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Exploring the relationship between environmentally related taxes and inequality in income sources: An empirical cross-country analysis

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EXPLORING THE RELATIONSHIP BETWEEN ENVIRONMENTALLY RELATED TAXES AND INEQUALITY IN INCOME SOURCES: AN EMPIRICAL CROSS-COUNTRY ANALYSIS - ENVIRONMENT WORKING PAPER No. 100

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ABSTRACT

This paper presents the first empirical analysis of the macroeconomic relationship between environmentally related taxes and inequality in income sources. The analysis also investigates whether this relationship differs between countries which have implemented environmental tax reforms (ETRs) and ones which have not. Following earlier empirical literature, income inequality is measured by the disposable-income-based Gini coefficient. The analysis is based on a panel of all 34 OECD countries spanning the period from 1995 to 2011. Information about the implementation of ETRS in the examined period is collected through a review of relevant academic and policy literature. Empirical results from econometric models reveal that, on average, there is no statistically significant relationship between the overall share of environmentally related tax revenues in GDP and inequality in income sources. However, the relationship varies with the taxed activity under consideration and the existence of an explicit mechanism to redistribute environmentally related tax revenues. In countries where such mechanisms are absent, energy tax revenues (% of GDP) are shown to have a positive, although modest, relationship with income inequality. In contrast, in countries where energy tax revenues are, at least partially, used to reduce tax burden on income and labour, there is a negative relationship between energy taxes and inequality in income sources. On the contrary, no significant relationship is identified between motor vehicle and other transport tax revenues and income inequality, while revenues from other environmentally related taxes, such as waste and air pollution taxes, are negatively associated with income inequality, regardless of the existence of an explicit revenue recycling mechanism.

Keywords: Energy tax, environmental tax reform, income inequality, Gini coefficient.

JEL Classification: E62, H23, Q48, Q52

RÉSUMÉ

Ce rapport présente la première analyse empirique des effets macroéconomiques des taxes liées à l'environnement sur les inégalités de revenus, ainsi que du rôle que des réformes spécifiques de la fiscalité environnementale peuvent jouer dans l'atténuation de ces effets. Les inégalités de revenus sont ici mesurées par le coefficient de Gini fondé sur le revenu disponible. Cette analyse empirique utilise un nouvel indicateur des réformes fiscales environnementales (RFEs) élaboré sur la base de l'information qualitative recueillie par une étude de la littérature. Contrairement aux études empiriques antérieures, ce document explore l'effet des taxes liées à l'environnement et des RFEs sur les sources de revenus des ménages, plutôt que sur les utilisations de ce revenu. Cette analyse repose sur un panel composé des 34 pays de l'OCDE et couvre la période comprise entre 1995 et 2011. Elle montre que la part générale des recettes tirées des taxes liées à l'environnement dans le produit intérieur brut (PIB) présente une corrélation positive avec les inégalités de revenus. Cependant, cet effet varie selon l'activité assujettie. Alors que l'on a démontré que les recettes issues des taxes sur l'énergie affichent une relation positive avec les inégalités de revenus, aucun effet tranché ne se dessine pour les recettes produites par les taxes sur les véhicules à moteur et les transports. En revanche, les recettes générées par les autres taxes liées à l'environnement, comme celles perçues sur les déchets et sur la pollution atmosphérique, affichent une relation négative avec les inégalités de revenus.

Les RFEs examinées jouent un rôle important dans l'atténuation des impacts négatifs des taxes liées à l'environnement (principalement celles sur l'énergie). On constate en particulier qu'elles annulent complètement ces impacts. Ce constat vient étayer l'argument selon lequel les effets distributifs des taxes liées à l'environnement ne devraient pas être considérés comme des obstacles insurmontables au recours à ces taxes dans ce champ de l'action publique, car des RFE conçues avec soin et bien ciblées peuvent atténuer les effets éventuels de ces taxes sur les inégalités de revenus.

Mots-clés: Taxe sur l'énergie, Réformes fiscales environnementales, inégalité des revenues, Coefficient du Gini.

Classification JEL: E62, H23, Q48, Q52

FOREWORD

The paper has been authored by Walid Oueslati (OECD Environment Directorate), Vera Zipperer (DIW Berlin), Damien Rousselière (University of Angers) and Alexandros Dimitropoulos (OECD Environment Directorate). The authors are grateful to delegates to the Working Party on Integrating Environmental and Economic Policies for helpful comments on earlier drafts of this paper. They would also like to thank Nils-Axel Braathen, Rob Dellink, Olivier Durand-Lasserve, Florens Flues, Mouez Fodha, Don Fullerton, Nick Johnstone, Tomasz Koźluk, Mauro Pisu, and Kurt van Dender, for comments on previous versions of the paper and Natasha Cline-Thomas for editorial assistance. The authors are responsible for any remaining omissions or errors. Work on this paper was conducted under the overall responsibility of Shardul Agrawala, Head of the Environment and Economy Integration Division.

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EXECUTIVE SUMMARY

The use of environmentally related taxes is often hampered by public concerns over their alleged distributional effects.[1] Probably the most widely discussed such concerns are related to the possible effects of environmentally related taxes on the *uses* of household income. In theory, the financial burden of some environmentally related taxes could be incurred disproportionately more by low-income households, because they arguably tend to spend a larger share of their disposable income on goods and services directly affected by the taxes, such as heating and electricity. Nevertheless, recent empirical evidence from the analysis of taxes on energy products shows that their effects on income uses vary significantly with energy carrier. The distributional effect of taxes on transport fuels has been found to be proportional or progressive in most countries, whereas taxes on electricity and domestic heating are to some extent regressive.

The uses of household income do not, however, constitute the only channel via which environmentally related taxes may affect income inequality. As any other type of tax applying to selected goods and services, environmentally related taxes change the *relative* prices of final consumption goods and the relative returns to production factors, such as labour, capital, energy, and materials in different industries. Relative wages (within and across industries) do not remain unaffected by these changes. Environmentally related taxes may also result in increased unemployment in the affected industries, possibly accompanied by a loss of industry-specific human capital. On the other hand, they also trigger investment and employment in more environmentally friendly economic activities, such as those concerned with the development of abatement technologies and the increase of resource efficiency. All of these developments induced by environmentally related taxes lead the labour market to a new equilibrium and, therefore, affect the *sources* of household income.

At the same time, environmentally related taxes provide public revenues which can be used, among other things, to compensate for any generated inequalities. In this spirit, a number of OECD countries have implemented environmental tax reforms (ETRs) over the last two decades, with a view to stimulating employment and promoting economic growth. ETRs are hereby defined as fiscal reforms which establish explicit revenue recycling mechanisms to shift tax burden from labour and personal and corporate income to environmentally harmful activities.

This paper presents the first empirical analysis of the macroeconomic relationship between environmentally related taxes and inequality in income sources. The analysis also investigates whether this relationship differs between countries which have implemented ETRs and ones which have not. Following earlier empirical literature, income inequality is measured by the disposable-income-based Gini coefficient.[2] The analysis is based on a panel of all 34 OECD countries spanning the period from 1995 to 2011. Information about the implementation of environmental tax reforms (ETRs) in the examined period is collected through a review of relevant academic and policy literature.

[1] Environmentally related taxes encompass "any compulsory, unrequited payment to general government levied on tax-bases deemed to be of particular environmental relevance" (OECD, 2001a). They are broken down into energy taxes, (including motor fuel taxes), motor vehicle and transport taxes, and other environmental taxes (including taxes on waste, wastewater and air pollution).

[2] The Gini coefficient measures the extent to which the distribution of income (or, in some cases, consumption expenditure) among individuals or households within an economy deviates from a perfectly equal distribution. The disposable-income-based Gini coefficient is the preferred measure for the analysis of the effects of ETRs, as the latter are largely manifested in the reduction of income taxes and the increase of social transfers.

Empirical results from econometric models reveal that, on average, there is no statistically significant relationship between the overall share of environmentally related tax revenues in GDP and inequality in income sources. However, the relationship varies with the taxed activity under consideration and the existence of an explicit mechanism to redistribute environmentally related tax revenues. In countries where such mechanisms are absent, *energy tax revenues* (% of GDP) are shown to have a positive, although modest, relationship with income inequality. In contrast, in countries where energy tax revenues are, at least partially, used to reduce tax burden on income and labour, there is a negative relationship between energy taxes and inequality in income sources. On the contrary, no significant relationship is identified between *motor vehicle and other transport tax revenues* and income inequality, while revenues from *other environmentally related taxes*, such as waste and air pollution taxes, are negatively associated with income inequality, regardless of the existence of an explicit revenue recycling mechanism.

Certainly, the short term costs of the introduction of an environmentally related tax are of high importance in a political economy framework. Especially for this reason, it is perhaps worthwhile to consider providing explicit revenue recycling mechanisms alongside the introduction of environmentally related taxes. Possible recycling mechanisms may include lump-sum redistributions, reductions in personal income taxes, increases of tax-free allowances, reductions of non-wage labour costs such as employers' social security contributions, or reductions in corporate income taxes to stimulate employment. However, it is important that the mechanism is designed in a way that lower income households are especially benefitted from the redistribution of tax revenues. This paper does not aim to evaluate the relative performance of different recycling mechanisms, as the collected information about implemented ETRs is not detailed enough to allow such an evaluation. This is, however, an interesting avenue for further research.

It is also important to note that any relationship between inequality in income sources and environmentally related taxes should not be viewed in isolation, but in comparison with the relationship of the former with alternative policy instruments. However, empirical investigations of the relationship between the most commonly used alternative policy instrument to environmentally related taxes, i.e. technology- and performance-based regulatory standards, and income inequality have been extremely scarce, rendering the conduct of such a comparative assessment currently impossible. This is, therefore, another promising area for further research.

INTRODUCTION

Environmentally related taxes are an important policy tool, aimed at improving environmental outcomes in a cost-effective way. Through environmentally related taxes, households and firms incorporate environmental costs and benefits into their budgets. In contrast to regulatory standards, environmentally related taxes leave individuals and enterprises flexibility on how to take environmental externalities under consideration. Under specific conditions, this encourages cost-effective solutions and innovation. Next to economic efficiency and environmental effectiveness, environmentally related taxes are regarded as transparent policy instruments and raise public revenues.

The implementation of environmentally related taxes is, however, often hindered by public concerns over possible distributional effects. Environmentally related taxes may influence the distribution of income through a number of channels. Economists and policymakers' attention has thus far mainly been attracted to the potential effects of environmentally related taxes on the *uses* of household income. Related concerns are based on the argument that the financial burden of specific environmentally related taxes may be incurred disproportionately more by low-income households, because they may tend to spend a larger share of their disposable income on goods and services directly affected by the taxes, such as heating and electricity (Johnstone and Alavalapati, 1998; OECD, 2006). Recent evidence from microeconomic analyses of taxes on energy products reveals, however, that their effects widely vary with energy carrier. In general, taxes on transport fuels have proportional or progressive effects, whereas taxes on heating fuels and electricity can be regressive (Flues and Thomas, 2015).

Environmentally related taxes can, nevertheless, also influence income inequality through channels affecting the *sources* of household income. Similarly to other taxes which apply to selected commodities, environmentally related taxes change the relative prices of final consumption goods and production inputs – through e.g. the change of prices of electricity and fuel, but also of inputs whose price strongly depends on transportation costs (see also Fullerton and Heutel, 2007; Martínez-Vázquez et al., 2012; Mieszkowski, 1969). This change of relative prices will induce changes to the demand for goods and the production patterns of firms, leading the labour market to a new equilibrium, where the level of wages and their distribution over workers will likely be different from the one observed before the introduction of the taxes. Environmentally related taxes may also result in increased unemployment in the affected industries, possibly accompanied by a loss of industry-specific human capital. At the same time, they also stimulate investment and employment in more environmentally friendly economic activities, such as those concerned with the development of abatement technologies and the increase of resource efficiency. Through these channels, environmentally related taxes affect the distribution of labour and capital income and, thus, inequality in income sources.[3]

The aim of this paper is to empirically investigate the relationship between environmentally related taxes, environmental tax reforms and income inequality. In contrast to earlier microeconomic studies in the field which usually seek to analyse the effects of specific environmentally related taxes on the *uses* of household income, the focal point of this paper is the general equilibrium relationship between environmentally related taxes, associated reforms, and inequality in income *sources*.

Microeconomic studies have shown that the distributional effects of environmentally related taxes depend, *inter alia*, on the activity on which the tax is levied (Flues and Thomas, 2015; Johnstone and Alavalapati, 1998; Kosonen, 2012; OECD, 2014a). Taxes on domestic heating and electricity, for example, are generally found to be, to some extent, regressive. In contrast, taxes on transport fuels and vehicles are often found to have a proportional or progressive effect, especially in countries with lower GDP (Bruha and Scasny, 2008; Flues and Thomas, 2015; OECD, 2014a). Despite not being able to distinguish between different energy products, the analysis presented here investigates possible differences in the macroeconomic relationship between energy, motor vehicle and transport, and other environmentally related taxes and income inequality.

Environmentally related taxes provide public revenues which can be used to reduce, or even completely offset the gross cost of the policy, as measured in terms of total welfare loss, or to compensate

[3] The possible distributional effects of environmentally related taxes are not limited to changes in household income and expenditure. The distribution of environmental benefits resulting from taxation (e.g. better air quality) is also an important discussion topic. Environmentally related taxes can, for example, lead to air quality improvements in most polluted areas, where low-income households are more likely to be located. At least in the short-run, such environmental benefits are, thus, more likely to be accrued by low-income households. In the longer-run, however, more affluent households' stronger preferences and higher willingness to pay for environmental quality may be translated in low-income renters having to move out of neighbourhoods where environmental conditions have been improved (see also Fullerton, 2011). Such possible dynamic effects underline the importance of taking measures which can ensure an even distribution of the resulting environmental benefits even in the longer-run.

for any generated inequalities.[4] Theoretically, if governments use these revenues to decrease other distortionary taxes, an environmentally related tax may lead to a double dividend (Goulder, 1995), meaning that it may simultaneously lead to environmental improvements and a more efficient tax system, thereby stimulate economic growth. This could be a strong argument in favour of a greener tax system.

For the purposes of this study, environmental tax reforms (ETRs) are fiscal reforms which establish explicit revenue recycling mechanisms to shift tax burden from labour and personal and corporate income to environmentally harmful activities (see also EEA, 2005). Most ETRs are intended to be revenue neutral.[5] The revenues from environmentally related taxes are used, for example, to decrease labour taxes or social security contributions, with a view to stimulating employment and inducing overall welfare gains.[6] Many European countries implemented such ETRs over the last two decades to provide explicit recycling mechanisms for environmentally related taxes, to increase the political feasibility of their implementation and promote economic growth. Scandinavian countries started implementing ETRs from the early 1990s, while a second wave of ETRs followed shortly after in countries including Germany, the Netherlands, and the United Kingdom.

The literature encompasses a number of insightful modelling and micro-simulation studies on the distributional effects of environmentally related taxes and ETRs (Andersen and Ekins, 2009; EEA, 2011; Flues and Thomas, 2015). However, empirical studies of the possible distributional effects of environmentally related taxes on the sources of household income are missing thus far. This paper takes a first step towards this direction by providing an empirical analysis of the relationship between environmentally related taxes, revenue recycling mechanisms, and inequality in income sources in a macro-level, cross-country set-up. The key policy questions of the study can be summarised as follows: (i) What is the empirical relationship between environmentally related taxes and inequality in income sources? (ii) Do environmentally related taxes levied on different economic activities (e.g. taxes on energy products versus taxes on motor vehicles) have a qualitatively different relationship with income inequality? (iii) How are environmentally related tax revenue recycling mechanisms associated with inequality in income sources?

The paper is organised as follows. The second section lays out the motivation for this study by providing an overview of trends in income inequality and environmentally related taxes over the last two decades. The third section reviews relevant empirical literature. Section 4 describes the dataset, presents the empirical set-up developed for the analysis, and discusses the main empirical results. The last section concludes and provides directions for future research on the evaluation of the relationships between environmental policy instruments and income inequality.

4 Governments might also use the revenues generated through environmental taxes for other purposes, such as to reduce debt or increase infrastructure spending.

5 Note that this definition of an environmental tax reform does not always coincide with the use of the term in different countries and contexts. Some countries use a different label for such reforms (e.g. "green tax shift") or do not label them at all. On the other hand, some countries implement environmental tax reforms without explicitly recycling revenues to reduce tax burden on labour or income. Such reforms are not taken into account in this analysis, as they are not expected to have a noticeable effect on income inequality.

6 Environmentally related taxes are often also earmarked and used to stimulate green investment, protect valuable environmental assets, etc. These practices are expected to increase the public acceptability of new environmentally related taxes and are often labelled as ETRs. However, they are not considered as environmental tax reforms in this study, as the generated environmental tax revenues are not used to reduce tax burden on labour or income and are, thus, not expected to have a noticeable effect on income inequality.

TRENDS IN ENVIRONMENTALLY RELATED TAXES AND INCOME INEQUALITY IN OECD COUNTRIES

The measure of income inequality adopted in this analysis is the disposable-income-based Gini coefficient (see Box 1). The selection of the Gini coefficient among other relevant measures of income inequality was mainly driven by the availability of data with much more complete country and time coverage. The disposable-income-based Gini was preferred to the market-income-based Gini for the purposes of the analysis, as the effects of recycling mechanisms are largely manifested in the reduction of income taxes and the increase of social transfers.[7]

Figure 1 shows the evolution of the disposable income Gini in OECD countries over the time period of study, 1995–2011. Disposable income inequality increased in 19 OECD countries over this period, whereas in the rest it declined. In percentage terms, the largest reductions of income inequality are manifested in Turkey and Ireland (about 14.5% and 15.6% respectively), whereas the largest increases in Finland and Denmark (18.2% and 19.8% respectively). The unweighted OECD average has only slightly increased in the examined period (about 0.6%).

Various reasons can explain these increases in income inequality. OECD (2011) identifies globalisation, technological progress, policy choices, regulation and institutions as some of its possible determinants. The report finds that neither rising trade integration nor financial openness had a significant impact on income inequality. On the other hand, growing outward foreign direct investment seems to have contributed to rising income inequality.

Box 1. A proxy for income inequality – the Gini coefficient

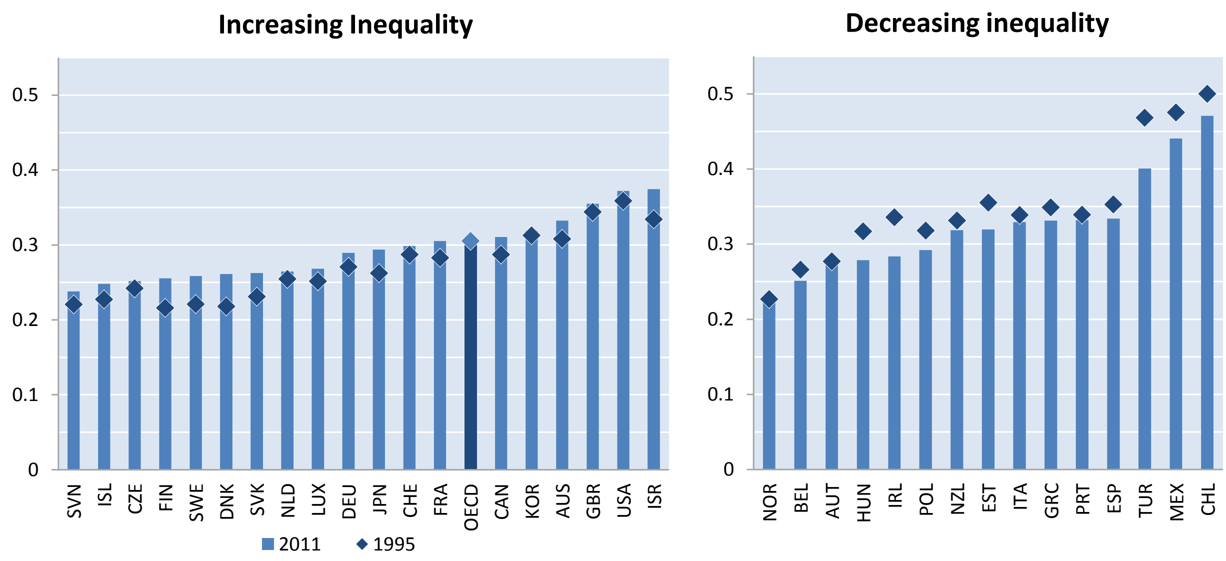
Based on household survey data, several measures of income inequality can be calculated, such as the Theil index, top income shares, ratios of the income received by the top and bottom 20% of the income distribution, and the Gini coefficient. The latter measures the extent to which the distribution of income among households within an economy deviates from a perfectly equal distribution. What the Gini coefficient does not measure, is the income distribution as such; i.e. the same value of the Gini coefficient may result from very different income distributions.

Looking at the construction of the Gini coefficient illustrates the scope of the indicator. The Gini coefficient is calculated on the basis of a Lorenz curve. The Lorenz curve shows the cumulative percentage of total income received by the cumulative percentage of beneficiaries, starting with the poorest individuals or households. The Gini coefficient corresponds to the ratio of the area between the Lorenz curve and the hypothetical line of absolute equality over the total area located below this line. It, hence, ranges from 0 (everybody has identical income) to 1 (all income is received by only one person).

[7] The difference between the market- and the disposable-income-based Gini coefficient is that the former is calculated on the basis of the distribution of household income before taxes and transfers, whereas the latter is based on the distribution of household income after taxes and transfers.

Figure 1. Trends in income inequality over the last two decades

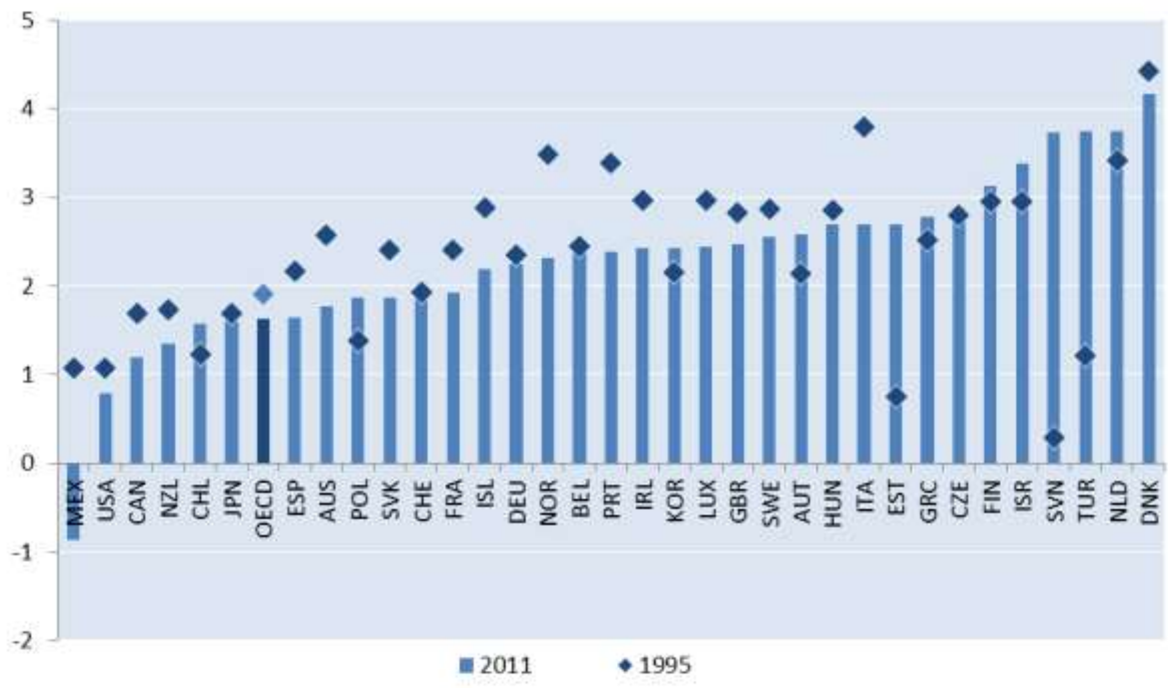
Net Gini coefficient from 1995 to 2011



Source: Authors' calculations based on inequality data from the Standardized World Income Inequality Database (SWIID v.4.0).

Compared to other tax revenues, the revenues raised by environmentally related taxes are generally not very high. As Figure 2 shows, these revenues account for a relatively small percentage of GDP in the majority of OECD countries. In 2011, this percentage ranged from 0.8% to 4.2%, with the exception of Mexico which effectively had net environmentally related subsidies in place (OECD, 2013). However, support for the consumption of gasoline and diesel fuel in Mexico has steadily been decreased, resulting in an effective elimination of these subsidies since 2014 (OECD, 2015; OECD/IEA/NEA/ITF, 2015). Even though the share of environmentally related tax revenues in GDP grew in 13 countries over the period considered in this analysis, it fell by around 14.4% across the OECD. This trend implies that environmentally related tax revenues have grown at a slower rate than GDP in the examined period. At least two factors may be responsible for this trend. First, the trend may be, to some extent, reflecting a gradual decoupling of resource use from economic growth. Second, it may be influenced by a shrinking of environmentally related tax bases due to increasing oil prices (see also OECD, 2006). The increase in international fuel prices in the examined period triggered a substitution away from motor fuel use, decreasing the base of environmentally related taxes. At the same time, the recent economic crisis reduced the sales of new vehicles in several countries, which are also an important source of tax revenue.

Figure 2. Share of environmentally related tax revenues in GDP across countries



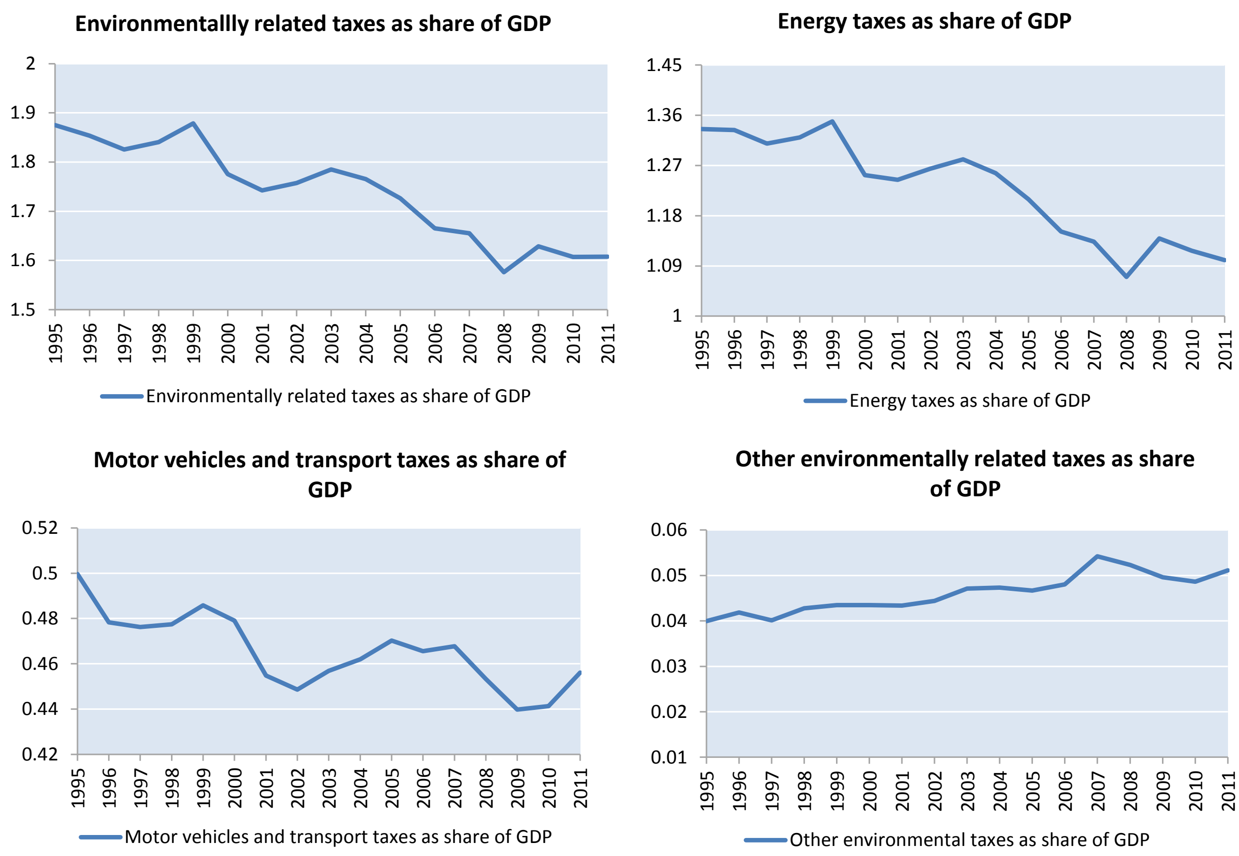
Source: Authors' calculations based on data from the OECD database on Instruments used for Environmental Policy and Natural Resources Management.

Figure 3 shows the evolution of the weighted OECD average share of environmentally related tax revenues in GDP in the period 1995–2011. Based on the OECD categorisation of taxed economic activities, the figure also presents the evolution of three categories of environmentally related taxes: *energy taxes*, *motor vehicle and transport taxes*, and *other environmentally related taxes*. In this context, *energy taxes* include taxes on fossil fuels and electricity, and transport fuel taxes; *motor vehicle and transport taxes* comprise import or sales taxes, recurrent taxes on registration or road use and other transport taxes (excluding transport fuel taxes); while *other taxes* encompass taxes on waste management, air pollution, and all other environmentally related taxes which are not taken into account in any of the other two categories.[8] Thus, the exact composition of the last category is country-specific, as governments tax environmental externalities in various ways. Overall, the share of environmentally related tax revenues decreased over the last two decades. This decrease in the aggregated measure comes mainly from the decrease in the energy and motor vehicle and transport tax revenues share in GDP. In contrast, revenues from *other environmentally related taxes* have gained more importance and increased as share of the GDP. The relative share of *other taxes* compared to the other categories of taxes remains, however, rather small.

[8] For an indicative list of *other environmentally related taxes* levied in OECD countries, see OECD (2006), p. 27.

Figure 3. Development of different environmentally related taxes as share of GDP over time

1995 - 2011, weighted OECD average (34 countries)



Source: Authors' calculations based on data from the OECD database on *Instruments used for Environmental Policy and Natural Resources Management*.

RELEVANT EMPIRICAL LITERATURE

While empirical literature has recently showed interest in the study of the effects of environmentally related taxes on economic growth (Abdullah and Morley, 2014), macro-econometric studies of the distributional effects of environmentally related taxes have been scant. Distributional effects have thus far been discussed in the context of micro-simulation studies (e.g. Bruha and Scasny, 2008; Flues and Thomas, 2015; Vandyck and Van Regemorter, 2014), which focus on the impact of environmental taxation on income use, and macroeconomic modelling exercises providing scenario analyses of the distributional impact of different environmental taxes (e.g. Dissou and Siddiqui, 2014; Siriwardana et al., 2013). Computable general equilibrium (CGE) modelling studies have also analysed the potential distributional consequences of environmental fiscal reforms (Durand-Lasserve et al., 2015). This paper complements these streams of literature by providing a cross-country, macro-level, empirical analysis of the relationship between environmentally related taxes, relevant tax reforms and inequality in income sources.

The approach used to estimate the distributional effects of environmentally related taxes in this paper is inspired by empirical macroeconomic studies of the relationship between fiscal systems and income inequality. This literature has looked into the effects of periods of fiscal consolidation, rates of personal and corporate income taxes, and income tax progressivity on income inequality. The literature on fiscal consolidation packages is especially important for the analysis at hand, as fiscal consolidation provides a shock to the fiscal system, in some aspects similar to the one induced by the introduction of an ETR. However, to the best of our knowledge, no study has looked into the relationship between environmental tax reforms and inequality in income sources in a cross-country setting.

A first block of relevant literature examines the relationship between income inequality, fiscal policy and economic growth. For example, Muinelo-Gallo and Roca-Sagalés (2013) use a dataset on 21 high-income OECD countries for the period 1972–2006 and show that the reduction of non-distributive expenditure is associated with both higher GDP growth and lower disposable income inequality.

Recent literature also suggests that tax progressivity is associated with lower income inequality. In their panel data analysis, Martínez-Vázquez et al. (2012) find that personal income taxes (as % of GDP) reduce income inequality and that this effect is more pronounced in countries where the tax system is more progressive. Along the same lines, Duncan and Sabirianova Peter (2012) and Woo et al. (2013) find empirical evidence that the progressivity of the tax system can reduce income inequality.

Empirical evidence on the effects of fiscal consolidation on income inequality is inconclusive. This might be due to the large heterogeneity in the size and progressivity of the fiscal consolidation programmes implemented in different countries (Joumard et al., 2012). Ball et al. (2013) and Woo et al. (2013) find support that fiscal consolidation measures increase income inequality. On the other hand, Agnello and Sousa (2012, 2014) conduct analyses on different samples and find mixed evidence for the direction of the relationship between fiscal consolidation and income inequality.

On the government expenditure side, increasing social spending seems to help reduce income inequality. Empirical evidence reveals a negative relationship between the share of social spending and the Gini coefficient (Chu et al., 2000; Martínez-Vázquez et al., 2012; Mulas-Granados, 2005; Woo et al., 2013). Chu et al. (2000) show that especially public health spending, pensions, and primary and secondary education spending reduces income inequality. Along similar lines, Martínez-Vázquez et al. (2012) find a negative effect of public spending for social welfare, education, health and housing.

EMPIRICAL ANALYSIS

The macroeconomic relationship between environmentally related taxes, revenue recycling mechanisms and income inequality

Environmentally related taxes change relative prices of goods and production inputs, shift supply and demand in labour, capital and goods markets, and move the economy to a different equilibrium from the one before their implementation. Wage, and thus, income distribution may well be different in the new equilibrium and this will be reflected in a change of the income inequality index. The direction of this change is difficult to predict, as it depends on a number of factors, such as the elasticity of demand and supply for different goods and the marginal rate of substitution between different production factors. In this framework, this study provides a first attempt to empirically estimate the macroeconomic relationship between environmentally related taxes and inequality in income sources.

The study also investigates the relationship between tax revenue recycling mechanisms and income inequality. In the examined period, several European countries tried to shift tax burden from labour and personal and corporate income to environmentally harmful activities. These countries coupled increases in environmentally related tax rates with reductions of income tax rates (especially those applicable to low-income households), taxes on corporate profits, and non-wage labour costs (e.g. social security contributions), or raises of tax-free allowances. These recycling mechanisms can affect income inequality in two ways. First, the reduction of labour costs can stimulate employment and, thus, reduce income inequality. Second, when revenues are used to reduce income tax rates for low-income households or increase tax-free allowances, the recycling mechanism will narrow the disposable income difference between low-income and other households and, therefore, result in lower income inequality.[9]

The empirical framework developed for this analysis is based on studies of the effects of fiscal policy on income inequality (e.g. Agnello and Sousa, 2012; Ball et al., 2013; Martínez-Vázquez et al., 2012; Woo et al., 2013). Similarly to the set-ups used in this literature, income inequality is measured by the disposable-income-based Gini coefficient.

We start with a rather generic specification which does not distinguish between different categories of environmentally related tax revenues or between countries which have and ones which have not implemented explicit revenue recycling mechanisms. It, thus, investigates the relationship between aggregate environmentally related taxes as a share of GDP and the Gini coefficient.[10] In a second step, environmentally related taxes are broken down to their three main components, i.e. *energy*, *motor vehicles and transport*, and *other environmentally related taxes*, to analyse whether the relationship between environmentally related tax revenues and income inequality varies with tax category.

The analysis also aims to provide insights into possible differences in the relationship of environmentally related taxes and their components between countries which have established environmentally related tax revenue recycling mechanisms and ones which have not. To this end, a literature review was conducted to collect information about the implementation of revenue recycling mechanisms in OECD countries in the examined period. This information is then used to construct two generic groups of countries: countries which have established such mechanisms to shift tax burden from income and labour to environmentally harmful activities, and ones which have not. The two groups are then analysed using the same empirical approach, with the intention to identify possible differences in the relationships of interest.

Formally, the generic model can be described as follows:

(1) $$gini_{ct} = \alpha_0 + \alpha_1 Etax_{ct-1} + \boldsymbol{\gamma X_{ct-1}} + \eta_t + \zeta_c + \epsilon_{ct} \,,$$

where *gini* is the disposable-income-based Gini coefficient, subscripts *c* and *t* denote country and year respectively, *Etax* denotes the share of environmentally related tax revenues in GDP, and $\boldsymbol{X}$ represents a vector of control variables varying across countries and over time. One-year lags are used for *Etax* and $\boldsymbol{X}$ to account for the time needed for changes in fiscal and other economic conditions to be translated to changes in income inequality (see also Mulas-Granados, 2005, and Woo et al., 2013, who also largely deploy one-

[9] However, if environmental tax revenues are used to replace progressive taxes, or if the revenue redistribution mechanism does not take special care of lower income households, ETRs may instead lead to higher income inequality. Nevertheless, reviewed literature suggests that in many cases, special provisions to protect lower-income households do actually feature in the design of relevant recycling mechanisms (e.g. increases of tax-free allowances in Estonia and the Netherlands, income tax rate reductions for medium and low-income households in Austria and Sweden). For more details, see Table 2.

[10] Macro-econometric studies of the effects of fiscal consolidation on the Gini coefficient have also used the share of various categories of tax revenues in GDP (see e.g. Mulas-Granados, 2005; Woo et al., 2013).

year lags in their analysis). Time fixed effects, η, are included in the regression to control for global, time-specific factors which influence income inequality. The model also controls for country-specific, time-invariant characteristics through country fixed effects ζ. Parameters $\alpha_{(.)}$, and vector of parameters $\boldsymbol{\gamma}$ are to be estimated, and ε is a random error term. The parameter of interest is α_1, indicating the relationship between environmentally related taxes (% of GDP) and income inequality.

Breaking down environmentally related tax revenues to their components, model (1) takes the following form:

(2) $$gini_{ct} = \beta_0 + \beta_1 EnerTax_{ct-1} + \beta_2 MotoTax_{ct-1} + \beta_3 OTax_{ct-1} + \boldsymbol{\delta X_{ct-1}} + \kappa_t + \lambda_c + \psi_{ct} \,,$$

where *EnerTax*, *MotoTax* and *OTax* stand for the share of energy, motor vehicles and transport, and other environmentally related taxes in GDP, κ and λ are time and country fixed effects, parameters $\beta_{(.)}$, and vector of parameters $\boldsymbol{\delta}$ are to be estimated, and ψ is a random error term. Likewise, the parameters of interest in this specification are β_1 to β_3.

Based on the literature review presented above, a number of control variables commonly identified among the determinants of income inequality are included in the econometric models (Martínez-Vázquez et al., 2012; Woo et al., 2013). These are factors which generally trigger changes in labour supply, labour demand or institutional set-ups. The economic indicators used as control variables in the analysis are: real GDR growth rate, inflation rate, unemployment rate, enrolment ratio in tertiary education, shares of personal and corporate income tax revenues in GDP, shares of taxes on goods and services (excluding environmentally related taxes) and property tax revenues in GDP, public and private expenditure on R&D as percentage of GDP, and the share of subsidies and transfers in government expenditure. Detailed information on these variables and the reasoning to include them in the econometric analysis is given below.[11]

Dataset

As a standard measure of income inequality, the Gini coefficient is used in various empirical applications and measures the discrepancy of perfect income equality and the actual situation observed in an economy (see Box 1). In contrast to the market-income-based Gini coefficient, the disposable-income-based Gini coefficient takes into account the redistributive effects of government policies, as it is based on the income received by households after taxes and transfers. As revenue recycling mechanisms often involve reductions in income tax rates or increases in transfers, the disposable-income-based Gini is more likely to capture the relationship between tax revenue recycling mechanisms and income inequality than its market-based-income counterpart, and was, thus, considered a more appropriate measure for the purposes of the analysis. The data on the Gini coefficient used in this study are taken from the Standardized World Income Inequality Database (SWIID), which currently offers the longest and most complete panel dataset on income inequality (see Box 2; Solt, 2009, 2014).[12] The calculation of Gini is based on disposable income per adult equivalent, defined by the Luxembourg Income Study as household disposable income divided by the square root of the number of household members.

Box 2. Gini coefficient – data sources

[11] Other control variables suggested in the literature, such as trade openness, as well as various measures of personal income tax progressivity, performed poorly and were not included in the final model specification. Their inclusion in the model does not change the conclusions of the analysis presented here.

[12] *http://thedata.harvard.edu/dvn/dv/fsolt/faces/study/StudyPage.xhtml?studyId=36908&tab=files*

Practically all measures of income inequality rely on household survey data. This poses a problem in terms of data comparability and availability. Household surveys are usually conducted every other year which makes it difficult to have yearly data points for income inequality. Next to data availability, the varying definitions across countries on e.g. income groups, and the variability of coverage of surveys pose problems of comparability of data across countries. Several databases try to combine microdata from different official sources to obtain the largest coverage of income data possible. Amongst them are original sources of harmonised official data, such as the Luxembourg income study or the EU-SILC database, or databases which combine national household survey data with the Luxembourg Income Study (LIS) and the Eurostat data, such as the UN University's World Income Inequality Database (UNU-WIIDER), the Deininger and Squire dataset of the World Bank, the OECD Income Distribution Database and the Standardized World Income Inequality Database (SWIID). The SWIID (Solt, 2009; 2014) offers the longest and most complete panel dataset of income inequality currently available and is therefore used in this analysis.

As mentioned before, the SWIID draws on various available data sources to construct a comprehensive cross-national database of Gini coefficients. It combines data from the Luxembourg Income Study with data from other cross-national databases and with data from national statistical offices and academic literature. As a basis, SWIID adopts the definition of equivalised income used by LIS, i.e. household income divided by the square root of household members. In an effort to harmonise data from these different sources, the SWIID uses a missing-data multiple-imputation algorithm (for more details, see Solt, 2009). The imputation of missing values explains why this dataset is much more complete than others. The completeness of SWIID comes, however, at a cost; some elements of the database are statistical estimates, not official data.

Data on environmentally related tax revenues are taken from the *OECD Database on Instruments used for Environmental Policy and Natural Resources Management*. As already mentioned, environmentally related taxes are defined as all "compulsory, unrequited payment[s] to general government levied on tax-bases deemed to be of particular environmental relevance" (OECD, 2001). The OECD database distinguishes three categories of environmentally related taxes: (i) *energy*, (ii) *motor vehicles and transport*, and (iii) *other environmentally related taxes*. This disaggregated information is used to test whether the relationship between environmentally related taxes and income inequality varies with the taxed activity. In all cases, the tax revenues are divided by the country's GDP to account for size effects of the economy in the regression model.

The empirical model also controls for changes in the economic and institutional environment affecting income inequality. Following Martínez-Vázquez *et al.* (2012), economic growth, as measured by the growth rate of GDP per capita, entails higher household disposable income. GDP per capita growth may imply higher or lower income inequality, depending on the progressivity of the tax system and the structure of the economy. The variable used to control for the implications of GDP growth on income inequality is the *growth rate of real GDP per capita* (2005US$, constant PPPs), from the OECD National Accounts Database.

Progressivity in personal income taxation and other redistributive measures (e.g. subsidies and transfers) are the main instruments used by governments to change the distribution of disposable income over households and reduce income inequality. Data on the progressivity of income tax systems in OECD countries are unfortunately only available for the period from 2000 onwards and, thus, do not provide long enough series to be used in this analysis. In the absence of complete information about income tax progressivity, data on *personal income tax revenues as percentage of GDP* (OECD Revenue Statistics) are used to control for some of the effects of income taxation on income inequality. However, these data do not provide much insight into how the income tax burden is distributed among households. Regarding the effects of government subsidies and transfers on income inequality, they are controlled for in the econometric model using data on the *share of subsidies and other transfers in government expenditure* (World Development Indicators, World Bank).

The effect of corporate income taxation on inequality in income sources is less clear-cut. However, higher corporate profit taxes may discourage corporate investment and thus result in higher unemployment and lower wages, especially for less skilled workforce. Data on *corporate income tax revenues as* *percentage of GDP* (OECD Revenue Statistics) are used to control for the relationship between corporate taxation and income inequality, which is expected to be negative.

Other indirect taxes, such as taxes on goods and services (e.g. VAT, sales taxes) and property taxes, also change the relative prices of goods and services and are, therefore, likely to have indirect effects on inequality in income sources. The direction of these effects is a priori ambiguous, as it depends on price and cross-price elasticities of demand for different goods and the elasticity of substitution between different production factors. The econometric model controls for the effects of these taxes on income inequality using data on revenues from *taxes on goods and services*, and *taxes on property, as a percentage of GDP* (OECD Revenue Statistics).

Demographic changes also have a significant influence on income inequality. Population growth is often associated with higher inequality for two main reasons. First, labour demand may be increasing at a slower pace than labour supply, inducing higher unemployment rates and a compression of wages, especially of lower-skilled workers. Second, more rapidly growing societies may well face an increase in the average ratio of profits and rents to labour earnings. As the distribution of the former is more unequal to the distribution of the latter, higher population growth rates may result in higher income inequality (Boulier, 1975). The age structure of the population is also important for income inequality. For example, the share of youth in the population is usually positively correlated with income inequality, as the income of low-income households has to be distributed among a larger number of individuals. The model accounts for the effects of such demographic changes using the *population growth rate* and the *age 15-64 dependency ratio* from the OECD Population Statistics. We expect to find a positive relationship of income inequality with the former, whereas a negative relationship with the latter.

Educational attainment is another important determinant of income inequality (e.g. Martínez-Vázquez *et al.*, 2012; Woo *et al.*, 2013). In particular, a broader coverage of secondary and tertiary education may well lead to a more equal distribution of income. The variable used in the analysis to control for education attainment is the *gross enrolment ratio in tertiary education* from the UNESCO Institute for Statistics. It is expected that a higher enrolment ratio will be associated with lower income inequality.

High unemployment and inflation rates can drive up income inequality. Unemployed individuals are often found in the lower income deciles, and, thus, a larger number of unemployed people are associated with higher income inequality. Data from the International Labour Organisation (*total unemployment as a percentage of total labour force*) are used to control for the effects of unemployment on income inequality. Inflation can also affect low-income households more than high-income ones and is, therefore expected to increase income inequality.[13] OECD's *growth rate of the consumer price index* is used to control for the effect of inflation changes.

High-skill-based technological progress is also suggested to be one of the forces behind recent increases in income inequality (e.g. Woo et al., 2013). Data on public and private spending on R&D (*R&D expenditure as % of GDP*, from World Bank's World Development Indicators) are used as a proxy to control for such possible effects of high-skill-based technological progress.

The model is estimated on data for all 34 OECD countries over the time period 1995 – 2011.[14] To address concerns related to gaps in the data, missing values for the expenditure variables, i.e. spending on

[13] Note that inflation also captures to a large extent changes in energy and fuel prices (for which national data are incomplete). World oil price fluctuations are taken into account in the model through time fixed effects.

[14] List of countries included in the analysis: Australia (AUS), Austria (AUT), Belgium (BEL), Canada (CAN), Switzerland (CHE), Chile (CHL), Czech Republic (CZE), Germany (DEU), Denmark (DNK), Spain (ESP), Estonia (EST), Finland (FIN), France (FRA), United Kingdom (GBR), Greece (GRC), Hungary

R&D as a share of GDP and subsidies and transfers as a share of government expenditure, are imputed with the random forest method (Stekhoven and Bühlmann, 2012). Details on the imputation approach are provided in Appendix 1. Table 1 provides descriptive statistics for the variables used in the empirical analysis.

Table 1. Descriptive statistics for the variables used in the analysis

Variable	Mean	Std. Dev.	Min	Max
Disposable-income-based Gini coefficient	0.308	0.064	0.216	0.510
Environmentally related tax revenues (%)	2.389	0.864	-1.552	5.428
Energy tax revenues (%)	1.658	0.675	-1.772	4.988
Motor vehicle and transport tax revenues (%)	0.638	0.459	0	2.306
Other environmentally related tax revenues (%)	0.092	0.131	0	0.952
Real GDP per capita growth rate (%)	2.200	3.089	-14.066	13.262
Population growth rate (%)	0.652	0.691	-1.770	4.028
Age-dependency ratio: 15-64 years old (%)	66.959	2.228	59.280	73.027
Enrolment in tertiary education (%)	56.462	19.015	7.381	101.759
Unemployment (%)	7.347	3.644	1.800	23.100
Inflation (%)	4.513	9.154	-4.500	89.100
Personal income tax revenues (%)	18.171	5.767	5.647	33.600
Corporate income tax revenues (%)	3.134	1.552	0.519	12.755
Revenues from taxes on goods & services (%)	8.489	2.315	2.492	14.654
Property tax revenues (%)	1.773	1.045	0.217	7.293
Government spending on subsidies & transfers (%)	60.519	13.819	16.925	82.847
Expenditure on R&D (%)	1.825	0.912	0.311	4.835

As already mentioned, information about the implementation of revenue recycling mechanisms was collected through a literature review. The reviewed literature comprised articles published in academic journals, books, and policy reports. When literature was unclear about the scope of the recycling mechanism, individual researchers and national experts were contacted to shed light on this issue. The main criterion for a recycling mechanism to be considered in the analysis was that it explicitly shifted burden from income and labour to environmentally harmful activities.[15] Other types of environmental tax

(HUN), Israel (ISR), Ireland (IRL), Italy (ITA), Japan (JPN), Korea (KOR), Luxembourg (LUX), Mexico (MEX), Netherlands (NLD), Norway (NOR), New Zealand (NZL), Poland (POL), Portugal (PRT), Slovakia (SVK), Slovenia (SVN), Sweden (SWE), Turkey (TUR), United States (USA).

[15] A special case considered in the analysis is Switzerland's ETR, which recycles tax revenues by providing per capita refunds. These refunds are foreseen to decrease income inequality.

reforms, such as the ones earmarking revenues for renewable energy investment projects or other environmental protection initiatives, are not in the scope of the analysis, as they are not expected to have a noticeable effect on income inequality.

Table 2 provides a full list of the identified ETRs and summarises some of their characteristics. For each reform, it presents the main sources of environmentally related tax revenues and the primary channels via which these revenues were recycled. Recycling mechanisms vary widely across countries, ranging from reductions of personal income tax rates and employers' social security contributions to decreases of corporate profit tax rates. The table also shows when ETRs were introduced and whether they were intended to be revenue neutral. Last, it cites the references from which relevant information was collected. These references mostly rely on official government sources (e.g. laws, publications of government budgets). However, accurate quantitative information, such as the exact amount of revenues collected through specific taxes and directed to the reduction of specific labour costs, is rarely provided in the literature. An implication of this lack of quantitative information is that the differentiation of recycling mechanisms according to the size of the tax shift is not possible.

Empirical results

Are environmentally related taxes associated with inequality in income sources?

The fixed-effects estimation results for equations (1) and (2) are presented in Table 3.[16] They reveal that there is no statistically significant relationship between the overall share of environmentally related taxes in GDP and income inequality in the following period. Disaggregating environmentally related taxes into energy, motor vehicles and transport, and other environmentally related taxes shows that the relationship with inequality in income sources varies substantially with taxed activity. Energy tax revenues are positively associated with the Gini coefficient of the following year.[17] However, this relationship is rather modest. In particular, an increase of this share by 0.1 percentage points is associated with an approximately 0.0006 point increase in the Gini coefficient. The magnitude of this relationship is relatively small, but it is more informative to view it in light of the magnitude of the estimated relationship between other sources of tax revenue and income inequality, as well as in light of the within-country volatility of the Gini coefficient. The relationship between income inequality and the share of energy tax revenues in GDP appears stronger than the relationship of the former with other potentially influential sources, such as other taxes on goods and services. At the same time, it is also important to note that the within-country standard deviation of the Gini coefficient is 0.012, while the one of energy taxes (% of GDP) is around 0.4. Ceteris paribus, an increase of energy tax revenues by 0.4 percentage points would be associated with an increase of about 0.0024 of the Gini coefficient, which is about 19% of its average variation within a country where no revenue recycling mechanism is in place.

[16] Formal statistical tests rejected the assumption that the country fixed effect is uncorrelated with the rest of the explanatory variables, indicating that the fixed-effects estimator should be preferred to the random-effects one (p-value of Sargan-Hansen statistic = 0.000; see also Arellano, 1993, and Wooldridge, 2010, pp. 310-312).

[17] The relationship between energy taxes and income inequality may well also vary across different types of energy taxes, but available data do not allow a disaggregation of this category and, thus, providing further insights into such possible differences.

Table 2. Overview of ETRs implemented in OECD countries until 2011

COUNTRY	YEAR	ENVIRONMENTALLY RELATED TAX REVENUE	RECYCLING MECHANISM	ETR TYPE	REFERENCES
Austria	2004	Increase of mineral oil and natural gas taxes and introduction of a coal tax.	Reduction of personal income taxes for low and middle income households. Reduction of corporate taxes and tax incentives for SMEs.	The environmental tax reform was part of a wider fiscal reform.	OECD (2007, 2009)
Czech Republic	2008	New taxes on natural gas, solid fuels and electricity.	Reduction of income and corporate profit taxes and (arguably) social security contributions.	Revenue neutral reform	GIZ (2013)
Denmark	1994	Increase of energy taxes and introduction of taxes on tap water, wastewater tax, and plastic and paper bags.	Reduction of marginal income tax rates.	Revenue neutral reform	Andersen et al. (2007), Speck & Jilkova (2009)
	1996	Increase of industrial energy tax rates, and introduction of a sulphur tax and a tax on natural gas.	Reduction of employers' social security contributions, subsidies for energy efficiency programmes and support for SMEs.	Revenue neutral reform	Andersen et al. (2007), Speck & Jilkova (2009)
	1998	Increases of energy taxes (petrol, diesel, coal, electricity, natural gas, light and heavy fuel oil).	Reduction of personal income tax rates and taxes on the yield of pension savings.	Revenue neutral reform	Andersen et al. (2007), Speck & Jilkova (2009)
	2007	Yearly price indexation of energy taxes.	Reduction of personal income taxes.	Revenue neutral reform (but part of the income tax reduction financed through increased revenues from other sources)	Larsen (2011)
	2010	Increased taxes on energy and wastewater and changes in motor vehicle taxation.	Revenues from energy taxes help reduce healthcare payments and the lowest tax rate. Households also compensated by green cheques (small tax deductions for every individual in the household).	Revenue neutral reform	Bragadóttir et al. (2014); Larsen (2011)
Estonia	2006	Increase of transport fuel taxes, introduction of a tax on natural gas and an electricity output tax.	Reduction of income tax rates. Increase in the tax-free allowance and tax exemptions for pensioners and families with more than two children.	Revenue neutral reform	Speck (2007)
Finland	1997	Energy, CO_2 and landfill taxes.	Reduction of personal income taxes and employers' social security contributions.	Revenue negative reform; aim was to foster employment.	Andersen et al. (2007), Speck & Jilkova (2009)
	1998	Energy and environmental taxes.	Further reduction of labour taxes.	Revenue negative reform; aim was to foster employment.	Andersen et al. (2007), Speck & Jilkova (2009)
Germany	1999	Increase of existing energy taxes (transport fuels, natural gas, light heating fuels, heavy fuel oil) and introduction of an electricity tax.	Reduction of employers' and employees' social security (pension) contributions.	Planned as revenue neutral, but eventually rather positive reform.	Andersen et al. (2007), Speck & Jilkova (2009), IEEP (2013)
	2006	Heating fuel tax on natural gas and heavy fuel oil.	Reduction of employers' and employees' social security (pension) contributions.	Planned as revenue neutral reform.	IEEP (2013)

The Netherlands	1996	Energy taxes levied on mineral oil products, natural gas and electricity, and taxes on water and waste disposal.	Reduction of income taxes, employers' social security contributions and corporate profit taxes.	Revenue neutral reform	Andersen et al. (2007), Ruijs & Vollebergh (2013)
	1999	Energy taxes.	Reduction of income taxes and increase of tax-free allowances. Reduction of employers' social security contributions, taxes for self-employed and corporate profit taxes.	Revenue neutral reform	Andersen et al. (2007), EEA (2011), Speck & Jilkova (2009)
Norway	1999	CO_2 tax extended to air transport, domestic sea transport of goods, and the supply fleet in the North Sea. Introduction of a tax on waste delivered to landfills and combustion plants.	Reductions in personal income tax.	Revenue neutral reform	Hoerner & Bosquet (2001), OECD (2001b)
Sweden	1991	New CO_2 and energy taxes and SO_2 tax.	Reduction of personal income taxes and social security contributions.	Revenue negative reform; aim was to reduce labour taxes.	Andersen et al. (2007), IEEP (2013), Speck & Jilkova (2009)
	2001	Increase of taxes on CO_2, motor vehicles, waste landfilling, gravel and pesticides.	Reduction of personal income taxes paid by medium and low-income households and social security contributions	Revenue negative reform; aim was to reduce labour taxes.	Andersen et al. (2007), IEEP (2013), Lindhjem et al. (2009), Speck & Jilkova (2009), OECD (2014b)
Switzerland	2008	National CO_2 tax levied on fossil fuels	Per capita refunds, known as eco-bonuses. Taxes paid by enterprises redistributed to enterprises and taxes paid by citizens shared equally among citizens.	Revenue neutral reform	EEA (2011)
United Kingdom	1996	Landfill tax.	Reduction of employers' insurance contributions.	Revenue neutral reform	Andersen et al. (2007), Speck & Jilkova (2009)
	2001	Climate change levy on energy products.	Reduction of employers' insurance contributions.	Revenue neutral reform	Andersen et al. (2007), Speck & Jilkova (2009)
	2002	Aggregates tax (sand, gravel, crushed rock)	Reduction of employers' insurance contributions.	Revenue neutral reform	Andersen et al. (2007), Speck & Jilkova (2009)

Note: Part of this table is based on Andersen *et al.* (2007), pp. 64-67.

In contrast to energy taxes, there is no statistically significant relationship between motor vehicle and transport taxes and income inequality, while increases in the share of other environmentally related tax revenues in GDP appear rather strongly associated with reductions in income inequality. Even though the size of the coefficient of other environmentally related taxes is more than fourfold the size of the coefficient of energy taxes, it is important to keep in mind that other environmentally related taxes comprise a much smaller percentage of GDP than energy taxes and that the average within country variation of the former is only about one sixth of the variation of the latter. As mentioned above, the composition of other environmentally related taxes varies importantly across countries, as different activities form the basis of this category in each country. Mostly, however, this category consists of waste, water and air pollution taxes. Considering the large variation in the composition of this tax category, it is rather difficult to attempt to interpret the negative relationship between other environmentally related taxes and inequality in income sources.

Estimation results broadly confirm expectations about the relationship between the control variables and inequality in income sources, and are in general (although not necessarily complete) agreement with the findings of empirical studies on the effects of fiscal consolidation and tax and expenditure policies on income inequality (Martínez-Vázquez et al., 2012; Woo et al., 2013). The analysis reveals that the growth of GDP per capita, unemployment, inflation, and high-skill-based technological progress (as approximated by R&D expenditure as % of GDP) are positively associated with income inequality. In contrast, higher shares of personal and corporate income taxes in GDP, higher government spending on social transfers, and higher rates of enrolment in tertiary education are inversely related to income inequality. Revenues from other taxes on goods and services and property taxes, as well as demographic variables, do not seem to have a statistically significant relationship with inequality in income sources.

Appendix 2 shows the results of a more complex model, namely a Panel Data Fractional Logit with correlated random effects, which was estimated to test the robustness of the findings presented here. This model is ideally suited for fractional response dependent variables (variables which take values between 0 and 1, like the Gini coefficient) and is robust to specific forms of endogeneity, especially the ones related to omitted variable bias. The results obtained from this model are consistent with the ones presented here.

Is the relationship between environmentally related taxes and income inequality different in countries which have implemented ETRs and in ones which have not?

Table 4 presents the results of models (1) and (2) when they are estimated on different samples; a sample containing the 11 countries which have established explicit recycling mechanisms in the examined period and a sample comprising the other 23 countries. The estimation results reveal notable differences between the two groups of countries. Environmentally related taxes are negatively associated with inequality in income sources in countries which have implemented ETRs in the examined period, whereas positively associated with inequality in countries which have not. This difference is driven by differences in the relationship between energy tax revenues and inequality in income sources between the two groups of countries. In countries with revenue recycling mechanisms, the relationship between energy tax revenues and income inequality is negative, whereas in countries without recycling mechanisms it is positive. Other environmentally related tax revenues are negatively associated with income inequality, regardless of whether the country has implemented an ETR in the examined period.

These results do not lend themselves as evidence of a negative effect of recycling mechanisms on the relationship between environmentally related tax revenues and income inequality. They only reveal that there is a significant difference in this relationship between countries which have and countries which have not implemented ETRs. There may well be factors which determine both the decision to establish an explicit recycling mechanism in a country and the level of the Gini coefficient that the model does not account for.

Table 3. Fixed-effects estimation results

	Aggregate model		Disaggregated model	
VARIABLES	coef.	s.e.	coef.	s.e.
Environmentally related tax revenues (% GDP)	0.0034	(0.0026)		
Energy tax revenues (% GDP)			**0.0057****	(0.0026)
Motor vehicles and transport tax revenues (% GDP)			-0.0002	(0.0053)
Other environmentally related tax revenues (% GDP)			**-0.0283****	(0.0113)
GDP per capita growth (%)	**0.0011*****	(0.0003)	**0.0011*****	(0.0003)
Population growth rate (%)	0.0025	(0.0018)	0.0023	(0.0018)
Age-dependency ratio: 15-64 years old (%)	-0.0022	(0.0014)	-0.0018	(0.0013)
Enrolment in tertiary education (%)	**-0.0003****	(0.0001)	**-0.0003****	(0.0001)
Unemployment (%)	**0.0013****	(0.0005)	**0.0011****	(0.0004)
Inflation (%)	**0.0008*****	(0.0002)	**0.0008*****	(0.0002)
Personal income tax revenues (%)	**-0.0019****	(0.0008)	**-0.0017****	(0.0007)
Corporate income tax revenues (%)	**-0.0020****	(0.0008)	**-0.0017****	(0.0008)
Revenues from taxes on goods & services (%)	-0.0009	(0.0014)	-0.0011	(0.0015)
Property tax revenues (%)	-0.0022	(0.0029)	-0.0027	(0.0029)
Government spending on subsidies & transfers (%)	**-0.0003****	(0.0001)	**-0.0003****	(0.0001)
Expenditure on R&D (%)	**0.0078***	(0.0042)	0.0066	(0.0042)
Observations		544		544
Countries		34		34
R^2-adjusted		0.978		0.979

Note: *** p-value<0.01; ** p-value<0.05; * p-value<0.1; s.e.: Heteroskedasticity-robust standard errors clustered by country. All models include country and year fixed effects, whose estimates are not reported.

Table 4. Fixed-effects estimation results: split samples based on the implementation of ETR

	Countries without revenue recycling		Countries with revenue recycling		Countries without revenue recycling		Countries with revenue recycling	
	Aggregate model		Aggregate model		Disaggregated model		Disaggregated model	
VARIABLES	coef.	s.e.	coef.	s.e.	coef.	s.e.	coef.	s.e.
Environmentally related tax revenues (% GDP)	**0.0063*** **	(0.0016)	**-0.0192** **	(0.0067)				
Energy tax revenues (% GDP)					**0.0082*** **	(0.0021)	**-0.0239*** **	(0.0052)
Motor vehicles and transport tax revenues (% GDP)					0.0025	(0.0049)	0.0094	(0.0114)
Other environmentally related tax revenues (% GDP)					**-0.0217* **	(0.0125)	**-0.0575** **	(0.0223)
GDP per capita growth (%)	**0.0009*** **	(0.0003)	**0.0008* **	(0.0004)	**0.0011*** **	(0.0003)	0.0007	(0.0004)
Population growth rate (%)	**0.0029* **	(0.0015)	-0.0011	(0.0020)	**0.0028* **	(0.0016)	-0.0021	(0.0021)
Age-dependency ratio: 15-64 years old (%)	-0.0013	(0.0014)	**-0.0053** **	(0.0022)	-0.0010	(0.0014)	**-0.0064*** **	(0.0017)
Enrolment in tertiary education (%)	**-0.0004** **	(0.0002)	-0.0002	(0.0002)	**-0.0003** **	(0.0002)	-0.0002	(0.0002)
Unemployment (%)	**0.0011** **	(0.0005)	0.0011	(0.0008)	**0.0011** **	(0.0005)	0.0007	(0.0007)
Inflation (%)	**0.0008*** **	(0.0001)	-0.0003	(0.0003)	**0.0008*** **	(0.0001)	**-0.0007* **	(0.0003)
Personal income tax revenues (%)	**-0.0020**	(0.0010)	-0.0001	(0.0009)	**-0.0018* **	(0.0009)	0.0001	(0.0009)
Corporate income tax revenues (%)	**-0.0034* **	(0.0018)	-0.0023	(0.0016)	-0.0028	(0.0016)	**-0.0032** **	(0.0014)
Revenues from taxes on goods & services (%)	0.0000	(0.0012)	0.0013	(0.0025)	-0.0001	(0.0014)	-0.00004	(0.0024)
Property tax revenues (%)	-0.0016	(0.0022)	**-0.0121** **	(0.0049)	-0.0021	(0.0023)	**-0.0111** **	(0.0045)
Government spending on subsidies & transfers (%)	**-0.0008*** **	(0.0002)	-0.00003	(0.0001)	**-0.0007*** **	(0.0002)	**-0.0002** **	(0.0001)
Expenditure on R&D (%)	**0.0111*** **	(0.0038)	0.0022	(0.0069)	**0.0097*** **	(0.0033)	-0.00004	(0.0060)
Observations		368		176		368		176
Countries		23		11		23		11
R^2-adjusted		0.981		0.959		0.982		0.964

Note: *** p-value<0.01; ** p-value<0.05; * p-value<0.1; s.e.: Heteroskedasticity-robust standard errors clustered by country. All models include country and year fixed effects, whose estimates are not reported.

CONCLUSION AND SUGGESTIONS FOR FUTURE ANALYSES

This paper provides a first empirical analysis of the macroeconomic relationship between environmentally related taxes and income inequality. In contrast to earlier empirical literature which investigates the potential distributional effects of taxes on the uses of household income, this study focuses on inequality in income sources. In particular, the study analyses the relationship between environmentally related taxes (as % of GDP) and the disposable-income-based Gini coefficient, as well as whether this relationship differs between countries which have established explicit mechanisms to shift tax burden from labour and personal and corporate income to environmentally harmful activities and ones which have not. The empirical analysis is based on a panel of all 34 OECD countries for the period 1995-2011, and information about the implementation of environmental tax reforms (ETRs) to establish such revenue recycling mechanisms in the examined period is collected through a review of relevant academic and policy literature.

Empirical results reveal that, on average, there is no statistically significant relationship between the overall share of environmentally related tax revenues in GDP and inequality in income sources. However, the relationship varies with the taxed activity under consideration and the existence of an explicit mechanism to redistribute environmentally related tax revenues. In countries where such mechanisms are absent, *energy tax revenues* (% of GDP) are shown to have a positive, although modest, relationship with income inequality. In contrast, in countries where energy tax revenues are, at least partially, used to reduce tax burden on income and labour, there is a negative relationship between energy taxes and inequality in income sources. On the contrary, no significant relationship is identified between *motor vehicle and other transport tax revenues* and income inequality, while revenues from *other environmentally related taxes*, such as waste and air pollution taxes, are negatively associated with income inequality, regardless of the existence of an explicit revenue recycling mechanism.

A recent micro-simulation-based OECD study showed that distributional effects also vary within the category of *energy taxes* (Flues and Thomas, 2015). Taxes on motor fuel usually have a progressive or proportional effect, while taxes on electricity and heating are to some extent regressive. In this spirit, an interesting direction for future analysis would be to investigate whether the relationship between energy tax revenues and inequality in income sources also varies with the activity taxed. Along the same lines, the study of the relationship between different components of *motor vehicle and transport taxes* and *other environmentally related taxes* and income inequality would contribute to the identification of specific activities and commodities whose taxation has a significant relationship with income inequality.

Another promising avenue for future research is the analysis of the relationship between the use of alternative policy instruments to environmentally related taxes and inequality in income sources. Perhaps the most commonly used such instruments are technology- or performance-based standards. The literature has so far largely neglected the possible relationship between regulatory standards and income inequality (Fullerton and Heutel, 2010, and Sutherland, 2006 are notable exceptions here). In practice, certain appliance standards might reduce or even eliminate the bottom end of a market (e.g. appliances with low investment/operating cost ratios). This may lead to distortions in the labour market equilibrium, with unknown effects on employment and wage distribution. It is, hence, of importance to consider the relationship between alternative policy measures and income inequality when discussing the relationship of the latter with environmentally related taxes.

Certainly, the short term costs of the introduction of an environmentally related tax are of high importance in a political economy framework. Especially for this reason, it is perhaps worthwhile to consider providing explicit revenue recycling mechanisms alongside the introduction of environmentally related taxes. Possible recycling mechanisms may include lump-sum redistributions, reductions in personal income taxes, increases of tax-free allowances, reductions of non-wage labour costs such as employers' social security contributions, or reductions in corporate income taxes to stimulate employment. However, it is important that the mechanism is designed in a way that lower income households are especially benefitted from the redistribution of tax revenues. This paper does not aim to evaluate the relative performance of different recycling mechanisms, as the collected information about implemented ETRs is not detailed enough to allow such an evaluation. This is, however, another interesting avenue for further research.

Much attention has thus far been paid on the possible effects of various kinds of environmentally related taxes on inequality in income uses. Similarly to all taxes which apply to selected commodities, however, environmentally related taxes change the relative prices of goods and production factors and can, thus, also affect inequality in income sources. The exploratory analysis presented in this paper provides a first step towards a better understanding of the empirical relationship between environmentally related taxes and inequality in income sources. It also provides a first attempt to compile information about environmentally related tax revenue recycling mechanisms established in OECD countries and utilise it to empirically investigate differences between countries which have implemented ETRs and ones which have not. The study's potential to identify causal relationships is mainly constrained by the limited availability of data on the progressivity of income tax systems in OECD countries and the limited information about the operation of revenue recycling mechanisms provided in the literature. Further research in this area would, thus, be substantially benefitted by the collection of more detailed data on the progressivity of income tax systems and the tax shifts induced by the implementation of revenue recycling mechanisms.

BIBLIOGRAPHY

Abdullah, S. and B. Morley (2014), “Environmental taxes and economic growth: Evidence from panel causality tests”, *Energy Economics*, Vol. 42, pp. 27-33.

Abrevaya, J. and C.M. Dahl (2008), “The effects of birth inputs on birthweight: evidence from quantile estimation on panel data”, *Journal of Business & Economic Statistics*, 26/4, pp. 379-397.

Agnello, L. and R.M. Sousa (2012), “Fiscal adjustments and income inequality: a first assessment”, *Applied Economics Letters*, Vol. 19/16, pp. 1627-1632.

Agnello, L. and R.M. Sousa (2014), “How does fiscal consolidation impact on income inequality?”, *Review of Income and Wealth*, Vol. 60/4, pp. 702–726.

Andersen, M.S. et al., (eds.) (2007), “Competitiveness Effects of Environmental Tax Reforms (COMETR)”, Final report to the European Commission, National Environmental Research institute, University of Aarhus.

Andersen, M.S. and P. Ekins (eds.) (2009), “Carbon-Energy Taxation: Lessons from Europe”, Oxford University Press.

Arellano, M. (1993), “On the testing of correlated effects with panel data”, *Journal of Econometrics*, 59/1, pp. 87-97.

Bragadóttir, H. et al. (2014), “The Use of Economic Instruments in Nordic Environmental Policy 2010-2013”, Nordic Council of Ministers.

Ball, L. et al. (2013), “The distributional effects of fiscal austerity”, *DESA Working Paper No. 129*, United Nations Department of Economic and Social Affairs.

Boulier, B. (1975), “The effects of demographic variables on income distribution”, Woodrow Wilson School Discussion Paper No. 61, Princeton University.

Bovenberg, A.L. and F. van der Ploeg, (1994), “Environmental Policy, Public Finance and the Labour Market in a Second-Best World”, *Journal of Public Economics*, Vol. 55/3, pp. 349-390.

Bruha, J. and M. Scasny (2008), “Distributional effects of environmental regulation in the Czech Republic”, In *3rd Annual Congress of Association of Environmental and Resource Economics – AERE*, pp. 4-7, Kyoto, Japan.

Chamberlain, G. (1982), “Multivariate regression models for panel data”, *Journal of Econometrics*, 18/1, pp. 5-46.

Charlot, S. R. Crescenzi, R. and A. Musolesi (2015), “Econometric Modelling of the Regional Knowledge Production Function in Europe”, *Journal of Economic Geography*, Vol. 15/6, pp. 1227-1259.

Chu, K-Y., H. Davoodi and S. Gupta (2000), “Income Distribution and Tax and Government Social Spending Policies in Developing Countries”, *IMF Working Paper No. 62*, International Monetary Fund.

Dissou, Y. and M.S. Siddiqui (2014), "Can carbon taxes be progressive?", *Energy Economics*, Vol. 42, pp. 88-100.

Duncan, D. and K. Sabirianova Peter (2012), "Unequal Inequalities: Do Progressive Taxes Reduce Income Inequality?", *IZA Discussion Paper No. 6910*, Institute for the Study of Labor.

Durand-Lasserve, O., et al. (2015), "Modelling of distributional impacts of energy subsidy reforms: an illustration with Indonesia", *OECD Environment Working Papers*, No. 86, OECD Publishing, Paris, *http://dx.doi.org/10.1787/5js4k0scrqq5-en*.

EEA (2011), "Environmental tax reform in Europe: implications for income distribution", *European Environment Agency Technical Report No. 16/2011*.

EEA (2005), "Market-based instruments for environmental policy in Europe", *European Environment Agency Technical Report No. 8/2005*.

Ekins, P. (1999), "European environmental taxes and charges: recent experience, issues and trends", *Ecological Economics*, 31/1, pp. 39-62.

Ekins, P. et al. (2011), "The implications for households of environmental tax reform (ETR) in Europe", *Ecological Economics*, Vol. 70/12, pp. 2472-2485.

Ekins, P. and S. Speck (eds.) (2011), *Environmental tax reform (ETR): a policy for green growth*, Oxford University Press.

Flues, F. and A. Thomas (2015), "The distributional effects of energy taxes", *OECD Taxation Working Papers*, No. 23, OECD Publishing, Paris, *http://dx.doi.org/10.1787/5js1qwkqqrbv-en*.

Fullerton, D. (2011), "Six distributional effects of environmental policy", *Risk Analysis*, Vol. 31/6, pp. 923-929.

Fullerton, D., and G. Heutel (2010), "The general equilibrium incidence of environmental mandates", *American Economic Journal: Economic Policy*, 2/3, pp. 64-89.

Fullerton, D., and G. Heutel (2007), "The general equilibrium incidence of environmental taxes" *Journal of Public Economics*, 91/3, pp. 571-591.

GIZ – Deutsche Gesellschaft für Internationale Zusammenarbeit (2013), "Environmental Fiscal Reform – Case Studies".

Goulder, L.H. (1995), "Environmental taxation and the "double dividend": a Reader's guide", *International Tax and Public Finance*, Vol. 2, pp. 157–183.

Hoerner, J.A. and B. Bosquet (2001), "Environmental tax reform: the European experience", Washington DC, Center for a Sustainable Economy.

ILO (2011), "The double dividend and environmental tax reforms in Europe", *EC-IILS Joint Discussion Paper Series*, No. 13.

Johnstone, N. and J.R.R. Alavalapati (1998), "The Distributional Effects of Environmental Tax Reform", *International Institute for Environment and Development*, Discussion Paper 24140.

Joumard, I., M. Pisu and D. Bloch (2012), "Less Income Inequality and More Growth – Are They Compatible? Part 3. Income Redistribution via Taxes and Transfers across OECD Countries", *OECD Economics Department Working Papers*, No. 926, OECD Publishing. http://dx.doi.org/10.1787/5k9h296b1zjf-en.

Kosonen, K. (2012), "Regressivity in environmental taxation: myth or reality?" in J. Milne and M.S. Andersen (eds.), Handbook of Research on Environmental Taxation, Edward Elgar, Cheltenham.

Larsen, T. (2011), "Greening the Danish Tax System", Federale Overheidsdienst Financiën – België, 71e jaargang, nr. 2, 2e kwartaal 2011.

Lindhjem, H. et al. (2009), "*The Use of Economic Instruments in Nordic Environmental Policy 2006–2009*", Nordic Council of Ministers.

Martínez-Vázquez, J., V. Vulovic and B. Moreno-Dodson (2012), "The Impact of Tax and Expenditure Policies on Income Distribution: Evidence from a Large Panel of Countries", *Review of Public Economics*, Vol. 200/4, pp. 95-130.

Mieszkowski, P. (1969), "Tax incidence theory: The effects of taxes on the distribution of income", *Journal of Economic Literature*, Vol. 7/4, pp. 1103-1124.

Muinelo-Gallo, L. and O. Roca-Sagalés (2013), "Joint determinants of fiscal policy, income inequality and economic growth", *Economic Modelling*, Vol. 30, pp. 814-824.

Mulas-Granados, C. (2005), "Fiscal Adjustments and the Short-Term Trade-Off Between Economic Growth and Equality", *Revista de Economica Publica*, Vol. 172, pp. 61-92.

Mundlak, Y. (1978), "On the Pooling of Time Series and Cross-section Data", *Econometrica*, Vol. 46/1, pp. 69–85.

OECD (2015), *OECD Companion to the Inventory of Support Measures for Fossil Fuels 2015*, OECD Publishing, Paris, *http://dx.doi.org/10.1787/9789264239616-en*.

OECD (2014a), "The political economy of the increase in Turkish taxes on motor vehicle fuels", COM/ENV/EPOC/CTPA/CFA(2013)8/FINAL.

OECD (2014b), *OECD Environmental Performance Reviews: Sweden 2014*, OECD Publishing, Paris, *http://dx.doi.org/10.1787/9789264213715-en*.

OECD (2013), *Inventory of Estimated Budgetary Support and Tax Expenditures for Fossil Fuels 2013*, OECD Publishing, Paris, *http://dx.doi.org/10.1787/9789264187610-en.*

OECD (2011), *Divided We Stand: Why Inequality Keeps Rising*, OECD Publishing, Paris, *http://dx.doi.org/10.1787/9789264119536-en*.

OECD (2009), *OECD Economic Surveys: Austria 2009*, OECD Publishing, Paris, *http://dx.doi.org/10.1787/eco_surveys-aut-2009-en*.

OECD (2007), *OECD Economic Surveys: Austria 2007*, OECD Publishing, Paris, *http://dx.doi.org/10.1787/eco_surveys-aut-2007-en*.

OECD (2006), *The Political Economy of Environmentally Related Taxes*, OECD Publishing, Paris, *http://dx.doi.org/10.1787/9789264025530-en*.

OECD (2001a), *Environmentally Related Taxes in OECD Countries: Issues and Strategies*, OECD Publishing, Paris, *http://dx.doi.org/10.1787/9789264193659-en*.

OECD (2001b), *OECD Environmental Performance Reviews: Norway 2001*, OECD Publishing, Paris, *http://dx.doi.org/10.1787/9789264195738-en*.

OECD/IEA/NEA/ITF (2015), *Aligning Policies for a Low-carbon Economy*, OECD Publishing, Paris, *http://dx.doi.org/10.1787/9789264233294-en*.

Papke, L.E. and J.M. Wooldridge (2008), "Panel data methods for fractional response variables with an application to test pass rates", *Journal of Econometrics*, Vol. 145, pp. 121–133.

Papke, L.E. and J.M. Wooldridge (1996), "Econometric methods for fractional response variables with an application to 401 (k) plan participation rates", *Journal of Applied Econometrics*, Vol. 11/6, pp. 619-632.

Roodman, D. (2009), "A Note on the Theme of Too Many Instruments", *Oxford Bulletin of Economics and Statistics*, 71/1, pp. 135-158.

Ruijs, A. and H.R. Vollebergh (2013), "Lessons from 15 Years of Experience with the Dutch Tax Allowance for Energy Investments for Firms", *OECD Environment Working Papers*, No. 55, OECD Publishing, *http://dx.doi.org/10.1787/5k47zw350q8v-en*.

Siriwardana, M., S. Meng and J. McNeill (2013), "A CGE assessment of the Australian carbon tax policy", *International Journal of Global Energy Issues*, Vol. 36/2, pp. 242-261.

Solt, F. (2009), "Standardizing the World Income Inequality Database", *Social Science Quarterly*, Vol. 90/2, pp. 231-242.

Solt, F. (2014), "The Standardized World Income Inequality Database", Working paper, SWIID Version 5.0.

Speck, S., Jilkova, J. (2009), "Design of Environmental Tax Reforms in Europe", in P. Ekins and M.S. Andersen (eds.), *Carbon Energy Taxation - Lessons from Europe*, Oxford: Oxford University Press.

Stekhoven, D.J. and P. Bühlmann (2012), "Missforest - non-parametric missing value imputation for mixed-type data", *Bioinformatics*, Vol. 28/1, pp. 112-118.

Sutherland, R.J. (2006), "The distributive effects of direct regulation: a case study of energy efficiency appliance standards", in N. Johnstone and Y. Serret (eds.), *The Distributional Effects of Environmental Policy*, Edward Elgar Publishing, UK.

Van Buuren S. (2012), "Flexible imputation of missing data", *Boca Raton*, CRC Press.

Vandyck, T. and D. Van Regemorter (2014), "Distributional and regional economic impact of energy taxes in Belgium", *Energy Policy*, Vol. 72, pp. 190-203.

Withana, S. et al. (2013), Annexes to Final Report - Evaluation of environmental tax reforms: International experiences. A report by the Institute for European Environmental Policy (IEEP) for the State Secretariat for Economic Affairs (SECO) and the Federal Finance Administration (FFA) of Switzerland, Brussels.

Woo, J. et al. (2013), "Distributional Consequences of Fiscal Consolidation and the Role of Fiscal Policy: What Do the Data Say?", *IMF Working Paper*, Fiscal Affairs Department, WP/13/195.

Wooldridge, J.M. (2014), "Quasi-maximum likelihood estimation and testing for nonlinear models with endogenous explanatory variables", *Journal of Econometrics*, Vol. 182, pp. 226–234.

Wooldridge, J.M. (2010), *Econometric Analysis of Cross Section and Panel Data*, 2nd edition, Cambridge, MIT Press.

APPENDIX 1 – IMPUTATION OF MISSING VALUES

In the presence of missing data, an important element of the analysis is to test the assumption that the data points for which no information is available are missing at random and follow no systematic pattern (Van Buuren, 2012). If testing reveals that this assumption is not justified, the analyst has to rely on imputation methods to fill the gaps in the data. The Missing Completely At Random (MCAR) test (Little, 1988) shows, for example, that the probability of missing values for spending on R&D as a share of GDP and subsidies and transfers as a share of government expenditure are higher, the higher GDP per capita growth is. Therefore, an imputation of the missing values for the variables used in the analysis is conducted with the random forest method (Stekhoven and Bühlmann, 2012). The random forest method is preferred over a multiple-imputation procedure (Van Buuren, 2012), because it is more flexible (as it is non-parametric), and because its implementation is relatively simple (as it sequentially proceeds from the imputation of one value to the imputation of the next). The random forest method is shown to be robust for a percentage of missing values as high as 30% (the government expenditure variable is here missing in 25% of the cases). The NRMSE and PFC test, which measure the performance of the imputation, produce values of 0.09 and 0.0016, indicating a very good performance of the imputation; the closer these test values are to zero, the better the imputation performs.

APPENDIX 2 – ROBUSTNESS TEST

In the fixed-effects specification presented in Section 4, a complication arises from the inherent difficulty in observing all factors influencing income inequality. This implies that econometric results might be biased due to unobserved heterogeneity (e.g. through omitted variable bias). In panel datasets with a fixed time and very large country dimension, these effects can simply be dealt with by including country and time fixed effects and by using dynamic panel estimation techniques (e.g. Anderson-Hsiao, Arellano-Bond, Blundell-Bond). However, the dataset used here contains only 34 countries and renders the use of such an estimation procedure invalid because estimations on a limited country-dimension can yield erroneous results (Roodman, 2009).

The sensitivity analysis presented here is based on a Panel Data Fractional Logit model (PDFL) with correlated random effects (Papke and Wooldrige, 1996, 2008; Wooldridge, 2014). This is a state-of-the-art generalised linear model ideally suited for the analysis of proportion data (like those on the Gini coefficient). PDFL is based on the assumption that the expected value of the Gini coefficient (conditional on the values of the independent variables) can be modelled as the logistic cumulative distribution function of a linear combination of the independent variables. The correlated random effects version of this model is also well-suited for dealing with unobserved heterogeneity, a form of endogeneity (Wooldridge, 2010: 766-769). It is based on the seminal work of Mundlak (1978) and Chamberlain (1982). The assumption of strict exogeneity of the regressors is relaxed by the inclusion of the average of time-varying independent variables. This way, unobserved factors that may simultaneously affect the Gini and the independent variables are controlled for. This method has been advocated as a robust alternative in empirical applications where no credible instruments are available to address endogeneity concerns (see for example Abrevaya and Dahl, 2013, Charlot et al., 2015). The model is estimated with bootstrapped standard errors, and the method of Quasi-Maximum Likelihood (QMLE, see Kieschinck and McCullough, 2003).

Table 5 presents the estimation results of the PDFL. As this is a non-linear model, the estimates cannot be interpreted as marginal effects. Table 6 presents the marginal effects of the PDFL, which are comparable to the estimates presented in Table 3. The results of the two estimation approaches are very similar. The only noticeable difference is that the share of the population at working age (15-64 years old) is statistically significant in the PDFL. As expected, there is a negative relationship between this share and inequality in income sources.

Table 5. PDFL estimation results

	Aggregate model		Disaggregated model	
VARIABLES	coef.	s.e.	coef.	s.e.
Environmentally related tax revenues (% GDP)	**0.0165****	(0.0065)		
Energytax revenues (% GDP)			**0.0259*****	(0.0072)
Motor vehicles and transport tax revenues (% GDP)			-0.0001	(0.0174)
Other environmentally related tax revenues (% GDP)			**-0.1191****	(0.0491)
GDP per capita growth (%)	**0.0049*****	(0.0011)	**0.0053*****	(0.0011)
Population growth rate (%)	**0.0114***	(0.0061)	**0.0104***	(0.0060)
Age-dependency ratio: 15-64 years old (%)	**-0.0101*****	(0.0029)	**-0.0087*****	(0.0028)
Enrolment in tertiary education (%)	**-0.0017*****	(0.0003)	**-0.0016*****	(0.0003)
Unemployment (%)	**0.0059*****	(0.0015)	**0.0055*****	(0.0014)
Inflation (%)	**0.0032*****	(0.0006)	**0.0033*****	(0.0005)
Personal income tax revenues (%)	**-0.0085*****	(0.0023)	**-0.0078*****	(0.0023)
Corporate income tax revenues (%)	**-0.0096*****	(0.0030)	**-0.0083*****	(0.0030)
Revenues from taxes on goods & services (%)	-0.0032	(0.0038)	-0.0036	(0.0040)
Property tax revenues (%)	-0.0101	(0.0166)	-0.0122	(0.0175)
Government spending on subsidies & transfers (%)	**-0.0018*****	(0.0005)	**-0.0016*****	(0.0005)
Expenditure on R&D (%)	**0.0355*****	(0.0104)	**0.0300*****	(0.0106)
Observations		544		544
Countries		34		34

Note: *** p-value<0.01; ** p-value<0.05; * p-value<0.1; Bootstrapped standard errors (2000 repetitions)
All models include year fixed effects, country random effects, mean independent variables fixed effects, and a constant term, whose estimates are not reported.

Table 6. PDFL marginal effects

	Aggregate model		Disaggregated model	
VARIABLES	coef.	s.e.	coef.	s.e.
Environmentally related tax revenues (% GDP)	**0.0035*** **	(0.0014)		
Energytax revenues (% GDP)			**0.0054** **	(0.0015)
Motor vehicles and transport tax revenues (% GDP)			-0.00003	(0.0036)
Other environmentally related tax revenues (% GDP)			**-0.0250** **	(0.0103)
GDP per capita growth (%)	**0.0010*** **	(0.0002)	**0.0011*** **	(0.0002)
Population growth rate (%)	**0.0024***	(0.0013)	**0.0022***	(0.0013)
Age-dependency ratio: 15-64 years old (%)	**-0.0021*** **	(0.0006)	**-0.0018*** **	(0.0006)
Enrolment in tertiary education (%)	**-0.0004*** **	(0.0001)	**-0.0003*** **	(0.0001)
Unemployment (%)	**0.0012*** **	(0.0003)	**0.0011*** **	(0.0003)
Inflation (%)	**0.0007*** **	(0.0001)	**0.0007*** **	(0.0001)
Personal income tax revenues (%)	**-0.0018*** **	(0.0005)	**-0.0016*** **	(0.0005)
Corporate income tax revenues (%)	**-0.0020*** **	(0.0006)	**-0.0017*** **	(0.0006)
Revenues from taxes on goods & services (%)	-0.0007	(0.0008)	-0.0008	(0.0008)
Property tax revenues (%)	-0.0021	(0.0035)	-0.0026	(0.0037)
Government spending on subsidies & transfers (%)	**-0.0004*** **	(0.0001)	**-0.0003*** **	(0.0001)
Expenditure on R&D (%)	**0.0074*** **	(0.0022)	**0.0063*** **	(0.0022)
Observations		578		578
Countries		34		34