Policies
to Promote
Sustainable
Consumption
Patterns

EUPOPP Work Package 5

Deliverable 5.2: Improving implementation of SC instruments by resolving the “environment/distribution conflict”

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Luca Panzone, Stephen Smith (UCL)

SEVENTH FRAMEWORK PROGRAMME

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1 Introduction

The EU FP7 collaborative research project “European Policies to Promote Sustainable Consumption Patterns (EUPOPP)” is carried out by several research partners throughout Europe, co-ordinated by Oeko-Institut in Germany. Deliverable 5.1.2 aims to discuss the distributional (ie equity) impact of policies that use price mechanisms, such as taxes, to encourage a shift to more sustainable consumption. For example, in some EU countries, the regressive distributional impact of energy taxes has been concerning in their impact on different levels of society, and makes implementation on a larger scale potentially problematic. The focus is especially on household energy for heating, lighting, and white goods. The first goal of this paper is to simulate the impact of potential sustainability pricing measures, such as energy taxes, to see how these additional costs may be borne by households. The second goal is to use microsimulation techniques to assess the impact of a range of policy measures, such as subsidies, to offset the effects on poorer households, while still maintaining sustainable policy.

Sustainable environmental policies have represented an important subject in both research and political agendas in the last decades. However, this is a relatively novel concept, as the historical focus of policymakers in the Western World has tended to focus primarily on economic growth and development. This bias toward the development economics aimed to understanding the dynamics of development with the main (and often only) objective of improving livelihoods, bringing its benefits to the widest range of people. However, sustainability of development processes became crucially important when the positive effects of industrialisation and the transition to rural to urban economies was related to negative externalities on the environment (Shafik, 1994; Antle and Heidebrink, 1995), such as pollution and resource exploitation. The negligence in tackling the problem over time caused an accumulation of Greenhouse Gases (GHG) in the atmosphere, and this generated an increase in the increase of the World temperature (Stern, 2007), which in turn made populations more subject and vulnerable to damaging environmental phenomena.

Part of the responsibility of the environmental externalities was the intensive use of non-renewable energy sources, whose combustion would inevitably produce a large amount of carbon dioxide (a molecule whose chemical formula is CO_2). The heavy dependence of World's economies on these carbon-intensive sources of energy implied not only a difficult task in trying to replace them with less polluting alternatives in the short-run, but also empowering the limited number of countries that have access to the raw materials (Karp and Newbery, 1991). However, the growing concerns regarding the effects of pollution from energy use (as well as other sectors) on the environment has called for governmental intervention in order to counteract the effects of climate change and reduce polluting behaviours.

Particularly of interest is the case of household energy consumption. There is a widespread perception that current energy use in European households is inefficient (Boardman, 2004; Geller et al., 2006). However, GHG reduction in this sector is potentially simpler and cheaper compared to other sectors (Wiel et al., 1998). In fact, the adoption of existing energy-efficient technology could allow a fast reduction in GHG emissions from residential buildings, and such technology is generally affordable or can be subsidised. Fritsche et al. (2009) highlight that the potential for reduction in non-petrol GHG emissions in the housing sector (essentially appliances, buildings, heating) is large, having a potential of 700 million tonnes of CO_2-equivalent per year for the next 20 years.

The achievement of the objective of a sustainable development applied to the residential energy sector entails crucially the joint effort of governments, institutions, and individuals, in a synergic approach that needs a proper intervention and coordination coming from regulatory and legislative institutions. Specifically, governments can rely on several policy instruments that could stimulate environmentally friendly consumption of energy within households, and an effective policy requires the use of the best instrument given the socio-economic context of the country where the instrument takes action (Wolff and Schönherr, 2010).

Earlier research has presented a relatively wide variety of instruments that can successfully reduce household energy consumption. Examples are labelling, taxation, and bans. Each of them has a strategic importance in the role they can play in reducing climate change from households, and research should be done for each one of them. However, for simplicity, the focus of this work is directed to the analysis of taxation. The choice of this instrument over others is justified by theoretical and practical reasons. In fact, bans might be controversial in their implementation, as it is reduces consumers and producers choices, and it can actually lead to a loss in welfare, possibly leading to the creation of illegal markets. Furthermore, alternative or efficient energy types may not be available everywhere, and a ban would penalise certain parts of the population over the others. On the other hand, labelling has private features: the decision of developing and using an energy-efficiency label hinges on the existence of a demand, hence a willingness to pay, for increases in the fixed costs of implementation (the purchase of the appliance), and the government would merely regulate the correct use of the label.

The last available instrument is taxation. This policy instrument would increase the relative cost of the most polluting item, giving an economic incentive to consumers to switch to cheaper and less polluting sources of domestic energy. However, policies that use a price mechanism to encourage a shift toward more sustainable consumption are liable to raise concerns about the distributional impact in the economy. In fact, the unit cost of a tax will be very likely more expensive for lower income groups compared to higher income groups, for whom energy expenditure have a lower share of total household expenditures. This effect is called "**regressive distributional impact of taxes**", and will be explained more carefully in the next section. The regressive distributional impact of energy taxes would make the implementation of a carbon tax in the EU slightly more problematic, since it would require the presence of a further mechanism to redistribute revenues to low-income groups, and restore the initial level of welfare while improving the environmental context.

In this work, we aim to establish whether the implementation of a carbon tax has a regressive effect in the residential demand for energy in the EU. To do so, the work consists of two different stages. Firstly, we draw a country-level demand function for energy in the European Union using an Almost Ideal Demand System (AIDS). In particular, we estimate an aggregate demand for four energy types in the EU: electricity, natural gas, coal, and heating oil. This is done using data from the International Energy Agency (IEA) and Eurostat. Secondly, we test the effect of a carbon tax of £ 70/tonnes of CO_2, and estimate the effect of such a tax on equity and inequality in the EU.

Essentially, this work tests hypothesis 6 and 1 in Wolff and Schönherr (2010). The understanding of the tax mechanisms and the link between energy sources highlighted in the demand estimation will allow a better understanding of the structure of the market (hypothesis 6), since the price mechanism would work only if consumers can switch from an energy source to the other. Low substitutability of different energy types, for example, would be an indicator of difficulties in switching energy sources after a tax, which would lead to an increase in energy-poverty, therefore lowering a household's investments in energy efficiency. Similarly, the logic of a tax instrument would be to increase energy efficiency and reduce GHG emissions, without imposing an uneven loss in welfare, and a tax that does not change welfare would generate a faster improvement on the society (hypothesis 1). On the contrary, a tax that impacts low-income groups more than high-income groups without a redistribution inevitably eliminates resources from those households more in need for investments in energy efficiency, limiting enormously the scale of the effect of the instrument.

This paper is structure as follows. The next section will present the existing economic theory on taxation, reviewing briefly how different taxes work, and what are the possible consequences of a tax on demand, supply, and welfare. We will then give an overview of the existing literature on carbon taxation, from the rationale that lead to the development of this tax, to the empirical analyses on distributional effects. Section 4 presents the structure of the empirical work: it presents the estimated demand for energy in the EU, and it identifies the potential for a rebound effect in the energy market. Section 5 presents the results of the microsimulation modelling, and it will highlight the most important findings from the estimated parameters. Section 6 analyses different possible redistributional mechanisms that could offset the regressivity observed in the previous section. Section 7 concludes. The econometric model, the data used in the statistical model, and the results of the AIDS model are included in the technical annexes.

2 Background: The Effects of Price-Based Instruments on Welfare

The use of taxes in economics has always been seen as a difficult task: taxpayers do not actually like taxes, yet they are an essential tool to pay for governmental and state expenses. From a neo-classical economic perspective, taxation is a tool that distorts the natural structure of markets. However, taxes do not always cause distortions: they play an extremely important role in the internalisation of an externality (Cooter, 1984). What this mean in practice is often human activities causes damages, and the consequence of this damages are not paid by the person causing them, but by someone else, such as pollution - this is called an **externality**. As an example, a person driving a car without a need pollutes, but he pays a small portion of the damage to the environment, as all people living in the area will have to bear a lower air quality. Taxation becomes then useful, if not essential, when market prices do not incorporate these external costs. When this is the case, the government intervenes charging the responsible person the price differential, so that he pays for present and future damages. This extra production costs will then be reflected in the market by a decrease in quantity supplied, and this lower quantity will cause ideally no damage to other people. In this way, the externality is said to be internalised in the market. This particular mechanism is generally referred to as Pigouvian tax.

Taxation can be implemented in two alternative ways: an ad-valorem and a specific tax. An **ad-valorem tax** implies that the good in question is taxed proportionally to its supply, implying no tax is collected when supply of the item is zero. A typical example of ad-valorem tax is Value Added Tax (VAT), which is a percentage on the total expenditure. In the case of a **specific tax**, the tax is added as a constant sum to the supply curve, implying that this type of taxation is independent on actual consumption. An example of specific tax is the tax on petrol, which is a constant value per litre, and excises in general.

Figures 1 and 2 represent the impact of both an ad-valorem and a specific tax on the demand and the supply of a good[1]. As can be seen, a price increase that is completely charged on the demand side of the market changes the slope of the curve and reduces quantity purchased at the equilibrium. Consequently, the tax carries a deadweight loss, a loss in consumer and producer surplus corresponding to the shaded area in figures 1 and 2. This lower surplus implies that taxes in general impose a distortion on the efficiency of the market and generate a loss of welfare in the economy (of the amount of the shaded area). As a result, there is general agreement among neoclassical economists that taxation should be applied only when the presence of externalities justify them. This is for example the case of environmental damages, to reduce poverty, and so on.

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[1] Figure 1 represent the market equilibrium for a "normal" good, and it does not apply in this form to exceptions such as Giffen goods, Veblen goods and so on.

Figure 1: Impact of an ad-valorem tax on market equilibrium

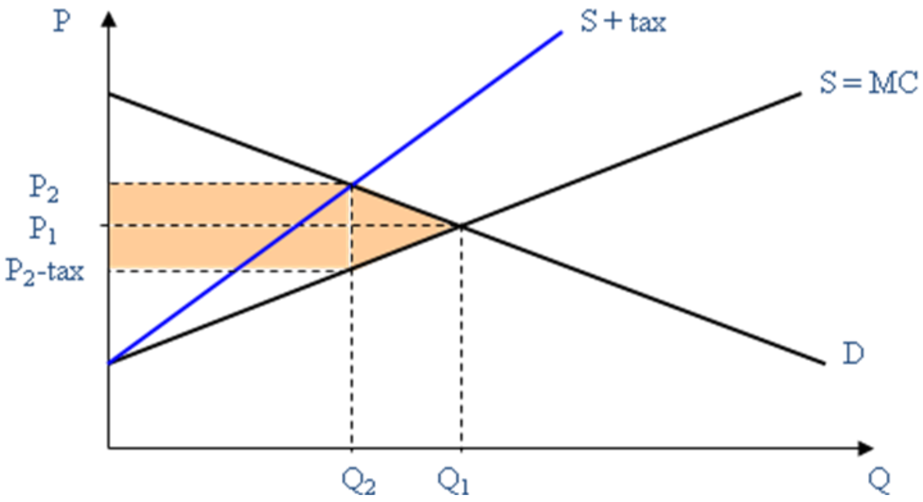
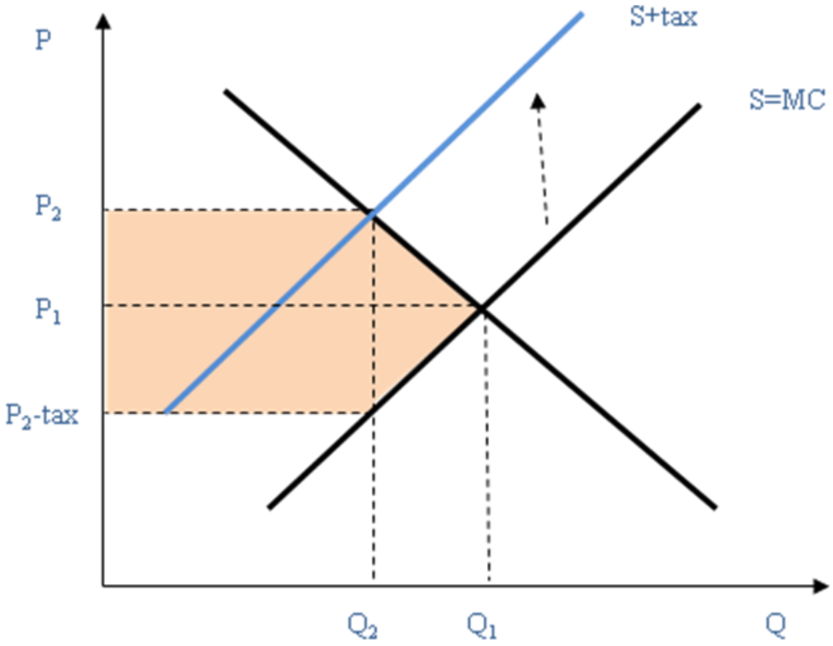


Figure 2: Impact of a specific tax on market equilibrium



2.1 Equity and taxation

A more pressuring problem related to taxes is that deadweight losses in the society may be unevenly distributed among different income groups. More specifically, taxation very often imposes a higher burden on low-income classes compared to richer segments of the population. On this line, taxes are classified as proportional, regressive or progressive, and these are defined in the next section.

A particular figure of a Pigouvian tax in its simplest form is its characteristic of perfect proportionality: every income class will pay the tax in proportion to their income. In other words if household A has an income 10 times higher than household B, it will pay a share of the tax that is also 10 times higher. The proportionality corresponds to a tax rate that is constant over income, so that every income group share the same tax burden. This corresponds to the black line in figures 3 and 4, where the total tax is a linear function of income, and the tax rate is flat, hence independent on income.

Contrary to the proportional case, a progressive tax tends to charge more high incomes over low incomes: richer people will pay a higher percentage of the tax compared to poorer incomes. This is the case of the income tax in developed countries, for example. The opposite is the case for regressive taxes, where lower incomes pay a hihger percentage of the tax compared to higher income groups. Regressivity is a common phenomenon for many taxes, and it is particularly frequent when taxation refers to sensitive classes of expenditures that capture most of the income of poor households, such as food, and energy.

Figure 3: Different categories of tax by total value of tax

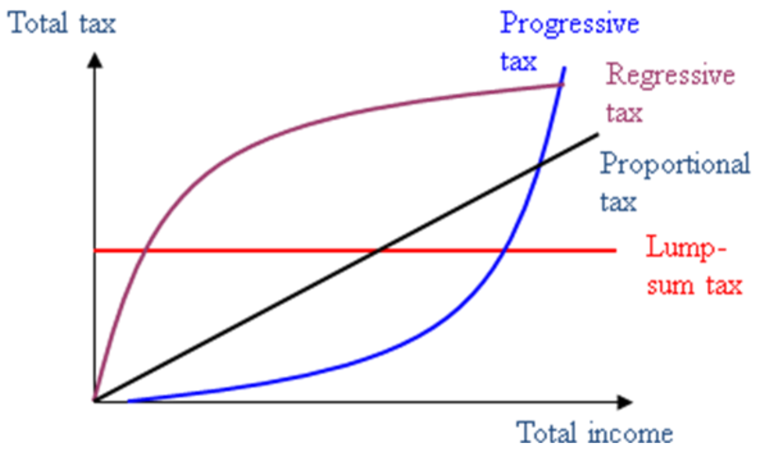
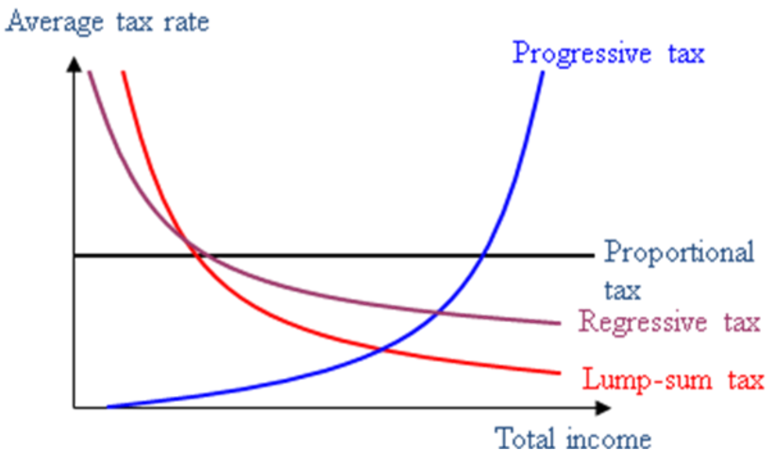


Figure 4: Different categories of tax by average tax rate



3 The Case of Energy Taxation

The analysis of this work focuses on the analysis of energy taxation as a mean to reduce GHG emissions, along with its effects on welfare. Governmental decision to tax energy arises from different needs (Newbery, 2005):

1. to have a control over energy trade balances;
2. to internalise social costs caused by energy consumption;
3. to collect money required for improving energy infrastructures;
4. to raise revenue to redistribute among different income groups.

Extremely important in environmental economics is point 2, the need to tax energy because of its polluting power. In fact, production and consumption of energy cause an increase of GHG emitted in the atmosphere by humans, causing damages that can be compensated by using revenues from energy taxation. This particular type of energy tax has become popular among environmental scientists and economists as "**carbon tax**".

Despite the widespread use of energy taxation, it is infrequent to encounter carbon taxes that clearly follow an environmental rationale (Newbery, 2005). Nevertheless, recent international agreements on climate change (e.g. the Kyoto protocol in 2009) have requested a more rational approach in linking energy taxation and environmental externalities. On this line, the objective of a carbon tax should be to increase the cost of energy in order to incorporate all social costs it produces damaging the environment (Newbery, 2005; Metcalf and Weisbach, 2009). Governments should then use all revenues from a carbon tax to compensate damages, as well as to invest in research and implementation of environmentally friendly technologies.

Due to difficulties in enforcement of the tax, energy taxes are generally input taxes (Newbery, 2005), and to maintain the productive side of the market efficient, the tax should be completely passed on to consumers (Metcalf and Weisbach, 2009; Diamond and Mirrlees, 1971a and 1971b). This passage is crucial, because passing the tax completely on the demand side will put an adjustment mechanism in motion, fostering changes in consumption, and then an adjustment of the supply side. In this case, a carbon tax corresponds to a price change from the prospective of the consumer, impacting directly quantity demanded (OECD 2000, p.8; Kilian, 2008). The price increase provides an economic incentive to households to switch from the baseline energy portfolio they are using to a new portfolio that would favour cleaner and more sustainable alternatives, and would discourage consumption of the most polluting options.

The importance of focusing on the demand side comes because of the difficulties to stimulate a change in household energy consumption using non-monetary instruments. On the other hand, there is a need for intervention, due to the significant role households play in emitting GHG. Specifically, GHG from household energy consumption in Europe are reported in table 1. It is possible to notice that 26% of CO_2 in the EU comes from households, a value that can reach or go over 50% in some European countries. Very high percentages characterise also emissions of Nitrogen oxides, while overall households seem to have a lower impact in the emission of other GHG. Nonetheless, considering the high environmental impact of these other gases, which is sensibly higher than the impact of CO_2 alone, intervention needs to address the emission of all GHG.

Table 1: Share of household produced GHG as a percentage of total GHG production by category of use of selected gases in selected EU countries

	Carbon dioxide			Methane			Nitrogen oxides			Sulphur oxides		
Activity	Heating	Transport	Total	Heating	Transport	Total	Heating	Transport	Total	Heating	Transport	Total
EU 27	9.4%	13.4%	25.9%	1.2%	0.7%	3.9%	3.3%	12.3%	16.8%	4.5%	0.1%	5.8%
Bulgaria	9.5%	2.0%	14.9%	2.9%	0.0%	12.2%	1.7%	4.3%	6.6%	1.8%	0.1%	1.9%
Czech Rep.	4.8%	5.0%	9.9%	1.8%	0.1%	1.9%	3.7%	5.6%	9.4%	12.8%	0.1%	12.9%
Denmark	3.9%	6.4%	9.9%	2.8%	0.4%	3.2%	0.5%	2.2%	2.6%	0.3%	0.0%	0.3%
Germany	16.0%	13.0%	29.1%	1.5%	0.3%	3.9%	6.0%	15.3%	21.3%	10.5%	0.1%	10.6%
Estonia*	1.1%	7.4%	8.5%	5.3%	0.3%	5.6%	3.4%	12.6%	16.0%	0.7%	0.2%	0.9%
Ireland	0.0%	20.2%	58.2%	0.0%	0.1%	0.4%	0.0%	3.9%	8.3%	0.0%	4.6%	25.7%
Greece**	8.7%	7.1%	15.9%	0.9%	0.7%	1.6%	2.4%	10.0%	12.5%	3.3%	0.1%	3.4%
Spain*	6.6%	16.3%	23.1%	1.7%	0.4%	2.0%	1.6%	22.6%	24.1%	1.3%	0.4%	1.7%
France	0.0%	24.0%	46.1%	0.0%	0.1%	6.4%	0.0%	25.4%	32.0%	0.0%	0.5%	9.3%
Italy	14.1%	12.8%	27.0%	1.2%	1.3%	2.4%	5.8%	15.0%	20.7%	2.8%	0.2%	3.0%
Hungary*	0.0%	0.0%	36.3%	0.0%	0.0%	11.0%	0.0%	0.0%	7.0%	0.0%	0.0%	17.5%
Netherlands	0.0%	11.6%	22.9%	0.0%	0.3%	2.4%	0.0%	9.7%	12.8%	0.0%	0.5%	0.8%
Austria	13.3%	15.5%	30.1%	2.0%	0.2%	3.5%	5.4%	16.3%	23.4%	25.4%	0.2%	29.5%
Portugal	0.2%	12.0%	15.9%	0.0%	0.3%	5.3%	0.3%	10.0%	12.4%	0.0%	0.1%	0.1%
Sweden	2.8%	19.6%	22.7%	4.0%	0.6%	4.6%	1.3%	7.9%	9.3%	0.7%	0.0%	0.8%
UK	17.1%	13.0%	30.1%	0.8%	0.2%	1.0%	6.1%	10.1%	16.2%	2.4%	0.2%	2.6%

Source: Eurostat database. Unless otherwise stated, data refer to the year 2006. * indicates data from 2003; ** indicate data from 2004.

Due to the large responsibility households play in environmental pollution, and the relatively low costs of driving change in this particular sector, there is a growing consensus that a carbon tax would be the best solution to improve sustainability in the energy sector (Metcalf and Weisbach, 2009). However, taxing energy can have side effects. In fact, compared to other expenditure categories (e.g. food, clothing), energy is overall an income and price inelastic good (see e.g. Brannlund et al., 2007). In practical terms, this means that households need energy to satisfy their basic needs, and they would still need to consume energy if price increases, whilst decreasing consumption of more elastic goods - as an example, they would buy less/cheaper clothing, and use the money saved to consume energy.

A low income and price elasticity of the energy category also would suggest the existence of constraints to energy switching behaviour. In fact, a petrol tax may impact relatively little car fuel consumption if cars can only function with petrol and alternative means of transportation are scarce or unreliable. Similarly, households living in buildings that can only a single energy commodity (e.g. only electricity) will find it more difficult to switch when prices increase, compared to households living more flexible buildings that can support the use of multiple energy sources.

The relative importance of energy at different income levels can be seen in figure A1 in Annex 1. The graphs here show that in Europe the share of household income spent on energy tends to increase as income decreases. Exceptions seem to be the Republic of Macedonia and Latvia, where the share of energy consumption is higher for middle-income classes compared to low and high incomes. This is not surprising, since energy is a necessity, which costs more on households as income decreases, with a pattern similar to other essential goods (e.g. food). If households' energy use remains unchanged when an energy tax is imposed (assumption that is probably not a bad first approximation), then the pattern of energy spending directly tells us that an energy tax will be regressive in most European countries.

In this context, it is conceivable that a price increase due to a carbon tax will have the tendency to be relatively more expensive for the lowest quintile of income compared to the highest. In fact, a 1 euro/unit of energy increase in the tax will charge more heavily on low incomes, compared to high ones. As an example, if household A and B consume both 100 units of energy, but A earns 10,000 euros and B 100,000, the 1 euro/unit tax would charge A with an extra 1% of his income (100/10,000), while B would pay only an extra 0.1% of his income. Consequently, it becomes of interest to understand the impact of redistributional effects in the case of a carbon tax, in order to establish whether redistributional mechanisms are needed in this particular context.

3.1 Empirical estimation of the impact of carbon taxation

As highlighted in the previous section, given the structure of the patterns of energy consumption, a carbon tax could be regressive. In fact, this tax would have an effect similar to a permanent price shock to the economy, which would reduce household income, the total demand for energy (due to income loss), as well as the demand for complementary goods (e.g. appliances, cars, foods, etc.) (Kilian, 2008). Furthermore, within each category, an advantage would be given to cleaner energy sources, and to less energy-intensive products, e.g. food that needs shorter cooking time would be preferred to completely raw foods.

The economic literature presents a large selection of empirical works aimed at determining the effects of a carbon tax on welfare. These studies generally apply microsimulation techniques, a class of econometric tools that allow the researcher to simulate a change in the economic context. In particular, microsimulation modelling applies a simulated tax to the existing reality, assuming that nothing else changes in the economy, and then illustrates how the *status quo* changes as a consequence of the tax (Bourguignon and Spadaro, 2006).

Previous empirical research in the area of carbon taxation has generally found mixed results (table 2). In fact, it appears that the institutional and economic context in which the tax operates plays a key role in determining the effect of the carbon tax. Despite the ex-ante uncertainty, Speck (1999) indicates in a review work that carbon taxes are in general moderately regressive, and whenever applied this is the outcome that policymakers should expect.

Table 2: Selected literature in the estimation of the distributional effects of carbon taxes on welfare

Authors	Country	Type of energy taxation	Distributional effects
Johnson et al. (1990)	UK	General environmental tax	Regressivity
Hamilton and Cameron (1994)	Canada	Specific tax on carbon emissions	Regressivity
Barker and Kohler (1998)	EU-11	Specific tax on carbon emissions	Regressivity
Labandeira et al. (2004)	Spain	Specific tax on carbon emissions	Regressivity
Tiezzi (2005)	Italy	Ex-post effects of an existing non-linear specific carbon tax	Non-regressivity
Oladosu and Rose (2007)	US	Specific tax on carbon emissions	Progressivity
Yusuf and Resosudarmo (2007)	Indonesia	Specific tax on carbon emissions	Progressivity
Callan et al. (2009)	Ireland	Specific tax on carbon emissions	Regressivity

If we analyse the literature presented in table 2, the dichotomous structure of the results appears evident. It can be thought *ex-ante* that colder countries would be more prone to a regressive effect of an energy tax. In fact, due to the adverse weather consumers cannot easily reduce consumption use, as this would have adverse effect on health and safety of the household. These would be even more complicated in countries with rather limited energy resources, since low income households would not be able to move away from their usual consumption portfolio, namely if this requires structural investments. This leads to a (at least partial) justification of the regressive effects that a carbon tax has shown in the case of the United Kingdom (Johnson et al., 1990) and Ireland (Callan et al., 2009), as well as Canada (Hamilton and Cameron, 1994). More surprising is the regressivity observed in the case of Spain (Labandeira et al., 2004), since its economy is expected to have a lower dependence on energy, at least for heating purposes, compared to Northern European and Northern American countries. However, the regressivity can possibly be explained the need to use energy also in warmer climates (for cooling needs) and for the increasing dependence of households on electricity. Barker and Kohler (1998) confirm these results, where the overall change in 11 EU countries in analysis (Belgium, Denmark, France, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, UK, and Germany) seems to be regressive.

As important as determining the existence of regressivity in an economy would be to establish the effects of the carbon tax after the revenues are redistributed among the population. In essence, if the tax is regressive, governments need to use revenues from the carbon tax to neutralise its effect on poverty, essentially returning some money to lower income households and re-establishing the initial *status quo* of welfare. On this line, different use of the revenues from the tax will crucially determine the change in welfare in the economy (Speck, 1999). As an example, Johnson et al. (1990) propose the redistribution of the benefits in a regressive tax reducing the income tax rate for lower incomes, whilst Callan et al (2009) consider effective the redistribution of the tax revenue in a similar case increasing social benefits or tax credit. Similarly, Barker and Kohler (1998) indicate that the reduction of employers' taxes would retain partial regressivity, whilst the lump-sum redistribution would determine an overall regressive effect.

Contrary to the findings of a regressive effect highlighted in the previous paragraph, the literature also presents socio-economic context where carbon taxation does not have a heavier impact on low income groups. Observing the impact of a new carbon tax, Tiezzi (2005) found that the tax rate of the newly implemented carbon tax tended to increase with income, hence being certainly non-regressive, and possibly progressive. Similarly, Oladosu and Rose (2007) find mild progressivity simulating a carbon tax in a region in the US, the Susquehanna River Basin, shared between the states of New York and Maryland. Finally, Yusuf and Resosudarmo (2007) find progressivity in a developing context, observing the effects of a carbon tax on Indonesian households.

The progressivity observed in these last three examples seems to go against the general expectation of regressivity of an energy tax (Labandeira et al., 2009). However, in each case the result seem to be driven by the peculiarity of the socio-economic context where the policy was operating. In fact, Tiezzi (2005) highlighted that the progressivity in the Italian case was caused by the fact that fuels were the most heavily hit by the tax, hence charging more on heavy car users, who generally belong to higher income groups. In the US case, Oladosu and Rose (2007) explain that the carbon tax hits particularly productive sectors of interest of higher income groups (e.g. metals, and utilities), whilst leaving substantially untouched key sectors for low income categories, such as food, housing, and services. Finally, the progressivity in Yusuf and Resosudarmo (2007) arises because low-income groups in rural context tend to use a substantially lower amount of energy compared to high income classes, hence taxation has little impact on them.

Considering the uncertainty linked to the sector, the analysis presented in this work aims to establish whether a carbon tax is either progressive, regressive, or proportional in the European energy sector. Specifically, this is done considering household demand of energy in all 27 countries in the European Union. In our work, though, we do not simulate a redistributional mechanism that reallocates all tax revenues among households, but we just observe the impact of a carbon tax on overall income. The reallocation mechanism is then left for future research in the area.

4 The Demand for Energy in the EU

The statistical analysis presented in the present section estimates the demand function for **Natural gas**, **Electricity**, **Heating oil**, and **Coal**. This has been estimated using an Almost Ideal Demand System (AIDS), a well known econometric model, presented in detail in Annex 2. While results can be found in Annex 4 (The coefficients of the 4-equation system are reported in table A1 in the annex), this section attempts to describe the structure of the energy market in the EU based on the statistical analysis.

4.1 The demand for different energy sources

Due to the strategic importance of energy in the economy of a household, prices play an important role in determining the demand for the different sources of energy. Specifically, an increase in the price of natural gas decreases its own expenditure share, with energy demand switching toward an increase in expenditure for heating oil and electricity. Similarly, an increase in electricity prices stimulates a larger share of expenditures being allocated to gas and electricity, while decreasing the demand for heating oil. An increase in the price of coal has no effect on the demand for natural gas, whilst decreasing the share in expenditure for electricity and heating oil. Finally, an increase in the price of heating oil increases the expenditure share in gas and heating oil, at the expenses of the electricity demand.

Household behaviour reveals that the demand for energy is diversified, and income and expenditure availability determines the choice and use of different energy types. In fact, the more a household spends on energy, the more electricity and less natural gas and heating oil they consume, as revealed from the Stone Index (an expenditure index). This is not surprising, as electricity can be used for a larger number of purposes (heating and leisure) compared to other sources, and heavy users tend have a more differentiated demand for energy. Similarly, as income (Gross National Income) increases, the consumption of electricity increases, decreasing consumption of natural gas, while the demand for heating oil seems to be unaffected by changes in GNI.

The demand for energy depends on the level of development of the economic context of the household. In fact, it appears that as economies grow stronger (GDP increases), consumers switch from electricity to gas, while the demand for heating oil is independent on GDP. Similarly, more efficient economies (those with lower energy intensiveness, i.e. those who need less energy to obtain a unit increase in GDP) tend to consume more natural gas and less heating oil, whilst presenting no impact on the demand for electricity. This finding suggests that increasing energy intensiveness (i.e. reducing energy efficiency) tends to increase the dependence of households on oil and its derivates, whilst efficiency-improving technologies increase the demand for natural gas. Technological improvements in the period in analysis, captured by the time trend variable, have successfully decreased the demand for electricity, albeit improvements have been rather slow. On the other hand, it seems that the same improvements did not have an impact on the demand for other energy sources.

Environmental variables also play an important role in the demand for different energy sources. Firstly, the weather is a crucial determinant of energy consumption. Colder countries (those with more Heating Degree Days, or HDD, representing the amount of yearly heat needed) tend to consume more heating oil and less natural gas, whilst demanding the same amount of electricity of warmer countries. The insignificance of the coefficient in the demand for electricity can be explained on two grounds. Firstly, electricity consumption for heating purposes, albeit increasingly common is relatively small compared to all other electricity uses. Secondly, in certain European countries, especially in Southern Europe, electricity consumption increases both to refresh very hot days (low values of HDD), as well as warming when the weather is cold (high values of HDD), hence cancelling the overall effect of the variable.

In terms of environmental characteristics of the economy, when GHG emissions increase, consumers tend to switch toward cleaner sources of energy. This finding is not surprising, since electricity can be produced from a variety of sources, and recent technological developments have increased the supply of electricity from hydroelectric or solar sources. In fact, results indicate that rapid increases in GHG emissions cause a decrease in both the demand for natural gas and, to a larger extent, the demand for heating oil, while increasing consumption of electricity.

Finally, governmental regulation also contributes in guiding the demand for energy, affecting welfare. In fact, when taxes on “energy” and “pollution or resources” increase, electricity tends to decrease, whilst the opposite happens to the demand for natural gas. This is justified by the fact that electricity is also used for leisure activities, and an increase in taxes reduces its consumption, increasing the amount of natural gas, which is specifically used for more essential activities such as heating and cooking. None of these taxes has an impact on heating oil, and transport taxation has no impact on residential energy demand.

4.2 Elasticities

The specific definition of elasticities is reported in Annex 2. Essentially, these values indicate how much the quantity consumed of each energy source changes in percentage points when price (in the case of price elasticities), expenditure (for expenditure elasticities), or other variables, increase of 1%[2]. The interest in price and expenditure elasticities lays in the need to understand how

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[2] This idea works also in reverse: a price decrease of 1% increases consumption of the same percentages.

price changes (natural or induced by governmental intervention) would affects the demand for energy in the EU.

Apart from heating oil, own-price elasticities are fairly high, and this clearly indicates that the energy market is generally characterised by a high sensitivity to price increases: even small price increases can impact demand at least proportionally. Results, which are reported in Annex 4, indicate that a 1% increase in the price of each energy good decreases consumption of natural gas by 1.6%, while the demand of electricity and coal goes down by around 1%, and heating oil by 0.3%. These results are supported by previous results that find an own-price elasticity for electricity greater than one (Filippini, 1997), or just below unity (Brannlund et al., 2007; Labandeira et al., 2006). Similarly, the literature reports an own-price elasticity of heating oils between -0.4 (Labandeira et al., 2006) and -0.93 (Brannlund et al., 2007), while for natural gas goes between almost zero (Labandeira et al., 2006) and just below -1 (Tiezzi, 2005).

To understand whether different energy sources substitute or complement each other, we calculate Allen elasticities of substitution[3]. Essentially, two products are substitutes if the increase in market price of one determines the increase the demand for the alternative; they are complements if the increase in price of one decreases the demand of both products. Allen elasticities confirm that consumption of heating oil and electricity complements that of coal, therefore an increase in price of either energy source will determine a decrease in consumption of all this products as a consequence. All other products actually substitute each other. These findings on cross-price elasticities seem to be reasonable: coal is essentially used for heating and cooking, and it is used in conjunction with other more efficient heating resources, as well as electricity, mainly for leisure, working, and cooling purposes.

A last important value is the expenditure elasticity of demand. According to the results (Annex 4), electricity is a luxury good, having expenditure elasticity higher than one. This means that an increase in expenditure by 1% will generate an increase in demand by around 1.06%, consistent with the findings of Filippini (1997). On the other hand, Labandeira et al. (2006), and Brannlund et al. (2007) find expenditure elasticities for electricity between 0.78 and 0.89. We find our result unsurprising: since an important use of electricity is for leisure, its consumption is bound to increase when income increases due to the presence of disposable income to be used in purchasing appliances that run on electricity.

Regarding all other products, coal has an almost perfect expenditure-elasticity, while natural gas and heating oil are slightly inelastic (their values are just below one), indicating an overall tendency to maintain a high level of consumption

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[3] We also calculated uncompensated cross-price elasticities, which are reported in Annex 4. However, in this section we limit our discussion on compensated elasticities of substitution because they release the assumption of no income effect of the price change.

of energy when expenditures increase. On the other hand, Tiezzi (2005), and Labandeira et al. (2006) identify natural gas as a luxury good in Southern Europe, while Brannlund et al. (2007) find oil and district heating as luxury good in Sweden. Labandeira et al. (2006) also find low expenditure elasticity in the demand for LPG in Spain.

Differences between elasticities presented here and values presented in the literature differ essentially in the fact that our results incorporate several countries, whilst the literature generally presents studies of a single economic context. Accordingly, when different countries are pooled in a single estimation, results would converge to the average of the group, hence presenting different values compared to individual countries.

4.3 Concluding remarks

These results highlight several points that need to be taken into account before a simulation exercise. Since taxation increases the price of the energy good that the tax refers to, the overall expectation is that a carbon tax will decrease energy consumption as a whole. Due to an own-price elasticity close or higher than one, people will react to a tax consuming proportionally less of each energy source, although it will affect coal (the cheapest alternative) less than all other energy sources. However, different energy products seem to be fairly easily substitutable, implying that substitution will generally be intense, and consumers will switch to cheaper sources of energy. In order to obtain the same benefit from energy, the possibility to afford more efficient appliances becomes paramount, but we do not model this efficiency-improving behaviour. As only richer households can afford to purchase new appliances, poor households are probably the most negatively affected by the price increase.

Our results highlight that a unit price increase from a tax will have a larger impact in the consumption of electricity (that has the highest own price elasticity) compared to all other sources of energy, despite being the cleanest alternative. The impact of taxes on disposable income will also cause a further decline in consumption, as it is the product with the highest expenditure elasticity. This will then drive the overall consumption of energy down, as electricity complements all other types of energy.

The obvious consequence is that the imposition of a tax will end up damaging the consumption of the cleanest alternative. This is not bound to happen if the tax is proportional to the level of GHG emission of each energy source. To account for this problem, in the simulation exercise presented in the next section we will differentiate taxation in order to be proportionally higher for the most polluting energy goods.

4.4 What can these results tell us about the possibility of a rebound effect?

A short detour from the main argument of this work is to consider if any of the following results can be helpful in directing researcher in the understanding of the so-called **rebound effect**. The rebound effect arises when any improvement in the efficiency of consumption of a certain energy good would produce savings in the household budget that would stimulate further consumption of the same (or complementary) energy goods (Brannlund et al., 2007).

In this work, we cannot actually identify the presence or the magnitude of a rebound effect. However, some coefficients seem to indicate the possibility that some products are more susceptible than other to the phenomenon. More precisely, the high value of the own-price elasticity of natural gas deserves a bit more attention. In fact, if efficiency improvements of natural gas reduce prices of 1%, we would see an increase in the consumption of energy by around 1.6%. The difference between the "natural" proportional price increase and the real "faster" increase would indicate the propensity of electricity to increase consumption because of efficiency improvements.

A second interesting remark could come from the negative coefficient of the "energy intensity" in the demand for natural gas. A negative coefficient indicates that an increase in efficiency (hence a decrease in intensity) would generate an increase in the demand for natural gas. This is the rationale behind the rebound effect. This finding confirms the possibility that natural gas is an energy product where the rebound problem might arise within the specific category of residential energy demand.

This point is however not conclusive, as the presence of a rebound effect should be estimated using a more dedicated model that could test specifically the matter, but this is not the objective of the current work. Consequently, the considerations contained in this section do not allow a conclusive analysis of the problem, but addresses future research on the understanding of the effects of energy efficiency in the demand for natural gas.

5 Microsimulating the Impact of a Carbon Tax

Having a model that estimated the demand for energy, we can now simulate the effects of a carbon tax on the demand for energy. In the case presented here, we simulate a specific tax for energy. We apply different taxes to different energy types, and the value of the tax reflects the polluting power of each of the four alternatives in the bundle.

In order to provide an acceptable value for the tax, we start from the social cost of carbon. The social cost captures those costs generated by pollution that are not actually charged in the price of the item when consumers purchase energy. There are several estimates of this value, differing on the methodology and the assumptions made on the estimation procedure. The Stern Review on climate change (Stern, 2007) identifies a total cost of GHG emissions to be around $ 350 per tonne of Carbon. Nordhaus (2007) challenged this estimate indicating that more realistic values are closer to $ 35 per tonne of carbon. In revising earlier estimates, Pearce (2003) finds a variety of values that fit into a $6.7-$298.5 interval (Pearce, 2003, table 2, page 370).

These different estimated costs differ essentially in the assumption regarding the optimal value of carbon emission, equity weights, and uncertainty of intertemporal damages and risks. In fact, carbon costs are bound to increase if action is not taken at baseline, and assumptions on the structural form of this increase, and the different impact it can have in different socio-economic context, are crucial in the a proper estimate of costs and damages.

In our experiment, we use the reference value for the carbon tax released by the UK Department of Environment, Food, and Rural Affairs (DEFRA). The value of the social cost of carbon proposed in 70 £/tonnes of C (Clarkson and Deyes, 2002; DEFRA, 2007), a value that fits into the interval of previous estimates indicated above. This value was then converted into Euro/unit of energy using the average exchange rate for 2009[4]. In order to convert the carbon tax, the following formula was used

$$\frac{Euro}{unit} = 70\frac{£}{tonneC} \times \frac{12}{44}\frac{tonneC}{tonneCO_2} \times 0.89\frac{Euro}{£} \times \frac{tonneCO_2}{unit} \quad (1)$$

The only data missing was the CO_2 content of a unit of source of energy. This value was obtained from an exiting report used in the Department of Environment and Climate Change (DECC) and Department of Environment, Food, and Rural Affairs (DEFRA) in the United Kingdom prepared by AEA Technology (2009). The final value of the tax used in our analysis is reported in table 7. The value of the tax is added, assuming that current taxes on energy do not cover the social cost of carbon at all. As can be seen, the price increase following the tax goes from just below 12% (for natural gas and heating oil) to 31% for coal.

Table 3: Values of taxes used in the simulation exercise

	Unit	euro/unit	% increase over the average initial price
natural gas	GJ	1.213	11.91%
heating oil	1000 liters	54.25	11.77%
electricity	kWh	0.0117	27.93%
coal	Toe	77.59	31.19%

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[4] http://www.ecb.int/stats/exchange/eurofxref/html/index.en.html

Assuming for a moment that initial amount of quantity will not change, a tax conceived in this fashion would increase total tax revenues of about 0.01%.

After the value of the tax is defined, we simulate the new scenario as presented in section 4.3. Results are presented the next section.

5.1 Redistributional effects

To establish the nature of the tax used in the simulation proposed here we draw two graphs reporting the tax rate versus income, and the total tax over income. This is shown in figures 5 and 6. It is worth pointing out that because of the large variability in the values, not all points could fit in the graphs. In fact, in order to fit the graph in a visible way, we have excluded all combination of pairs tax-income and tax rate-income outside of a range, where all axis report the truncation points. Importantly, the fitted lines are estimated including all the points.

Compared to figures 3 and 4, it appears evident that a specific carbon tax is at least moderately regressive: the level of taxation is going to be heavier for those countries with lower income, and within countries by individuals of lower income classes. Total taxation seem instead to be closer to proportionality (suggesting no impact on welfare), although analysing the energy tax rate regressivity become more evident. This entails that the use of a carbon tax must be conceived together with a redistributive mechanism that uses the revenues from the carbon tax and uses them in order to compensate lower incomes of the loss in welfare they had because of the new circumstances.

Figure 5: Graphic representation of energy tax rate over income in the EU

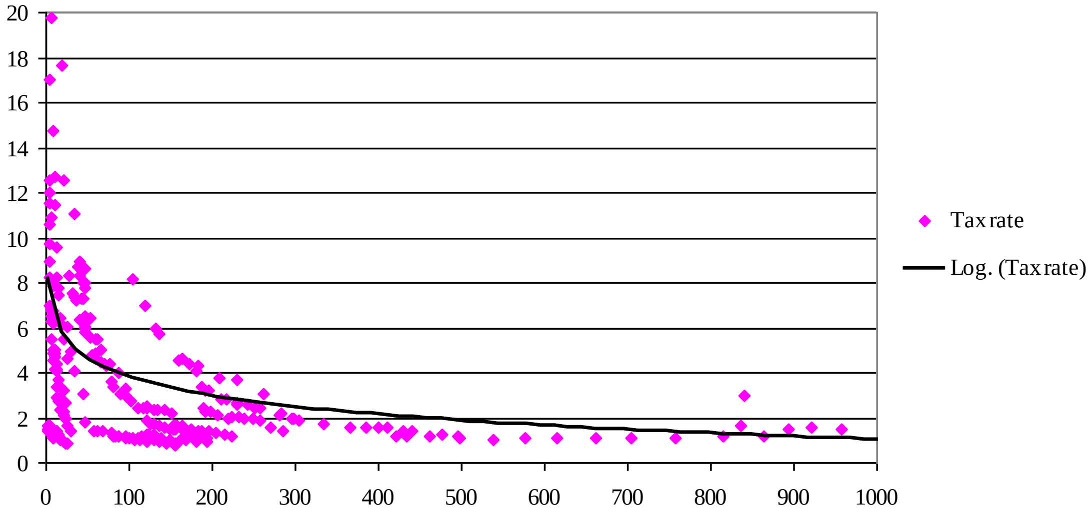
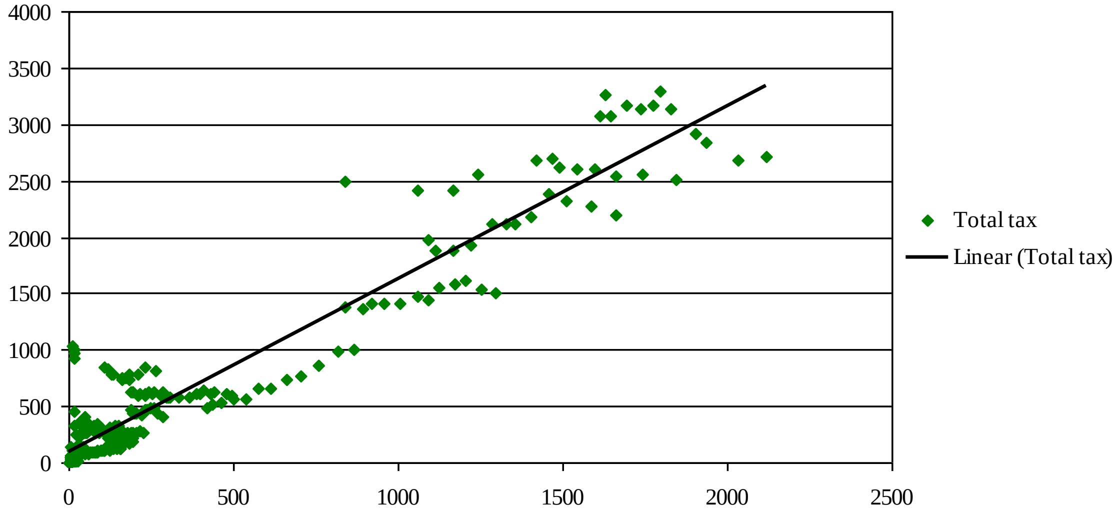


Figure 6: Graphic representation of total energy tax over income in the EU



6 Policy Responses to the Distributional Effects of Environmental Taxes on Household Energy Cosumption

A household energy tax at a level reflecting current estimates of the social cost of carbon would raise substantial fiscal revenues, of the order of some 3-5% of total tax revenue in EU countries. Introduction of a new tax on this scale would present fiscal policy-makers with considerable opportunities to use the revenues to facilitate major reforms in other aspects of the tax system, or in public revenues and expenditures more widely. Thus, for example, in Sweden, carbon tax revenues were used to allow large reductions in marginal tax rates on labour income, and the carbon tax was seen as having both an environmental and a fiscal policy rationale (Bohm, 1993).

The revenues raised by environmental taxes on energy consumption also provide considerable scope for parallel policy measures to be taken to offset undesired distributional effects, where these would arise from the higher level of energy taxation. The extent of distributional impacts and equity concerns seems likely to be greatest with environmental taxes levied on domestic energy consumption in northern European countries. In northern Europe, the bulk of domestic energy use is for heating, and the pattern of energy use across households at different levels of income is consistent with energy for heating having the characteristics of a necessity.

Energy use rises less than proportionately with household income in most northern European member states, although there are significant differences between countries with similar winter temperatures, reflecting differences in the characteristics of the housing stock. Household energy demand for heating in Germany and Denmark is, for example, markedly lower at given levels of income, and more responsive to household income, than household energy demand in the UK and Ireland, where the housing stock is on average less well-insulated (See annex 1). In southern European countries, household energy demand is significantly more positively related to household income, reflecting the lower needs for winter heating, and higher demands for cooling and air conditioning in summer, which typically have the demand characteristics of a luxury. As a result, taxes on domestic energy would raise fewer concerns about distributional incidence in southern Europe than in the north.

The overall distributional incidence of the introduction of an energy tax will depend both on the pattern of energy tax payments and on the use of the revenues. The appropriate incidence concept, in a situation where the tax would be introduced on a revenue-neutral basis, is the concept of differential incidence - in other words, the difference between the distributional incidence of the energy tax, and of the offsetting tax reductions. In this last section we provide some examples of possible alternatives to redistribute the earnings of an environmental tax that could offset the regressive effects observed in the statistical analysis. The choices that are made on the use of the revenues can have a critical impact on the overall distributional effects, and we analyse all the implications of all the possible alternatives.

6.1 Lump-sum revenue return

It is relatively straightforward to see that there are ways in which offsetting tax changes could be made that would, on average, return more to the poorest income groups in the population than they would pay in household energy tax. Since household energy consumption is positively related to household income (albeit rising much less than proportionately with income), households' energy tax payments would rise, in absolute (money) terms, with income. Thus, returning the revenues in the form of an equal lump-sum amount to all households would on average return more to low-income groups than they paid in energy tax (and less to high income groups than they paid in tax). Thus a lump sum revenue-return would, on average, more than compensate - in terms of tax payments - for the household energy tax.

Smith (1992) presented estimates of the distributional impact of the European Commission's 1992 proposal for a carbon/energy tax, showing that in the UK the average additional energy tax payment per household would be £1.89 per week. The total revenue derived from the tax would thus have been capable of financing an equal payment of the same amount, £1.89 per week, to all households. Since the household energy tax payments of the bottom decile were, on average, estimated to be only £1.03 per week, this lump sum of £1.89 per week would substantially exceed the average household energy tax payments of the poorest 10% of households. Indeed, the lump-sum return of revenues would exceed average household energy tax payments in each of the five poorest deciles. The overall distributional incidence of tax payments from a policy package consisting of the household energy tax plus lump-sum return of revenues would be progressive.

It will be noted that the claim made for a policy involving lump-sum return of revenues is limited to the observation that it would be adequate to compensate poorer household groups, on average, in terms of the amount of tax they pay. The lump-sum payments do not necessarily compensate poorer households sufficiently to ensure that the effect of the household energy tax on their overall welfare is positive, once the welfare impact of induced changes in consumption behaviour is included. The poorest deciles would be likely to experience both the largest increases in tax payments as a percentage of income, and also the largest volume reductions in energy consumption as a percentage of initial consumption. The economic costs associated with induced reductions in energy consumption are therefore also likely to higher for poorer households than for better-off households.

6.2 Problems with lump-sum revenue return

Nevertheless, whilst a policy package combining a household energy tax and equal lump-sum return of revenues seems likely, in principle, to leave households in the bottom deciles of the income distribution better-off on average, in terms of tax payments and, probably, economic welfare, than before the reform, a number of difficulties may be observed with compensation through an equal lump-sum payments to all households.

6.2.1 Failure to maximise potential efficiency gains

Firstly, using the revenues from the household energy tax to pay for lump-sum compensation to each household will tend to require that the tax revenues are returned in ways which do not maximise the potential benefit in terms of greater economic efficiency in taxation. If the distributional incidence of taxes is thought of in terms of a simple linearisation of the relation between income and tax payments, so that tax payments consist of a lump-sum component ("intercept") and an income-related component ("gradient"), then the relationship between distributional compensation and efficiency may be seen in the following way. Introduction of a regressive tax increases the intercept component in the relationship between income and tax payments. Offsetting the additional regressivity so as to leave the distributional incidence of the overall tax system no more regressive than before requires that the package of tax reductions should reduce the intercept component by at least as much as this initial increase. Returning all of the revenues from an energy tax as an equal lump sum per household would clearly satisfy this requirement, but any package of tax reductions achieving a gradient-to-intercept ratio at least as high as that of the energy tax would suffice to offset the regressive incidence of the new tax.

The revenues from the energy tax would have an opportunity cost, in the sense that if they are not used to offset the regressive distributional incidence of the tax, they could be deployed in ways which would reduce the overall efficiency costs of raising tax revenues. Whilst the existence of a "double dividend" from environmental taxes, in terms of both a reduction in environmental damage and a reduction in the distortionary cost of taxation has been contentious (Goulder, 1995), it should be clear that using the revenues raised from an environmental tax to reduce the rates of distortionary taxes will reduce the deadweight costs of taxation, *by comparison with a situation where the revenues are simply returned as a lump sum to taxpayers.*

It is considerably less clear that levying an energy tax, and reducing the rates of other taxes, will both improve the environment and reduce the distortionary costs of taxation by comparison with the initial situation. As Bovenberg and de Mooij (1994) have made clear, environmental taxes may, themselves, have effects on the labour market which may be non-trivial.

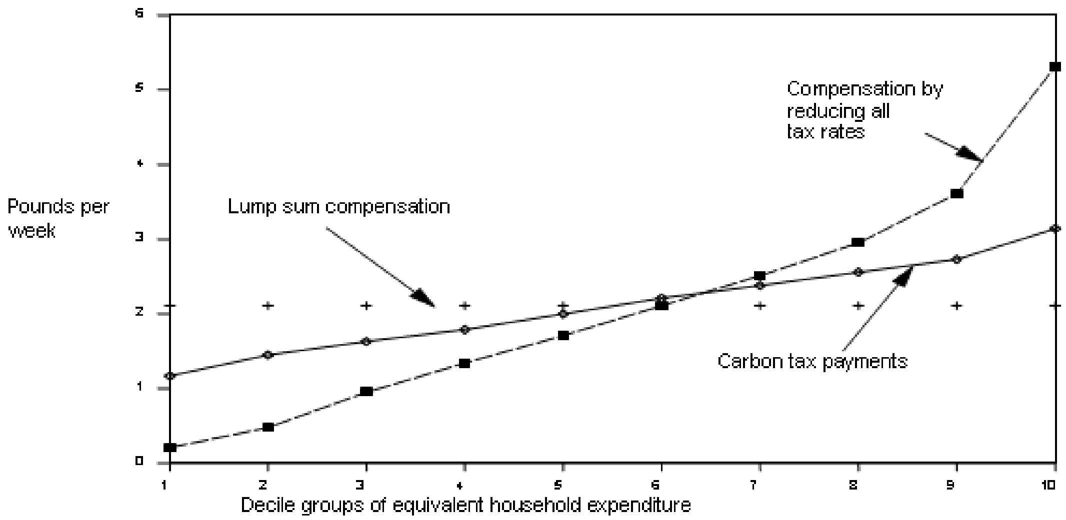
by the resolving the “environment/distribution conflict” 27

Generally speaking, economic efficiency would be maximised by the use of the revenues from environmental taxes to permit reductions in the *rates* of other taxes, and hence in the gradient of the linearised relationship suggested above, rather than in the lump-sum, "intercept" component of these taxes. However, reducing the rates of other taxes in the system will generally be ineffective at compensating poorer households for the additional environmental tax payments, since most tax payments are made by better-off households.

This should be clear from Figure 7, which contrasts the distributional effects of two possible patterns of revenue return, which may perhaps be seen as representing a reduction in the intercept term, and gradient respectively. In the first case, the revenues raised from the carbon tax are used to finance a lump-sum for each household (the horizontal line); this is more than sufficient to compensate for the carbon tax payments of households in the bottom five deciles. In the second case, the revenues are used to permit a general reduction in all tax rates.

In Figure 7 the distributional incidence of a proportionate reduction in all rates of income tax, national insurance contributions, VAT and excise duties is shown, with an aggregate revenue cost equal to the yield from the energy tax. This provides little compensation to the poorest households, since they pay little tax to begin with, whilst providing better-off households with a substantial reduction in their tax burden, more than offsetting the energy tax they would pay. Taken together with the energy tax, this form of tax reduction would have a sharply regressive distributional impact; the share of poorer households' incomes paid in tax rises, whilst the share of richer households' incomes paid in tax falls.

Figure 7. Distributional incidence of a carbon tax and two possible uses of the carbon tax revenues in Great Britain, 1988



Source: Smith (1992)

The implication of this is that revenue uses which would maximise the scope for reductions in the distortionary cost of taxation will generally require a pattern of tax adjustments which run counter to those that would needed to rebalance the distributional incidence of the tax system. Using revenues for compensation will then typically fail to maximise the potential efficiency gains that would be available. It is, however, far from clear that there is much scope for efficiency gains without accepting, at the same time, a more regressive distributional incidence to the tax system. If initial policy optimises the trade-off between equity and efficiency goals, the introduction of an energy tax does not significantly alter the attainable points on that trade-off, and the scope for "double dividend" efficiency gains may be small.

6.2.2 Practical complexity of paying equal amounts to all households

A second consideration arises as it may be difficult in practice to achieve an exactly equal lump-sum return of revenues to all households; there is no single parameter of the taxation or social security system which can be adjusted so as to pay an equal lump sum to all households. Nevertheless, it may be possible to achieve a satisfactorily close approximation to an equal return of revenues through a package of measures involving increases in social security benefit levels, increases in the state pension level, and increases in income tax allowances; although some households would be affected by more than one of these, and others (such as single working adults with low incomes) may benefit from none, the overlaps and omissions would be relatively limited (Johnson, McKay and Smith, 1990).

However, it will almost certainly be impossible to make an equal lump-sum return of revenues through *tax* reductions alone; increases in income tax allowances will not benefit those households with insufficient incomes to be paying income tax, and it would be difficult, if not impossible, to design changes to VAT or other taxes on expenditures which would give an equal amount back to all households. It will be necessary, if an equal lump-sum return of revenues is to be made, that the return of revenues is in part made through increases in public expenditures on state pensions and other social security benefits. This is perhaps not a serious problem, except in a presentational or a semantic sense; there is little economic significance in the distinction between making transfers to households through a reduction in taxes or through an increase in benefits. Nonetheless, there may be political difficulties if the effect is to appear to increase the overall burden of taxation.

6.2.3 Compensating social security benefit recipients

A third issue is the potential cost of a uniform lump-sum payment to all households. Since public policy is likely to be concerned more about some households (e.g. the poor) than about others, is it possible to target the return of revenues so that it does not absorb all of the revenue raised from the tax? One possibility would be to seek to limit the offset to existing recipients of social security benefits. This could then be provided by raising benefit levels by an amount that would compensate for the additional taxes on energy.

The precise effects of benefit changes on the resources provided to individual households will depend on the structure of the benefit system. For example, if social security benefits take the form of some guaranteed minimum subsistence level of income, provided to those with no resources of their own, this subsistence minimum could be increased by an amount which would reflect the additional energy spending of a household living at the subsistence level. An adjustment of this sort would, in principle, provide full compensation for households wholly dependent on social security benefits.

However, in addition, many social security systems seek to provide some level of support to households with some resources of their own; thus, for example, households with low levels of earned income may benefit from assistance calculated on the basis of an income-related "taper". A household's entitlement is a function of the maximum amount payable, a threshold below which the maximum is paid, and a rate of withdrawal as income rises above the threshold level. If the system is adjusted to compensate for higher energy prices by increasing the maximum amount payable, whilst keeping the rate of taper constant (to avoid increasing the overall marginal rate at which income is withdrawn), the effect would be to compensate households receiving full *and* partial benefit by the full amount of the increase in the basic benefit level. In addition some households previously not entitled to benefit would now have an entitlement to a small amount of benefit providing partial compensation for the higher tax. If the density of the income distribution is high at this point, the rise in the benefit amount could lead to a substantial increase in the numbers of recipients entitled to benefit (and in the consequent administrative cost).

In part, social security changes of this kind may be achieved "automatically" if benefit levels are indexed to the price level. As Crawford et al. (1993) discuss, in the context of policies to extend VAT to domestic energy in the UK, there are two main reasons why indexation of social security benefit levels would, in practice, be unlikely to provide adequate compensation to social security benefit recipients in the UK for their average additional energy spending. **One** is simply an issue of timing. If indexation is based on past, rather than current, price changes, social security benefit levels will not be adjusted immediately to reflect the higher price of energy. It is clear that if the indexation lag were regarded as a problem, it could easily be dealt with, in the case of predictable price increases due to taxation changes, by some form of anticipatory inflation adjustment, to take effect at the same time as the tax increase.

The **second** deficiency of indexation is that social security benefits are indexed on the basis of a price index which does not reflect the importance of energy *in the spending of benefit recipients*. Benefit levels in the UK are indexed by a general index of prices, which is weighted by the average spending pattern of non-pensioner households. The index used therefore does not reflect the particular circumstances of benefit recipients, for at least three reasons: pensioners (who represent a large proportion of benefit recipients) are not included in the index; using an index which includes the spending of better-off households reduces the importance of energy in the index; and, because the spending of the poor is lower, their spending pattern is naturally under-weighted in an index weighted by average household spending.

6.2.4 Adequacy of compensation based on average spending

A fourth issue is whether compensation based on the average spending of households in a particular group should be regarded as adequate. The equal lump-sum amount paid to all households is more than enough to compensate households in the bottom decile of the income distribution for the additional taxes they would pay, on average. However, the adequacy of the lump sum as compensation for individual households within the decile will vary; households spending less than the average on energy will be significantly over-compensated, whilst those spending much more than the average on energy will find that the lump sum is less than the amount of the additional taxes they pay. The next section discusses how far the position of individual households around the decile averages should be a concern for policy, and, to the extent that it should be, what form of offsetting policy measures might be required to reflect the variation in the effects on individual households.

6.3 Differences between households and their relevance for distributional policy

Smith (1992) showed that there would be substantial variation around the average in the adequacy of uniform lump-sum compensation, especially where the compensation merely returns the average energy tax paid by the bottom decile (£1.03 per week) rather than the total revenues (equivalent to £1.89 per week per household). This reflects the range of energy spending of the households *within* each decile group. Thus, for example, although compensation through a lump sum payment of £1.03 per week would on average exactly offset the additional tax payments of households in the bottom decile group, it would lead to appreciable gains or losses (in excess of 0.5 per cent of gross household expenditure) for about two thirds of households in the group. About one quarter of households would find that the compensation fell short of the additional tax by more than 0.5 per cent of their gross spending, whilst about 40 per cent would be over-compensated by more than 0.5 per cent of gross spending. A lump sum compensation payment of £1.89 per week, equal to the average additional tax payment over all households, would increase the proportion of households in the bottom decile gaining more than 0.5 per cent of total spending to some 85 per cent; only one household in twenty in the bottom decile would then be under-compensated by more than 0.5 per cent of total spending. These results raise four main issues, which are now discussed in more detail.

6.3.1 Seasonality and infrequency in the data

To start with, it is possible that at least part of the variance in tax payments may not reflect long-run differences in the underlying levels of energy spending of different households, but may arise from the "snapshot" data on household spending, which may fail to pick up seasonal variations in energy spending or occasional infrequent purchases (e.g. refilling an oil storage tank). The recorded spending of individual households in household survey data may then exaggerate underlying differences in their consumption of energy. It would appear, however, that such errors are likely to be relatively infrequent and/or small.

6.3.2 The relative importance of needs and preferences in the variance of household spending

A second point is that where there are genuine long-term differences in the level of spending of different households in the same decile group, the key issue for policy is to identify what gives rise to the variation. In particular, are the differences in household energy spending simply a reflection of different preferences, or a reflection of differences in needs for energy spending? Where the observed differences in household spending and household energy tax payments reflect the former, it is difficult to see any case for households with above-average spending to be compensated for their above-average tax payments. If some households in the bottom decile spend more on the decile average on domestic energy, for example, simply because they have a stronger preference for warmth relative to other goods and services than other households in similar economic circumstances, there is no obvious reason for this to be treated any differently in distributional policy than any other difference in preferences between households.

On the other hand, household spending patterns may also reflect differences in needs, and a distributional policy aiming either to provide a given minimum standard of living or to narrow differences in standards of living between poor households and the average may need to provide greater assistance to households with higher needs. Thus, differences in energy spending may reflect various household characteristics affecting the need for energy spending. The elderly, for example, may have a need for more spending on heating, both because they are at home more of the day than the working population, and because of their greater vulnerability to the cold. There may be important regional differences in energy spending needs, reflecting both differences in climate (which appears to underpin a substantial proportion of the variation in domestic energy consumption across member states of the Community) and preferences.

Note that the cross subsidy obligations imposed in the past on nationalised industries tended to limit the variance in supply costs between households, with the effect that public policy did not, in most cases, need to address the issue of assessing the effect of differences in supply costs on defining differences in households' needs for energy and for the products of other nationalised utilities. In a privatised utilities industry it becomes more difficult for government to enforce such cross-subsidy obligations, and supply costs are likely to become increasingly divergent between different groups of customer.

Also, residential accommodation may differ in insulation and thermal efficiency; older houses may require greater energy inputs than new houses to reach the same internal temperature. Some of these differences between houses may reflect the operation of various possible market failures in energy efficiency, including a lack of information, poor incentives in rental property, current income constraints, "myopia" and, perhaps, "irrational" behaviour by certain consumers.

The above arguments concerning the variation in needs for energy spending between households simply concern the provision of adequate financial resources to enable households to purchase sufficient energy, given their needs for energy. It is possible, however, that public policy may seek to do more than this, and may be concerned about the actual amounts of energy consumed by poorer households. Concern of this sort may arise for two reasons.

One may be simply a "paternalistic" view of distributional policy; the objectives of society may not be formulated in terms of the provision of adequate income, but may take the form of concern about the actual consumption by poorer households of certain merit goods, one of which may be energy. Whilst economic policy-makers have tended to be sceptical about arguments for intervention taking this form (on the grounds that provision of income rather than the equivalent value of goods will always provide households with at least as much benefit, and possibly more), it is possible that the objectives of policy-makers could take this form (Dilnot and Helm 1987). Thus for example public policy might be concerned specifically with the amount of heating available to certain groups of the population such as the elderly, and with avoiding deaths from hypothermia, rather than with the provision of additional financial resources to the elderly more generally.

A second group of reasons for concern about the actual consumption of energy by poorer households is that the constraint on household consumption patterns which induces them to purchase inadequate amounts of energy may not be a direct income constraint at all. Thus, for example, low-income elderly households may be particularly averse to exposing themselves to the risk of unexpectedly high fuel bills, and may keep their energy spending low, not because they could not afford more energy, but because they wish to minimise the risk that their energy bills will turn out to be unexpectedly high. In these circumstances, merely providing poor elderly households with more income may not induce much increase in energy consumption; however, relatively inexpensive measures targeted at the underlying unpredictability of energy bills (such as provision of continuous slot-metering) may be more effective.

6.3.3 Targeting and the observability of needs

If there are indeed differences between households in the need for energy spending, and if the variation in needs is seen as a concern for policy, can the differences in need be compensated effectively through financial transfers? This depends, in practice, on the amount and type of information required to identify which households have above-average needs. If the factors governing household needs for energy are observable, then it is possible for social security to be targeted to those households with high need. On the other hand, if households' energy needs cannot be observed (or can be, but at prohibitive cost), a policy based on targeted compensation may be ineffective, requiring an alternative approach.

In some circumstances, as Blackorby and Donaldson (1988) have shown, free (or cheap) supply of goods may lead to more effective targeting than the provision of cash compensation, as households with high needs effectively self-select for high levels of (subsidised) consumption. Of course, households with low needs but a strong preference for the good will also benefit from a policy of cheap supply. Public policy then has to weigh the potential efficiency gain from more efficient targeting against the efficiency loss from providing goods at less than their resource cost; only where the latter is small relative to the former will targeting through a low price and self-selection be worthwhile.

The practical relevance of this line of argument turns on whether unobservable differences in household needs for energy are large relative to other factors affecting households' energy consumption, such as income and preferences. Across the population as a whole, it is perhaps unlikely that this condition would be satisfied; it would seem plausible that much of the variance in household consumption could be related to observable factors, such as region, numbers of people in the household, their ages, and their employment status, all of which are already - or easily could be - used to target benefit payments. The remaining, unobservable, sources of variation are likely to be comparatively small, on average, and insufficient to justify the efficiency cost of providing energy at a price below its full social cost. On the other hand, there may be a case for suggesting that, amongst certain groups, unobservable sources of differences in energy consumption are rather larger; thus, for example, amongst the elderly the amount of energy required will be greatly affected by their degree of physical activity, which could be only partly observed by the social security system.

It would be possible to design systems of cheap energy supply targeted at the elderly, providing energy at below its full marginal social cost to households on the basis of the number of elderly residents. The low price could apply to all units of energy supplied to such households, or to all units up to some limit of *n* units per quarter, after which the standard price would apply. The latter might be appropriate if it is believed that very high spending mainly reflects preferences rather than needs[5]. Clearly there would be a substantial administrative cost in implementing such arrangements, which would have to be weighed up against the potential greater target efficiency of the overall social security system in this area.

Cheaper energy for individuals with high needs could be implemented through various forms of adjustment to the tariff structure for domestic energy supplies. Most utilities supply individual customers according to a tariff of charges which includes both a fixed "connection" cost, unrelated to the amount consumed, and a variable charge levied on each unit used.

From the point of view of environmental policy, externalities associated with energy consumption should be reflected in an increase in the cost of energy consumption at the margin. The distributional problem arises because higher energy taxes increase the cost of marginal consumption by increasing the cost of all units consumed. It might be possible to reduce, or eliminate the distributional problem by measures which increase the marginal cost of consumption, whilst reducing the average cost, either through a reduction in the fixed cost element, or by reducing the price for an initial "allowance" of a given number of units.

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[5] Note, however, that unless n is set above the consumption of at least some households it is equivalent to a simple cash transfer

In countries where utilities are in public ownership under close government control, "non-commercial" objectives, including social objectives, may frequently enter decisions about utility prices and the tariff structure for utility supplies. One case, discussed by Maddock and Castaño (1991) where manipulation of the tariff structure has been employed specifically in order to achieve distributional goals is the case of electricity supply in Colombia, where supplies are charged according to a rising block structure, with a fixed connection fee and 5 rising marginal rates for successive blocks of consumption. Using data for about 1000 households in the city of Medellin and an estimated behavioural model of household consumption behaviour, Maddock and Castaño show that this pricing system has achieved a considerable measure of redistribution. The poorest income group gains an amount equivalent to some 5 per cent of income, compared to the charges they would pay with a uniform tariff.

Compensation for environmental taxes on energy through a reduction in the fixed connection charge for energy supply, or through use of a rising block tariff in which the initial units of consumption were charged at a lower rate than the remaining units consumed would correspond to the equal lump-sum return of revenues discussed above, if the tariff reduction were applied to all customers. Alternatively, it might be possible to target the tariff reduction to particular groups of consumers, about whom there was particular concern.

Whilst superficially attractive as a means of compensating for higher marginal energy charges - and perhaps politically-attractive because it makes clear the linkage between higher energy prices and the compensation provided - the manipulation of utility tariffs as a means of compensating for environmental taxes on energy would involve a number of significant problems. The first is that it raises the same problem of the information requirements for targeting as are raised in providing compensation through public transfer programmes. If it is intended to target compensation to elderly consumers, or to low-income consumers, then the utility company needs to have access to data about the characteristics of individual consumers of exactly the same sort as would be required by government social security agencies in providing compensation through direct transfers. In general, it is unlikely that utilities will have better access to information about the relative characteristics of consumers than government social security agencies, and they may have to duplicate many of the information-gathering activities already performed by the social security agencies for other purposes.

It might be thought that an effective way of targeting assistance with utilities bills would be to concentrate the help on low energy consumers. This will not, however, target help on a number of the groups of greatest concern, and may also provide considerable benefit to comparatively well-off groups. This is because household energy consumption is often closely related to working patterns and other "lifestyle" factors. Some of the consumers with high energy bills (in *absolute* terms), include the unemployed and the elderly, who are at home during the day, and therefore use much more energy for heating than richer consumers who are out at work.

A second problem (although one whose significance can be overstated) may be the impact of targeted tariff changes on the incentives for energy conservation. Reductions in the connection charge and an initial allowance of low-priced units are fully equivalent if the initial allowance corresponds to genuinely intra-marginal units of consumption, and little impact might be expected on the level of energy consumption (except for an income effect). However, if the initial allowance exceeds the consumption level of some consumers, then the marginal cost of energy use is reduced for those users, and the effectiveness of energy taxes in reducing energy related emissions may be more significantly reduced.

Other practical problems which may arise if utility tariff changes are used to compensate for energy taxes include problems relating to the divisibility of consumption units. If the allowance of low-priced consumption is large relative to the connection charge, there may be an incentive for artificial splitting of household units, to benefit from more low-priced consumption allowances. In a similar vein, there may be difficulties of achieving equity between households consuming more than one fuel (e.g. electricity and piped gas) and households consuming a single fuel, since the former could benefit from twice the compensation of the latter. More generally, there is a problem that the wedge which is driven between the tariff structure and the real costs of supply connection may induce inefficient decisions relating to household connection; households no longer would base their connection decisions on the real costs of connection.

Greater difficulties arise in providing compensation through utility tariff adjustments where the utilities companies are in private ownership. Requiring utilities to price according to a structure bearing no relationship to underlying supply costs would create new requirements for regulation. In particular, it would either be necessary to coerce utilities into supplying low consumers for whom charges would not cover connection costs, or to provide public subsidies to cover the costs of supplying these consumers (in which case issues of compliance monitoring would arise).

A related strategy, which has some practical attractions especially in a system of private utility suppliers, has been suggested in Poterba (1991). This would be to provide a tax credit for energy supplies, up to a certain limit. Consumers might be required to demonstrate their actual level of consumption to the income tax authorities, and would then have their income tax bill reduced by a corresponding amount, up to a given threshold. Of course, the tax credit would be only of benefit to taxpayers, but it would be possible to use a similar system, integrated with the income tax or public transfer systems, for providing payments to non-income taxpayers. The attraction of these arrangements over other tax or transfer adjustments is that they could target assistance both on particular groups, and in proportion to their consumption, so as to identify within the target groups households or individuals with particularly high energy needs.

6.3.4 Policies to reduce variance in needs

A last point is that it may be possible - and more efficient - to try to reduce the causes of variation in needs, than to try to target compensation in proportion to needs. If, for example, differences in needs reflect market failures in energy efficiency bearing particularly heavily on certain groups of the population, then it may be possible to eliminate (or at least reduce) the underlying causes of the variation in need by measures to remove the source of the market failure. Whilst spending on such measures may have a resource cost, this could be outweighed by two corresponding resource savings. Firstly, the resource cost of making transfer payments to poor households with high needs would be reduced. Secondly, correction of the market failure should, itself, involve efficiency gains from a more efficient allocation of resources.

More generally, to rely solely on pollution taxes on energy will not be an efficient way of reducing domestic energy use if there are significant market failures in the energy market which prevent economically efficient projects for investment in fuel efficiency from being carried out. An energy tax based on the marginal social cost of carbon would remove one impediment to optimal investment in energy efficiency: the divergence between the private and social costs of energy consumption. This would also increase the private profitability of marginal investments in energy efficiency. However, other possible market failures in energy efficiency may also present a *prima facie* case for government intervention on efficiency grounds, targeted towards the specific sources of the market failure. Elimination of these market failures may also contribute efficiency gains, and *could* also lead to reductions in energy use (although the latter effect is far from certain, and will depend on the character of the energy demand of the consumers subject to the market failure).

6.4 Concluding remarks

The extent to which a household energy tax would raise significant distributional issues seems likely to vary between the member states of the Community. In some member states where household energy demand is predominantly for heating, taxation of domestic energy is likely to be significantly regressive, because the proportion of household spending on energy is higher among poorer households than among better-off households. As a result, the additional tax paid on domestic energy will be higher *as a percentage of income* for poorer households than for those higher up the income distribution.

The large revenues that would be raised from a household energy tax provide scope for actions by governments to offset distributional problems where they arise. Even where the tax burden is regressive, a lump-sum redistribution of revenues, for example, through increased social security payments and tax thresholds (income exempt from income taxes) would be sufficient to ensure that the net impact of a carbon tax on poorer income groups was on average positive. Nevertheless, the situation of the average household may conceal wide variations even within income deciles; some may be much worse off than the average. Specific targeted interventions, perhaps including reduced energy costs for the vulnerable elderly, or measures to improve the heat efficiency of their homes, may in some cases be required.

7 Conclusions

The importance of climate change policy has been evident in the recent political agenda of several developed and developing countries. The need to ensure a sustainable development, and to reduce the damages that previous generations have caused in the environment, has led several governments to agree on the need to intervene and improve the current situation.

In order to reduce the level of GHG emissions in the atmosphere, several instruments are available. These go from mild interventions such as labelling, to much stronger tools such as a ban on those energy products that have the largest impact on the environment. This paper focuses only on economic mechanisms that aim to internalise the social costs of carbon pollution into the price of energy. Accordingly, we simulate the effect of a carbon tax on the demand for energy in the countries of the European Union. We use a value of the Carbon Tax corresponding to £ 70 per tonne of carbon, as indicated in Defra (2007) and Clarkson and Deyes (2002) for the UK. Of course, this value is clearly biased toward the needs of a unique European country, but it corresponds to a starting point toward an integrated carbon taxation system in the EU, and it compensates the lack of estimates in most EU countries.

Evidence gathered in this simulation exercise indicates that within the European Union a Carbon Tax is going to have a regressive effect on the economy, implying that it will charge low-income groups more than high-income groups. Accordingly, such kind of price intervention is going to decrease welfare unevenly, increasing the levels of inequality in the society. A consequence of this finding is that a need for a carbon taxation must be complemented by the need to maintain (or improve) equality within individual countries as well as within group of countries. This can be achieved via a redistributional intervention, where the revenues of the Carbon Tax are redistributed to lower income groups, and different options are proposed in the last section of this work.

The analysis of different redistributional mechanism highlights that *how* the additional tax revenue is used will be critical in determining the overall distributional impact. If the revenue is used in a way which maximises the "double dividend" efficiency gains, it will tend to be used to reduce tax rates, and this will confer much greater benefits on better-off households, and the overall distributional impact of the carbon tax will remain regressive. The revenue could, however, be used in a way which returned at least as much, on average, to poorer income groups as they paid in carbon tax, by making a lump-sum return of revenues.

It is clear, however, that this would undermine the efficiency gains from tax reductions, since it does not reduce the *marginal* rates of tax. There is thus a clear trade off between efficiency and equity in the use of the revenues, and the efficiency gains through less-distortionary taxes can only be achieved by sacrificing the distributional neutrality of the package. Further research would be needed in order to quantify costs and benefits of the different options, locating the most effective policy instrument among those available.

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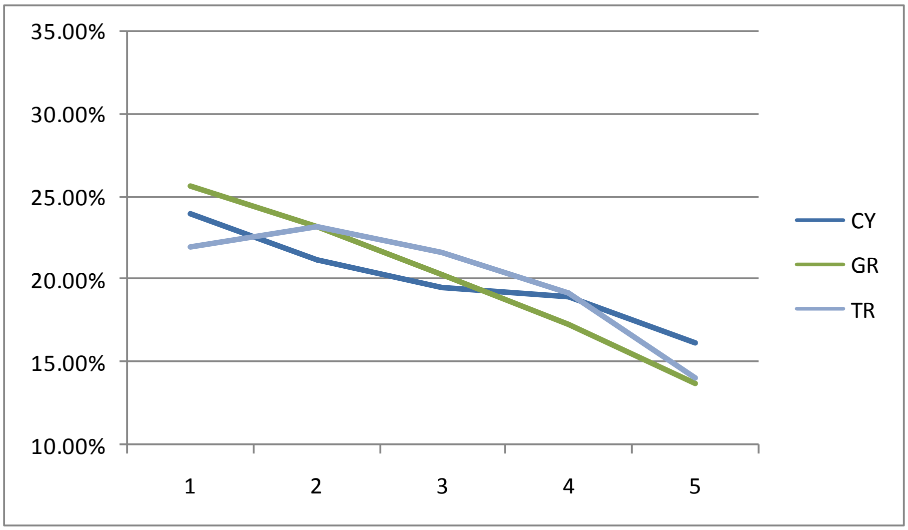
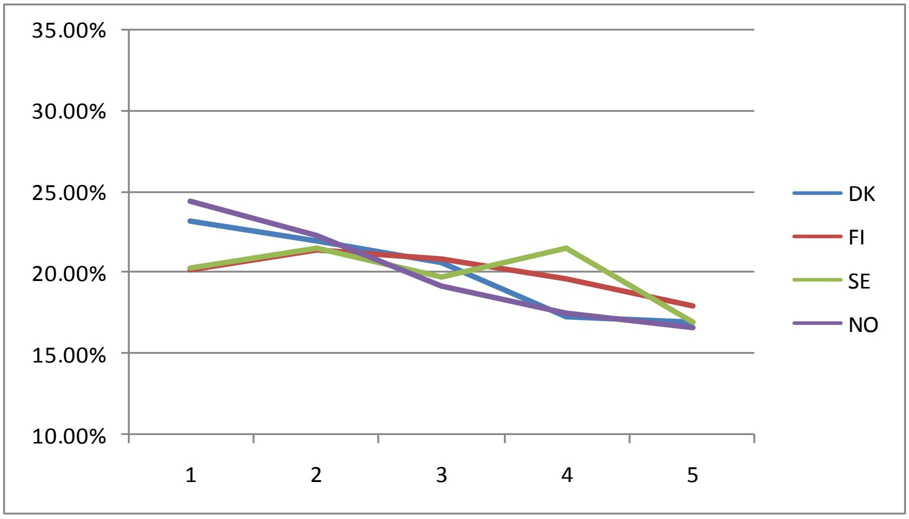
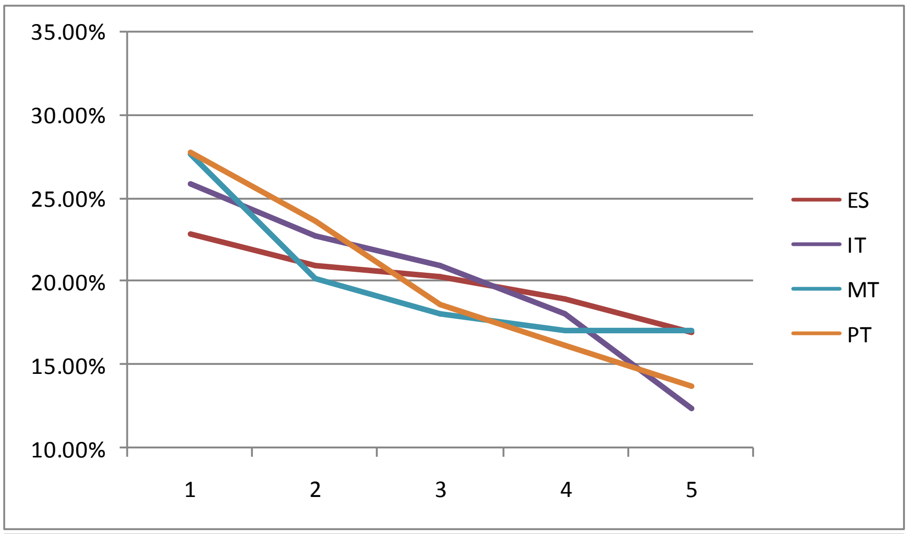
ANNEX 1: GRAPHICAL REPRESENTATION OF HOUSEHOLD ENERGY EXPENDITURE BY QUINTILES OF INCOME

The graphs below represent household energy expenditures (per thousand euros) by quintile of income. Each quintile contains exactly 20% of the population. The same graph is reported for all the 27 countries of the European Union, including four non-EU countries (Croatia, Macedonia, Norway, and Turkey), which are reported for a matter of comparison. Data have been obtained from the EUROSTAT Database.

Figure A1: Energy consumption in the EU by quintiles of income



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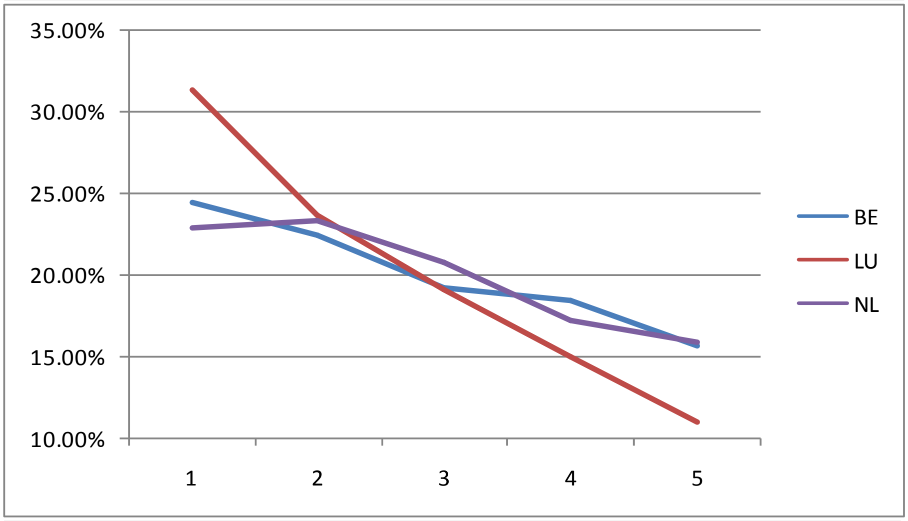
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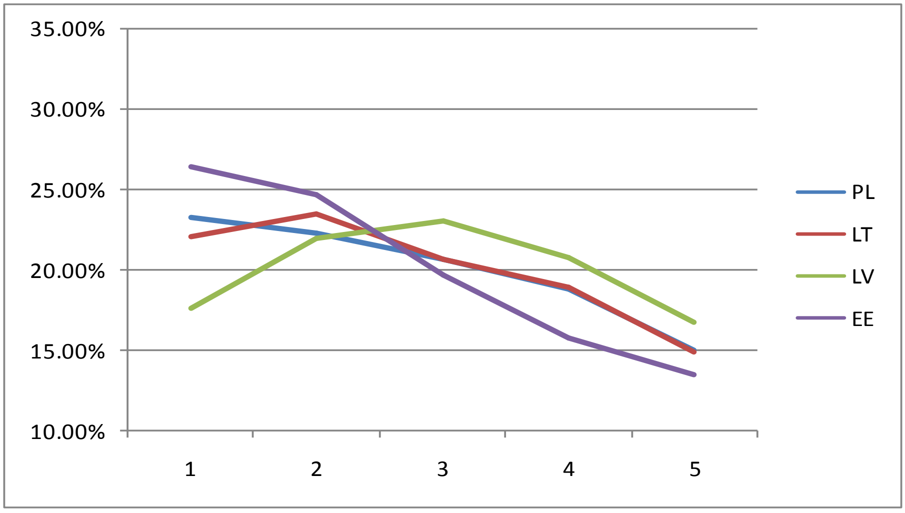
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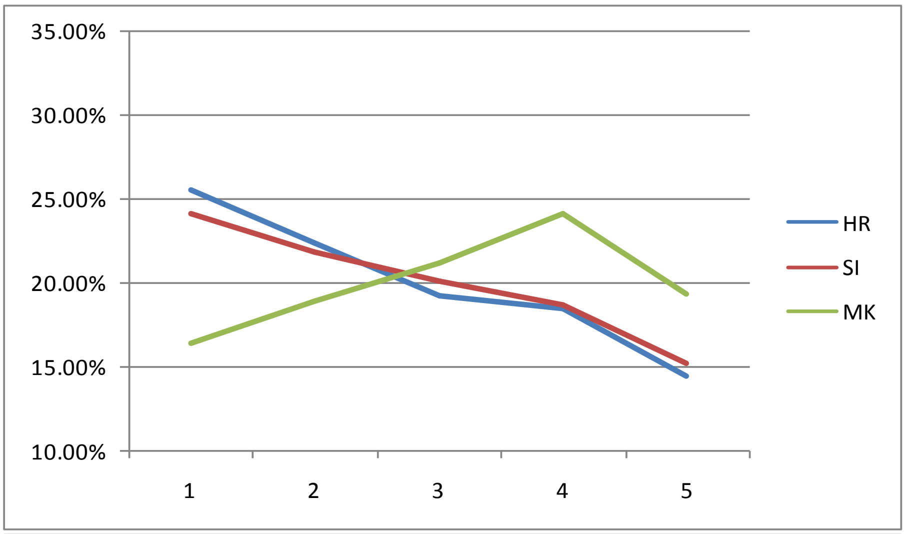
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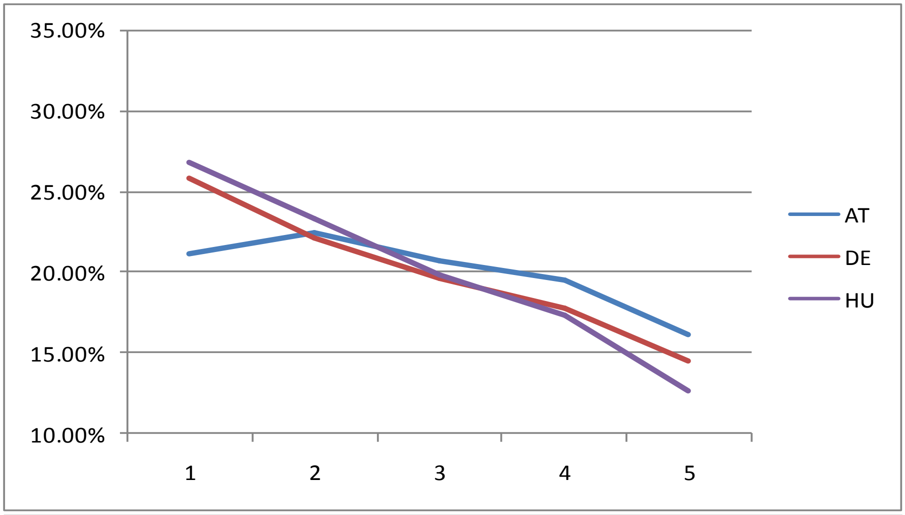
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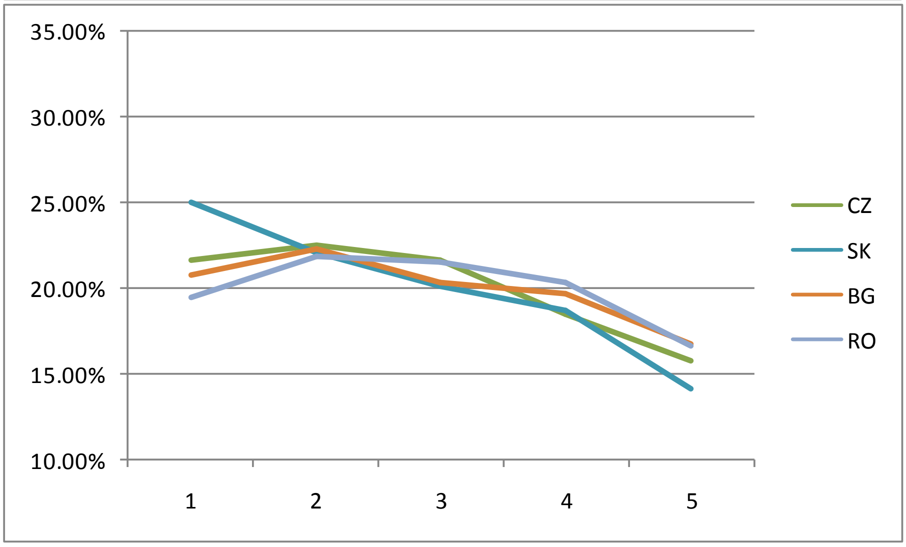
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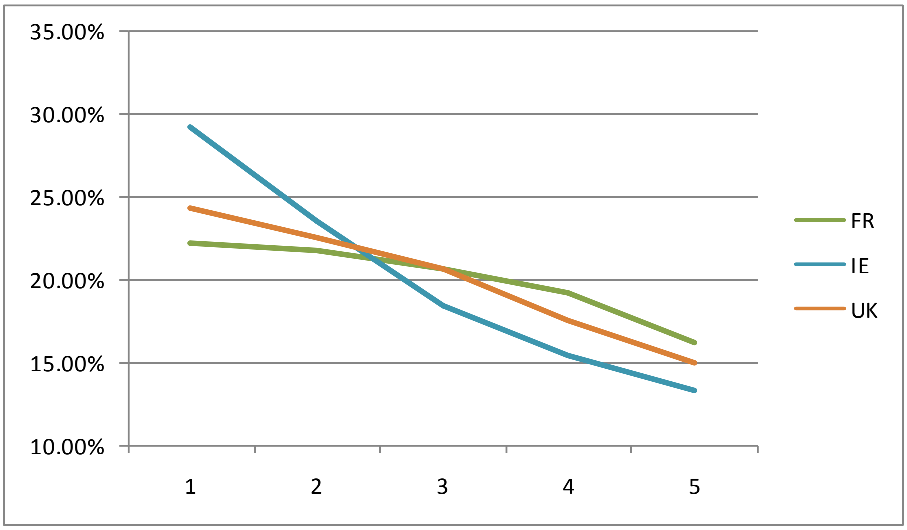

Note: acronyms in the legend correspond to: AT = Austria; BE = Belgium; BG = Bulgaria; CY = Cyprus; CZ = Czech Republic; DE = Germany; DK = Denmark; EE = Estonia; ES = Spain; FI = Finland; FR = France; GR = Greece; HR= Croatia; HU = Hungary; IE = Ireland; IT = Italy; LT = Lithuania; LU = Luxembourg; LV = Latvia; MT = Malta; MK= Macedonia; NL = Netherlands; NO = Norway; PL = Poland; PT = Portugal; RO = Romania; SE = Sweden; SI = Slovenia; SK = Slovakia; TR= Turkey; UK = United Kingdom.

ANNEX 2: METHODOLOGICAL FRAMEWORK

In order to simulate the effect of a tax on energy consumption, we need to define a demand function for such good. Once the demand function is obtained, the value of the tax then changes prices to a new level. Then, the same demand equation is re-estimated using the new post-tax price, registering how the price increase changes the structure of the household energy portfolio, and how the tax rate (the relative amount of tax paid - the tax paid per unit of income) differs for different levels of income. This section describes the structure and the assumptions upon which the demand equation is estimated, and the structure of the simulation.

A. The Almost Ideal Demand System

In order to estimate a demand function for energy in the EU we use a linear Almost Ideal Demand System (AIDS) (Deaton and Muellbauer, 1980). According to this methodology, households start from the usual utility maximisation problem, from which they define the amount of good they need, and allocate their total budget for expenditure in the category. Starting from this problem, Deaton and Muellbauer derived a demand function in the form

$$\mathrm{w}_{\mathrm{it}} = \alpha_i + \gamma_i \log(\mathrm{p}_{\mathrm{it}}) + \sum_j \gamma_j \log(\mathrm{p}_{\mathrm{jt}}) + \beta_i \log(\mathrm{X}_{\mathrm{t}}/\mathrm{P}_{\mathrm{t}}) \qquad (2)$$

where w_{i} is the expenditure share of the category *i*, p_{it} and p_{jt} indicates respectively the price of product i and the prices of its alternatives j at time t. X_t indicates total household expenditures, while P_t is a price index in the form

$$\log(\mathrm{P}_{\mathrm{t}}) = \alpha_{\mathrm{i}} + \sum_{\mathrm{k}} \gamma_{\mathrm{k}} \log(\mathrm{p}_{\mathrm{kt}}) + \frac{1}{2} \sum_j \sum_k \gamma_{kj} \log(\mathrm{p}_{\mathrm{kt}}) \log(\mathrm{p}_{\mathrm{jt}}) \qquad (3)$$

However, in the literature this is often replaced by Stone's index in the form

$$\mathrm{P}_{\mathrm{t}}^{*} = \sum_{\mathrm{k}} \mathrm{w}_{\mathrm{i}} \log(\mathrm{p}_{\mathrm{kt}}) \qquad (4)$$

and this approximation is particularly valid in the case of a linear demand system as the one presented in this work (Blanciforti and Green, 1983). The term (X_t/P_t) corresponds to the total quantity purchased (expenditure divided by price), but this is a quantity index, therefore includes the total units of energy demanded (irrespective on the type), adjusted by market share.

The model can also incorporate other exogenous factors influencing demand (see e.g. Blanciforti and Green, 1983; Verbeke and Ward, 2001), appending such factors to the constant term of equation (1) and (4), as

$$\alpha_{\mathrm{i}} = \alpha_0 + \delta_{\mathrm{i}} \mathrm{C}_{\mathrm{ht}} \qquad (5)$$

The demand equation then becomes

$$\mathrm{w}_{\mathrm{it}} = \alpha_0 + \delta_i C_{ht} + \gamma_i \log(\mathrm{p}_{\mathrm{it}}) + \sum_j \gamma_j \log(\mathrm{p}_{\mathrm{jt}}) + \beta_i \log(\mathrm{X}_{\mathrm{t}}/\mathrm{P}_{\mathrm{t}}) \qquad (6)$$

where C_{ht} is a set of variables specific to country *h* at time *t*. The demand for the different *N* alternatives is then estimated simultaneously, adjusting for unobservable demand shocks such as tastes and preferences (for example environmental friendliness), which are common and contained in the residuals of equation (5).

In order to achieve identification of the parameters, hence giving precise number and realistic estimates, the model needs to comply with some restrictions that originate from economic theory and make the results consistent with economic principles. These are precisely three:

1. Adding-up condition: this condition refers to the budget constraint. In fact, the total sum of the intercept would correspond to the total budget, as when all covariates are zero, people would distribute their total budget according to baseline preferences, whose sum must equal 1. Furthermore, the sum of the effects of each price variable across type of expenditure must be equal to zero, because their combined effect should leave the overall demand within the category unchanged - i.e. if the price of a good changes, some products will be consumed more, other less, giving no change in the total average expenditure. The same happens for the quantity index, as the total effect would cancel out across equations. These conditions are written as

$$\sum_{i=1}^{n} \alpha_{\mathrm{i}} = 1 \;,\; \sum_{i=1}^{n} \gamma_{\mathrm{ij}} = 0 \;,\; \sum_{i=1}^{n} \beta_{\mathrm{i}} = 0 \qquad (7)$$

2. Simmetry condition: this condition imposes that the economic effect of the price of a good over the other is the same irrespective of the direction of the change. Specifically, the change in price of good A will have an effect on B symmetrical (i.e. identical in magnitude and in sign) to the effect that a price change of B will have on A. This condition is written as

$$\gamma_{\mathrm{ij}} = \gamma_{\mathrm{ji}} \qquad (8)$$

3. Homogeneity condition: this last condition imposes a further constraint assuming that prices do not play any combined role in the demand apart from determining the allocation of resources among alternatives. In other words, individual prices change the market share, increasing or decreasing it, but the overall combined effect is going to be zero. This condition is written as

$$\sum_{j} \gamma_{\mathrm{ij}} = 0 \qquad (9)$$

These restrictions make the estimation of N simultaneous equation unfeasible using Least Square methods because of perfect multicollinearity; therefore the estimation is usually made on (N-1) categories, and the coefficients of the last category are obtained from the adding-up and symmetry condition (Filippini, 1995; Poi, 2002).

In the case presented here, the AIDS model is a panel, therefore characterised by fixed and random effects. Whilst we capture the presence of random effects using Seemingly Unrelated Regressions (SUR), we capture country-specific fixed effects using country-specific variables, and time-specific effects using a time trend variable. We assume the absence of unobserved fixed effects, as well as the absence of autocorrelation to simplify the estimation.

B. Elasticities

An important feature of this model is that it enables the calculation of elasticities. Specifically, elasticities are a set of parameters that define how changes in a certain economic variable influence the amount of product consumed (either in terms of quantity or value, i.e. expenditures). Specifically, we calculated three different types of elasticity.

- Price elasticity: this value tells us the percentage change in quantity purchased as a consequence of a price change of 1%. These can refer to a price change of the product, or of its substitute/complements. Specifically, price elasticities can be of two types:
    a. Own-price elasticity: this data refers to the change in quantity of a good purchased when its own price changes. According to consumer theory, and the law of demand, a price increase will cause the decrease in the quantity of that good consumed. This is therefore reflected in a negative value of cross-price elasticities. In this case, when the absolute value of the own-price elasticity is greater than unity, an increase in price of a unit has a high impact in the change of quantity purchased, which leads to a more-than-proportional decrease in quantity consumed.

If the price elasticity equals one, the product is said to be unit-elastic; if it is greater than one, the product is defined as elastic; otherwise the product is classified as inelastic.

b. Cross-price elasticity: This particular type of elasticity measures how the change in price of a good affects the demand of a similar good in the market. More specifically, this value identifies whether two products are **substitutes** or **complements**. Complements are products that are used jointly; therefore a change in price of one will decrease the demand for both products. As an example, the increase in the price of petrol reduces the demand for petrol, as well as the demand for petrol-fuelled cars.

   Similarly, substitutes are products that are used as alternative to each other; therefore the increase in price will decrease the demand of one item and stimulate the demand for the other item. As an example, a price increase in wine will decrease its consumption and increase the consumption of alternative alcoholic drinks, e.g. beer. These definitions define the interpretation of the results: negative cross-price elasticities will identify substitutes, while positive values will identify complements.

Since the price change has not only an impact on consumers' preference, but also affects their income, the price elasticity should incorporate this changes. However, this value of elasticity is called "Uncompensated elasticity": the value we obtain does not compensate for the loss of income generated by the price change - it considers that consumers change their utility function only because of a change in price.

- Expenditure elasticity: This value tells us the percentage change in quantity purchased when energy expenditures increase by 1%. Since total expenditures correspond to the budget, they determine the allocation of resources according to needs and preferences. Accordingly, an increase in expenditure will determine an increase in the consumption of those goods perceived as more valuable; hence the expectation is to have a positive sign. This value is also essential in determining the type of good in analysis. What economists call *normal goods* (i.e. goods that behave according to general demand theory) have elasticity between 0 and 1. On the other hand, *luxury goods* have an elasticity higher than 1: a unit increase in price will increase expenditures by more than one unit.

- Allen elasticity of substitution: it tells us the percentage change in quantity purchased of a good changes when the price of another products increases by 1%. This particular type of elasticity observes the change in quantity holding prices of all other alternatives (i.e. excluding the two goods in analysis) as fixed.

Elasticities can be calculated in detail using the coefficients obtained in equation (5) as follows (see Filippini, 1995):

a. Expenditure elasticities

$$\eta_i = 1 + \frac{\beta_i}{w_i} \qquad (10)$$

b. Elasticities of substitution

$$\sigma_{ij} = 1 + \frac{\gamma_{ij}}{w_j w_i} \qquad (11)$$

c. Uncompensated elasticities

$$\varepsilon_{ij} = -\delta_{ij} + \frac{\gamma_{ij}}{w_i} - \beta_i \frac{w_j}{w_i} \qquad (12)$$

In equations (9) to (11), the value w_i is the estimated value of the market share per product obtained from equation (5).

C. Microsimulation

Once the demand function for energy is estimated, the effect of the tax can be simulated. In order to do so, we use a static arithmetical microsimulation model (see Burguignon and Spadaro, 2006, and Boccanfuso et al., 2008, for a classification of the different alternative methodologies). Compared to behavioural alternatives, the model proposed in this work assumes that the tax instrument does not have an impact on socio-demographic characteristics of households in the market. Similarly, compared to dynamic alternatives, the technique we use assumes no changes in the inter-temporal allocation of consumption, and no change in any economic decision of households (Burguignon and Spadaro, 2006).

The objective of the simulation is to observe how consumption shares change when the price is changed by the tax. All changes are compared to the *status quo*, and in order to achieve significant results we need to assume that total household energy expenditures do not change, implying that consumers are going to allocate the same amount of money to energy expenditure before and after the tax is in place. A further assumption is that energy is going to be taxed at the level of the supplier (as suggested by Metcalf and Weisbach, 2009), but the value of the tax is passed entirely onto the consumer, hence increasing the final price of energy by the full amount of the tax.

The procedure used to microsimulate a tax is the following:

1. Firstly, we assign a value to the tax, consistent to environmental economics literature. In this particular experiment, we assign a specific tax, therefore making it additive to the value of the price. The steps taken in assigning a value to the tax are described in section 7. The value of the tax is then added to the price of energy, obtaining a new price for each energy type.
2. Using the new price, we recalculate the value of the market share w_i for each energy type.
3. Having estimated the new household portfolio of energy, we then multiply w_i by the value of total expenditure (which we assume unchanged), and we obtain the new energy expenditure by category.
4. We then calculate the quantity of energy consumed as

   $$q_i = \frac{\exp_i}{(p_i + tax_i)} \tag{13}$$

5. The total quantity of energy consumed per each category is then used to calculate the total energy tax paid by each country at a given time as

   $$total\_tax = \sum_i (q_i \times tax_i) \tag{14}$$

   This value corresponds to the amount of income lost because of the taxation, which has caused the budget for energy to shrink.
6. Finally, the tax rate of the carbon tax is calculated as

   $$tax\_rate = \frac{total\_tax}{income} \tag{15}$$

Having calculated the total tax and the tax rate, it is possible to test graphically whether the carbon tax as tested in this particular case is regressive, neutral, or progressive just comparing the relation between the results from equation (14) and (15) over income.

ANNEX 3: DATA

The data used in the estimation of a demand for energy originate from two different databases: the EUROSTAT database and the IEA database, available at www.esds.ac.uk. All the data used in the model refer to residential energy use; therefore it only includes information on household consumption of different types of energy. The data included in the model include all 27 countries that belong to the European Union: Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, United Kingdom. Data cover the period going from 1996 to 2007.

The data we use correspond to prices and quantities of **natural gas**, **electricity**, **heating oil**, and **burning coal**, as well as the total amount of quantity consumed for each energy source. Data on household energy consumption for non-domestic use (e.g. fuel) was excluded from the analysis, because the structure of its taxation is sensibly different from other types of energy households consume (the redistributional effects of carbon taxation on petrol in the US are analised in Bento et al., 2009). Units were all converted into euros per unit, in order to obtain final expenditures in euros at current prices.

Eurostat data on prices appeared in classes of consumption, which were recorded differently before and after 2007. Consequently, the price variable included in the model corresponds to the overall average[6]. Similarly, Eurostat proposes six-monthly prices for energy, and the yearly prices were calculated as the mean for the year.

Total household expenditure for each energy type was calculated multiplying prices by quantity consumed per country per year. Total expenditures correspond to the sum of the total expenditure per product.

In order to adjust for different country-specific economic variables, several variables were included. Specifically, these are:

- Gross Domestic Product (GDP), in billions of euros: this variable indicates a country's overall economic output, and it is an indicator of the country's size of the economy, as well as its performance.
- Gross National Income (GNI), in billions of euros: this variable represents the nation's total final income in a year.
- Actual heating degree days (HDD): this variable expresses the energy needs of the country in a specific year. Contextually, it measures the severity of cold weather in a specific year based on outdoor and indoor temperatures. Eurostat calculates this value as

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[6] Averages were always calculated omitting missing variables.

$$\begin{aligned} HDD &= (18\,^{\circ}C - T_m) \times d & \text{if } T_m \leq 15 \\ & 0 & \text{if } T_m > 15 \end{aligned}$$

15°C is used as heating threshold, and

$$T_m = \frac{(T_{min} + T_{max})}{2}$$

T_m is the daily average between the maximum and the minimum outdoor temperature, which are then added up to a year to obtain the final yearly value (Gikas and Keenan, 2006).

- Total revenue from environmental taxation: in order to estimate the impact environmental taxation has on the demand for household energy, the total revenue from environmental outcome was included as dependent variable in the regression. The definition the European Commission gives with regard to environmental taxes is as follows: "*A tax whose tax base is a physical unit (or a proxy of it) of something that has a proven, specific negative impact on the environment*" (European Commission, 2001). Value added taxes are excluded from this total value. This value is reported by member states for every year. The inclusion of environmental taxation is deemed relevant in the demand system, because earlier works highlight the share of total revenues from environmental taxation is large: households pay as much as firms in energy taxes, whilst paying more in transport taxes (Steinbach, 2007). This variable is included in three parts: revenues from energy, transport, and pollution and resource tax.
  - Revenues from energy tax, in billions of euros: This variable includes revenues from taxes on all energy products, used for both transport and stationary purposes. Transport-related energy includes, among others, petrol and diesel, while stationary energy products refer to fuel oils, natural gas, coal and electricity (European Commission, 2001);
  - Revenues from pollution/resources tax, in billions of euros:
    - Pollution taxes: this variable includes revenues from taxes on all emissions that pollute air and water, as well as from solid waste management and noise. However, as mentioned earlier, CO2-taxes are not included in this category, but in the revenue from energy taxation.
    - Resource taxes: this variable includes taxes on resources. Despite the fact that resource extraction is not necessarily environmentally harmful in itself, it can lead to environmental problems, such as pollution and soil erosion, hence it may be taxed (European Commission, 2001);

    - Revenues from transport tax, in billions of euros: this variable includes taxes related to the ownership and use of motor vehicles. This includes, among other things, taxes paid on different sources of transport (e.g. planes), and all related transport services (e.g. duty on charter or scheduled flights), provided they fit the definition of environmental tax. Taxes on petrol, diesel and other transport fuels are not included in this category, but under revenues from energy taxes (European Commission, 2001).

- Energy intensity: this variable measures the influence of the energy intensity of the economy on the demand for energy. Energy intensity is a measure of how much energy is used to produce a unit of economic output. Its value is calculated as the gross inland consumption of energy divided by the country's GDP (Eurostat uses GDP at constant prices, where the base year is 1995=100). The variable is measured in kilogram of oil equivalent per 1000 euro (Gikas and Keenan, 2006).
- Greenhouse Gas (GHG) Emissions: this variable measure the influence the level of emissions has on the demand for energy. This value is measured in CO2 equivalent, indexed on actual base year =100, corresponding to 1990 for the non-fluorinated gases (CO2, CH4 and N2O), and to 1995 for the fluorinated gases (HFC, PFC and SF6). Emissions of the 6 greenhouse gases covered by the Protocol are weighted by their global warming potentials (GWPs). The fact this variable is indexed means the value used measures the increase or the reduction of emission from the base year. Therefore, this variable measure the impact that GHG emission changes have on demand.
- Time trend: this variable captures characteristics that influence energy expenditure over time, for instance technological improvements. We assume a simple linear time trend, which assumes no diminishing return of time effects.

These data were all sourced from the EUROSTAT database. The dataset was characterised by a large number of missing observations. In order to preserve the integrity of the data, missing values were replaced in different ways. Firstly, if they were the first or last year available of a country-specific series, they were substituted by the year immediately after or immediately before respectively. If the value was within the series, this was substituted by the mean value of the country for the specific variable.

For prices, the missing data were obtained using a different procedure. Since IEA provided Consumers Price Indexes (CPI) for all the period and energy sources in analysis, missing data were calculated using the country's value of the CPI. When the CPI was not available, the mean value of the country was used. Finally, for those countries with no price series, the data was substituted by the (weighted) average price of the energy source in OECD countries.

ANNEX 4: RESULTS OF THE AIDS MODEL

This annex reports the results of the AIDS model applied to energy consumption in the EU. Table A1 reports the coefficients of the four equations representing the demand for **Natural gas**, **Electricity**, **Heating oil**, and **Coal**. Due to estimation problems, only the first three equations can be estimated, whilst the demand function for coal is used as reference, and its coefficients have been obtained based on the constraints presented in equation (6) of Annex 2. This implies that coefficients for coal present no standard error, and no inference can be done on them.

Table A2 reports the correlation matrix of the residuals of the different equations, which correct for the presence of unobservable variables that influence all demand equation simultaneously. This indicates that the three equations are negatively correlated, suggesting substitutability among the different sources. In fact, increasing the share in consumption of a particular source of energy decreases the share in consumption of all other sources of energy, as expected from the budget constraint.

Table A3 includes the model diagnostics, which draw the picture of a properly specified model. As can be seen, all equations are characterised by a high R-squared, indicating that the variables included in the model explain a large amount of variance in expenditure patterns. Furthermore, the chi-square statistics indicates that all models have a good structure, where enough variables are significantly different from zero. The Breusch-Pagan test of independence indicates that the three equations included in the estimation are correlated (chi^2 (3) = 229.365, p-value = 0.0000), indicating that the use of SUR techniques is the most appropriate to estimate efficiently the coefficients.

The estimated coefficients of table A1 have been used to obtain the elasticities reported in table A4, following the procedure explained in Annex 2.C.

Table A1: coefficient estimates of an AIDS model including tax variables

	Demand equation for:						
	Natural gas		Electricity		Heating oil		Coal
	Coef.	S.E	Coef.	S.E	Coef.	S.E	Coef.
Log P_{gas}	-0.1144***	0.0238	0.0651***	0.0149	0.0396***	0.0131	0.0096
Log P_{el}	0.0651***	0.0149	0.0068	0.0130	-0.0561***	0.0089	-0.0159
Log P_{coal}	0.0096	0.0079	-0.0159***	0.0054	-0.0086**	0.0043	0.0149
Log P_{heat}	0.0396***	0.0131	-0.0561***	0.0089	0.0251**	0.0106	-0.0086
Stone's Index (Total expenditure index)	-0.0139*	0.0081	0.0359***	0.0083	-0.0220***	0.0074	-0.0001

GDP	0.0024***	0.0006	-0.0035***	0.0006	0.0005	0.0006	0.0006
GNI	-0.0026***	0.0006	0.0036***	0.0006	-0.0005	0.0006	-0.0006
HDD	-0.0363***	0.0079	0.0024	0.0078	0.0304***	0.0074	0.0035
Revenues from energy taxation	0.0169***	0.0031	-0.0141***	0.0031	-0.0023	0.0030	-0.0006
Revenues from pollution and resource taxation	0.0578***	0.0193	-0.0826***	0.0188	0.0121	0.0183	0.0128
Revenues from transport taxation	0.0050	0.0122	0.0112	0.0119	-0.0082	0.0115	-0.0080
Energy intensity	-0.0002***	0.0000	0.0000	0.0000	0.0002***	0.0000	0.0001
GHG change	-0.0010*	0.0005	0.0036***	0.0005	-0.0028***	0.0005	0.0001
Year	0.0027	0.0019	-0.0002***	0.0019	-0.0012	0.0018	-0.0012
Intercept	0.6174***	0.1397	0.2322	0.1409	0.2498**	0.1245	-0.0995

*, **, and *** indicate significance at 10%, 5%, and 1% respectively

Table A2: Correlation matrix of residuals:

	Natural gas	Electricity	Heating oil	Coal
Natural gas	1			
Electricity	-0.5381	1		
Heating oil	-0.5432	-0.3511	1	
Coal	NA	NA	NA	NA

Table A3: Descriptive statistics of the AIDS model

Equation	Obs	Parms	RMSE	R-sq	chi2	P
Natural gas	324	13	0.11212	0.5538	424.11	0.0000
Electricity	324	13	0.107643	0.7952	1242.07	0.0000
Heating oil	324	13	0.105503	0.78	1217.95	0.0000
Coal	Reference					

Table A4: Estimated elasticities of an AIDS model including tax variables

		Demand equation for:			
		Natural gas	Electricity	Heating oil	Coal
Uncompensated price elasticities	Natural gas	-1.6153	0.0941	0.2488	0.4722
	Electricity	0.4058	-1.0250	-0.2418	-0.7757

	Heating oil	0.2312	-0.1002	-0.8349	-0.4206
	Coal	0.0545	-0.0267	-0.0465	-0.2726
Allen elasticities of substitution	Natural gas	-2.4610	1.5755	2.2431	3.5942
	Electricity	1.5755	1.0176	0.4860	-0.2492
	Heating oil	2.2431	0.4860	1.8165	-1.4034
	Coal	3.5942	-0.2492	-1.4034	36.6085
Expenditure elasticities		0.9237	1.0577	0.8744	0.9968