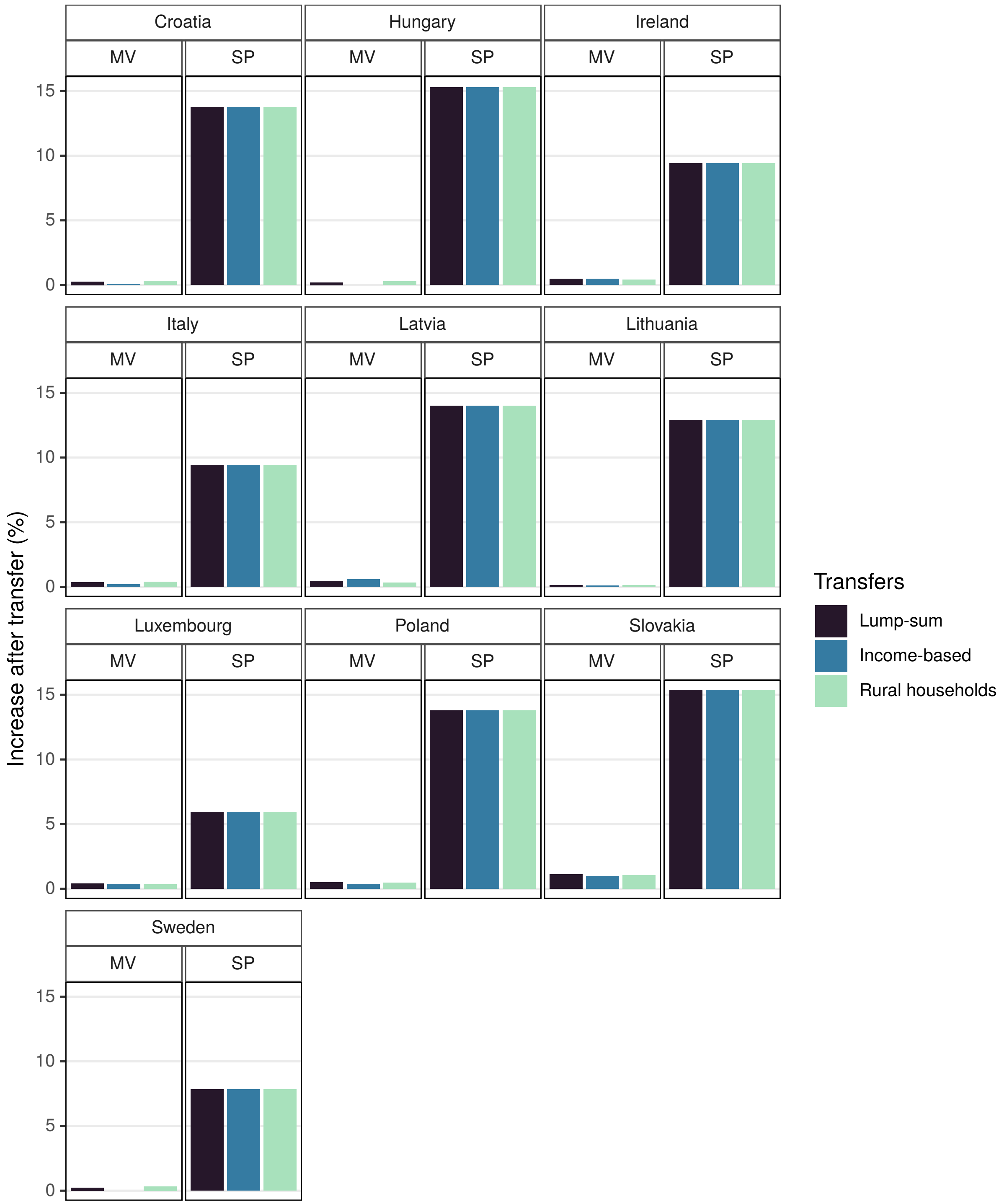


Note: negative values indicate net tax payments, positive values net tax rebates. Emissions reduction target of 5%

Figure 15: Change in the median voter (mv) and the social planner (sp) carbon tax rates, (%)

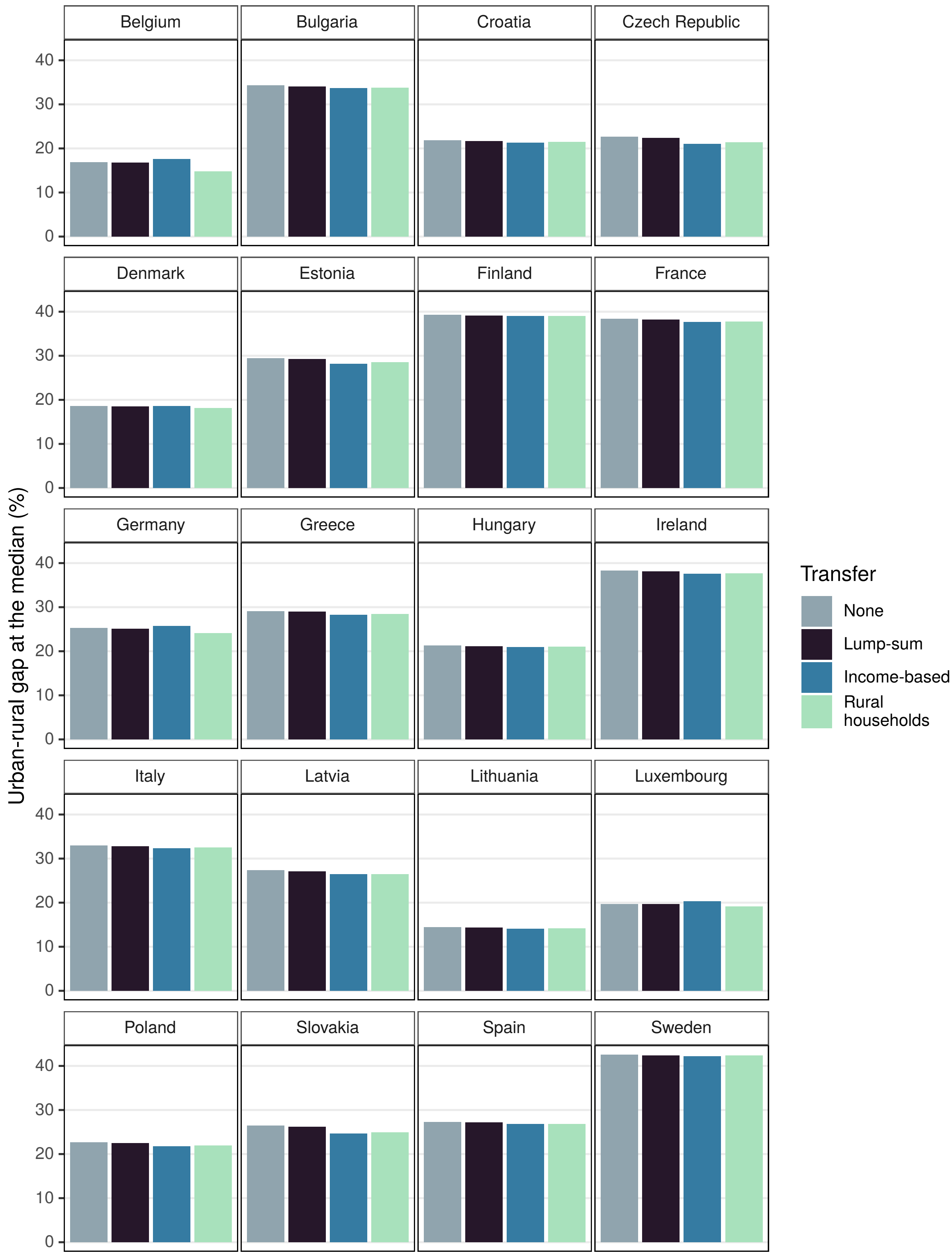


Note: Emissions reduction target of 5%.



Croatia
Hungary
Ireland
Italy
Latvia
Lithuania
Luxembourg
Poland
Slovakia
Sweden
MV
SP
15
10
5
0
Increase after transfer (%)
Transfers
Lump-sum
Income-based
Rural households

Figure 16: Gap between the median voter tax rates in the urban vs rural population, as a share of median voter tax rate in the urban population (%), for different transfer schemes.



Note: Emissions reduction target of 5%.