

# The welfare effects and the distributive impact of carbon taxation on Italian households

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## Abstract

In this work the welfare effects and the distributive impact on Italian households of the Italian Carbon tax are calculated. The Carbon tax has been introduced in Italy at the beginning of 1999 asking for smooth increases, over a number of years, in the prices of most fossil fuels. Its welfare effects have been calculated using True Cost of Living index numbers and the Compensating Variation. The parameters have been obtained through estimation of a complete Almost Ideal demand system, using households data from 1985 to 1996. The welfare loss turns out to be quite substantial and affects Italian households in a non-negligible way, but the distribution of welfare losses across different levels of total monthly expenditures does not allow sustaining the regressivity of Carbon taxation, as the effect becomes bigger as we move up the income distribution. This evidence might encourage the use of Carbon taxes, at least in the transport sector, as cost-effective instruments of environmental policy, especially after the ratification of the Kyoto Protocol on Climate Change.

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## 1. Introduction

Over the last decade and, particularly, after the Framework Convention on Climate Change of 1992, many OECD countries have considered the introduction of “Green Tax Reforms” aimed at reducing, through higher prices, either the use of scarce resources or emissions of pollutive substances. In this context carbon/energy/fuel taxes have frequently been advocated, especially as a way to comply with the Kyoto Protocol obligations. To date some countries have implemented taxes based on the carbon content of energy products, or energy related taxes:<sup>1</sup> Sweden and

Norway in 1991, The Netherlands in 1988, Denmark in 1992, Finland in 1990, Italy and Germany in 1999 (OECD, 2001, pp. 51–52). The United Kingdom adopted in 1996 a landfill tax and has introduced in 2001 the “climate change levy”, a tax on industry and business use of energy. In France and Switzerland proposals were advanced in 1999, but rejected in 2000 (OECD, 2001, p. 52). The United States, Australia and New Zealand, after having explored the possibility, have abandoned the idea (Baranzini et al., 2000, p. 396). Finally, the European Union (EU) after a long discussion, during the 1990s, on the opportunity of introducing a European Carbon tax,<sup>2</sup> does not appear to

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<sup>1</sup> There are different kinds of emission taxes considering the carbon content of energy products (Baranzini et al., 2000, pp. 396–397). They vary according to the tax base (what is actually taxed): (1) a Carbon tax is a charge to be paid on each fossil fuel, proportional to the quantity of carbon emitted when it is burned. (2) A CO<sub>2</sub> tax is specified per ton of CO<sub>2</sub> emitted. It can be easily translated into a Carbon tax, by knowing that a ton of carbon corresponds to 3.67 tons of CO<sub>2</sub>. A true emission tax would impose a charge per unit of CO<sub>2</sub>, if this is the greenhouse gas one wants to reduce. (3) An energy tax depends on the

(footnote continued)

quantity of energy consumed, and it is specified in some common unit (for instance British Thermal Units, BTU). It also covers nuclear and renewable energy and it can be less cost-effective than a carbon or CO<sub>2</sub> tax because the link between the objective (emissions abatement) and the tax base is less direct. Scheraga and Leary (1992, quoted in Baranzini et al. (2000) footnote 6, p. 397) have shown that an energy tax could be 20–40% more costly than a Carbon tax, for equivalent reductions in emissions.

<sup>2</sup> In 1992, the European Commission proposed a Directive (COM(92) 226 final) for the introduction of a tax on all energy

attach a priority role to it in the Kyoto Protocol strategies. There thus seems to be a widening gap between the political discourse and the policy practice, if one takes into account that the share of environmental taxes in total tax revenues in EU-15 was 5.8% in 1980; 6.8% in 1994 and 6.7% in 1997 (EEA, 2000, pp. 23–24) whereas taxes on labour accounted for 51.4% of all EU taxation in 1995 (Baranzini et al., 2000, p. 396). The recent EU approval of the Kyoto Protocol obligations and its ratification by most of the EU member countries,<sup>3</sup> gives reasons to think that carbon or energy taxation might still have a role in the future European environmental policy or, at least, in the policy of its member countries,<sup>4</sup> although probably circumscribed to the transport sector. Despite the problems in finding common positions in the EU, the European Commission (2000) has continued to advocate environmental taxes as important tools of environmental policy.<sup>5</sup>

In order to make these taxes more politically acceptable it has been suggested to use the proceeds from a green fiscal reform to significantly reduce existing taxes and therefore the welfare cost of Carbon taxation (Pearce, 1991). The rationale is that taxes on environmentally damaging activities, largely considered as cost-effective instruments of environmental policy, could be used in a revenue neutral context: when other taxes are present, there is the possibility of swapping an environmental tax for an existing tax so that the government budgetary position remains unchanged. A “double dividend” could then be produced, i.e. improvements in the environmental variable which is the target of the environmental tax and overall improvements of the allocation of goods in the economy (Bosello et al., 2001, p. 10).

The purpose of this paper is, first of all, to assess the welfare effects of Carbon taxation on Italian house-

holds, i.e. to measure the gain or loss of welfare caused by the introduction of the new tax on households with different expenditure levels.<sup>6</sup> These effects will be calculated through the Compensating Variation which is an exact measure of a welfare change. Secondly, to assess the distributive impact of the Italian fiscal reform, i.e. the distribution of the welfare change across different types of households and different expenditures levels. Finally, the environmental effectiveness of the fiscal reform will be assessed, as a first approximation, through estimation of the demand elasticities for fuels.<sup>7</sup> Five households’ profiles will be taken into account and changes in the prices for fuels will be considered. The study simulates the ex ante effects on households of a real, not hypothetical environmental tax reform, introduced in Italy at the beginning of 1999. As far as we know, there are no other such studies for Italy, which is the first southern European country having introduced a green fiscal reform. Moreover, households data are used which allow for behavioural responses and for comparisons to be made across different households profiles and across different levels of expenditures.

The structure of the paper is as follows. In Section 2 some theoretical considerations are introduced trying to explain the economic rationale, the double dividend issue and the distributional implications of Green Taxes. In Section 3 the design and purpose of the Carbon tax introduced in Italy in 1999 is illustrated. Section 4 explains how True Cost of Living Indices can be used to calculate welfare changes following a fiscal reform and how they can be obtained from a demand system. Section 5 comments on the calculations’ results. Finally, in Section 6 we make some final considerations. The paper also includes a technical appendix where the specification of the demand model, the data and the estimation method used are presented.

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products, excluding renewables, but no agreement was reached in the Ecofin Council. In 1995 the Commission amended its initial proposal (COM(95) 172 final) to overcome the obstacles raised during the previous discussion, but still the Council was not able to reach an agreement on the modified CO<sub>2</sub>/energy tax proposal. In 1997, the Commission adopted a proposal for a Council Directive restructuring the Community framework for the taxation of energy products (COM(97) 30). The proposed directive does not introduce a carbon and energy tax, but establishes a minimum level of taxation on all energy products. Member states may take into account all indirect taxes (except VAT) borne by a product in order to fulfil the required tax level. Thus, depending on their national environmental policy objectives, Member States are free to apply taxes on CO<sub>2</sub> emissions or other emissions, taxes on energy, or excise duties.

<sup>3</sup>The European Union has approved the Kyoto Protocol on 31 May 2002 and most of its member countries have ratified it on the same day. See <http://unfccc.int/resource/kpstats.pdf>.

<sup>4</sup>Especially if the Kyoto CO<sub>2</sub> reduction targets cannot be met by voluntary action and programmes in the industrial sector.

<sup>5</sup>See ENDS Environment daily 05.06.2002 for the recent development in the EU energy tax plans ([www.environmentdaily.com](http://www.environmentdaily.com)).

## 2. The political economy of green taxation

Economists have long advocated public policy intervention for environmental protection. To many of them taxes and charges are the most effective instruments to achieve a given environmental target. The rationale for the use of taxes in environmental policy is provided by the growing bulk of environmental externalities: impacts on the environment which are side effects of consumption and production processes and which do not enter the calculations of those responsible for these processes. When these effects are negative, externalities are costs that can be partially or wholly internalised by levying a

<sup>6</sup>Welfare, in this context, is measured as the cost or expenditure necessary to reach a given standard of living.

<sup>7</sup>The price elasticity of demand is the percentage change in the demand for a fuel following a 1% change in its price.

tax on the activity, giving rise to the effect (Ekins, 1999, p. 41). The transport and energy sector, in particular, have been offering increasing evidence, over the last decades, of such negative externalities in terms of their impacts on the climate, health and, more generally, on the ecosystem, caused by the greenhouse gases released by fuels.

Emissions taxes, among others, are claimed to be market based instruments of environmental policy, because when the authority has set the appropriate tax rate, emissions intensive goods will have higher market prices (Baranzini et al., 2000, p. 396). The market will thus spontaneously work to reduce emissions. These market based instruments possess the important property of being cost-effective: the total cost of reducing emissions to achieve a specific environmental objective is minimised, because each polluter is free to choose the most efficient way to comply with this policy measure.

Carbon taxes, or other emissions taxes, are usually introduced as part of a package of policy measures aimed at reducing emissions and are usually part of a more general fiscal reform, because they replace other taxes and try to reduce the distortionary impacts of traditional taxes on labour, for instance. Moreover they are usually gradually phased in to avoid inflationary effects, and exemptions are granted to energy intensive industries or to disadvantaged sectors of the economy.

When designing environmental taxation policy makers have traditionally focused on the likely efficiency effects of the environmental tax that is on a comparison between costs and benefits. The gross costs are given by the abatement expenditures and price distortions between goods generated by the tax. The benefits are given by the possibility of gaining two potential dividends (benefits) that increase the appeal of taxes in comparison with other policy measures: improvements in environmental quality and a reduction in other existing distortionary taxes that may have a positive impact on economic growth, employment or technological development. The first of these dividends is not controversial, but it is very difficult to calculate, whereas the relevance and magnitude of the second is still open to debate and has given rise to a large literature referred to as the “double dividend hypothesis” (Bosello et al., 2001; Goulder, 1995; Pezzey and Park, 1998).

The possibility of gaining a double dividend is linked to the redistribution of the fiscal revenues generated by the tax to the population or to the economy (revenue recycling). One particular way of recycling implies revenue neutrality: the tax revenues are used to decrease other taxes so that the government budgetary position remains unchanged and the overall tax burden remains the same. The Italian green fiscal reform was introduced in a revenue neutral context.

A bit more specifically, swaps of environmental taxes for distortionary taxes could produce a first dividend by

discouraging environmentally damaging activities and a second dividend by reducing the distortionary cost of the tax system (Goulder, 1995, p. 158). The literature on the double dividend hypothesis that has been developed since the beginning of the 1990s can be divided into two groups of contributions (see Bosello et al. (2001) for details): the first one focuses on the welfare effects of environmental taxation, i.e. on the impact, over some kind of welfare measure, of distortions of the tax system before and after the fiscal reform. The emphasis is thus on individual welfare rather than on the specific ways in which fiscal revenues are recycled and their consequences for the economy. The second group of contributions focuses, instead, on the impact that recycled fiscal revenues can have on macroeconomic variables, for instance employment. This work falls into the first group of contributions.

The relevant literature draws a distinction between a weak double dividend and a strong double dividend (Goulder, 1995). There is a weak double dividend when the gross cost of the environmental tax reform combined with lump-sum transfers of the revenues is greater than the gross cost of the environmental tax reform accompanied by cuts in distortionary taxation. To make the environmental fiscal reform convenient on efficiency grounds in presence of a weak double dividend one should know the dimension of the Environmental Benefit produced. One gains a strong double dividend, instead, when the second dividend is even larger than the gross costs, so that the environmental fiscal reform implies a net efficiency gain. In this case the exact knowledge of the Environmental Benefit produced is unnecessary in order to justify the environmental tax. However the literature shows that the strong double dividend can occur only under strict and rather unlikely assumptions about the functioning of the economy, therefore the double dividend notion should be the relevant one to policy makers.

Even when carbon taxes are appealing on pure efficiency grounds, their consequences in terms of competitiveness and distributive impacts may be fundamental factors determining their political acceptability and, therefore, their actual implementation.

A carbon tax is reflected in the firms’ cost structure and it is thus one factor affecting competitiveness. Given that not all firms may react in similar ways a carbon tax may produce competitive losses or disadvantages depending on the specific circumstances.

The distributional implications of carbon taxes are also a major issue in determining their political acceptability. Although the distributive impact can be measured in a number of ways, the majority of the existing studies focus on measures across different income groups. Intuitively one expects carbon taxes to be regressive, i.e. to burden the poor proportionately more, because low income households spend a larger

Table 1  
Country studies on the distributive impact, on households, of green taxation

Country study	Type of energy taxation	Dimension of the distributive impact	Distributive effect
Sweden (Bränlund and Nordström, 1999)	CO <sub>2</sub> tax levied on all fossil fuels	Income groups; number of children per household;	Regressive in case of no tax replacement; not so in a revenue neutral context
UK (Smith, 2000 <sup>a</sup> )	Road fuels tax	Income groups; regions	Not regressive when all households are considered; Regressive if only car-owning households are considered
Spain (Labandeira and Labeaga, 1999)	Carbon tax on all fossil fuels	Expenditure groups; different demographic profiles	Not regressive
Australia (Cornwell and Creedy, 1996)	Carbon tax on fossil fuels used in production and consumption	Income groups	Regressive when no technological substitution is allowed; less so when technological substitution is allowed
UK (Symons et al., 1994)	Carbon tax on fuels	Expenditure groups	Regressive in case of no tax replacement; less so in a revenue neutral context
5 European countries (Symons et al., 2000)	Energy/carbon taxes	Income groups	Regressive in Germany, France and Spain; progressive in the UK; neutral in Italy
EU-11 (Barker and Köhler, 1998)	Excise duties on energy products	Expenditure groups	Weakly regressive in most countries when domestic energy is included. Weakly progressive when only road fuels are taxed on their own.

<sup>a</sup> Results from the Smith paper are derived from the IFS Commentary no. 65: Blow, L. and Crawford, I. (1997). The distributional effects of Taxes on private monitoring.

fraction of their available income on energy than high income households do. The existing empirical studies suggest that carbon taxes may be mildly regressive, but this often depends on the modelling framework used. Moreover this regressive effect is much attenuated, or even reversed, in a revenue-neutral context. Symons et al. (2000), for instance, found that while energy or CO<sub>2</sub> taxation is regressive in Germany, France and slightly in Spain, it is progressive in the UK (except for the highest income group) and neutral in Italy. Moreover, interesting results are obtained when energy products are distinguished between domestic energy and transport fuels (Baranzini et al., 2000, p. 405). Barker and Köhler (1998) found that while taxation of transport fuels is weakly progressive, taxation of domestic energy has a weakly regressive impact. Table 1 tries to summarise the results of some empirical studies on the distributive impact of carbon-energy taxes.

Finally, the effectiveness of a carbon tax should also be evaluated in terms of its environmental impact, i.e. in terms of the reduction of carbon dioxide emissions it can achieve. This may depend to a large extent on the sensitiveness of energy demand to price changes. Thus if energy demand is relatively insensitive to price changes, i.e. it is inelastic, emissions will not decrease sufficiently to obtain a given abatement objective. The responsiveness of the quantity demanded of an energy product to the market price can be calculated through the price elasticity of demand obtained by dividing the percentage change in the quantity demanded by the corresponding percentage change in its price.

The aim of this paper is to provide a country specific analysis of the consequences of the use of green taxes in order to add empirical evidence to some of the theoretical issues raised in this section. The focus is on a specific country, Italy, and on one of the subjects involved in the green fiscal reform, households. More specifically, three of the issues raised above will be covered. First, we will look at the welfare costs or benefits, in terms of real expenditure, to different households, of the Italian Carbon tax. Second, we will calculate the distributional impact of the tax on households with different income levels. Third, the price elasticity of demand for domestic fuels and for transport fuels is calculated as a first approximation of the environmental impact of the tax.

### 3. Carbon taxation in Italy

With the approval of the Financial Law for 1999, a carbon tax on the consumption of energy products and related compensation measures has been introduced in Italy (L. 23.12.1998 n. 448, art. 8). The new green tax is based on two main components (OECD, 2000, pp. 23–24): a reduction in CO<sub>2</sub> emissions through a re-modulation of excise duties<sup>8</sup> on mineral oils to be

<sup>8</sup> As Barker and Köhler (1998) have pointed out (p. 386) there is a main difference between a carbon/energy tax and excise duties. The Carbon tax is included in the basic prices of the energy industries. Excise duties on the other hand are to be paid further down the chain

achieved with a smooth transition from 1999 to 2005; the introduction of a consumption tax on coal and natural bitumen used in the combustion plants as defined by the EU Directive 88/609/1998. The following products are involved: leaded and unleaded petrol; Diesel oil (used for both heating and for transports); natural gas (used for both heating and transports); heavy fuel oils; Liquefied Petroleum Gas (LPG). This is in line with the national actions defined in 1998 (CIPE<sup>9</sup> resolution of 19.11.1998) to reduce CO<sub>2</sub> emissions in order to comply with the obligations of the Kyoto Protocol.

To modify the structure of excise duties, the target vector of the above energy products tax rates has been identified.<sup>10</sup> This is aimed at satisfying both the necessity to tax each fossil fuel according to its specific CO<sub>2</sub> emissions and the requirements of the EU Directive (COM/97/30) on the harmonisation process of excise rates on energy products, according to which minimum excise rates are fixed at the European level based on the product and the sector of utilisation. Indicating with  $\alpha_i$  is the excise duty on product  $i$ , the new energy excise rates in Italy are structured as follows:  $\alpha_i = k\beta_m + A_i$ , where  $k$  is the ratio between the Italian excise duty on product  $i$  prior to the introduction of the new tax and the minimum excise rate level proposed by the European Directive<sup>11</sup> COM/97/30;  $\beta_m$  is the minimum excise level proposed by the above mentioned European Directive and  $A_i$  is the environmental component of the tax, proportional to the kgs of CO<sub>2</sub> emitted by the fossil fuel  $i$  under consideration. This term is equal to 10 Lire per kg of CO<sub>2</sub> released in the combustion of 1 kg of fuel up to 2.75 kg of CO<sub>2</sub>. For emissions level in the range 2.75–4 kg of CO<sub>2</sub> per kg of fuel a linear increase of 400 Lire for each additional kg of emissions is assumed.<sup>12</sup> This procedure has allowed setting out the excise rates for mineral oils to be applied on 1 January 2005. According to the Law, during the years from 1999 to 2004 the rates are supposed to be raised smoothly within a range not lower than 10% and not higher than 30% per year of the difference between excise rates prior to the green reform and target level excise rates. In addition to that, a

consumption tax of 1000 Lire per ton has been introduced for coal and natural bitumen used in the combustion plants as defined by the EU Directive 88/609. Table 2 shows price increases in the consumption of the taxed products to be achieved by the end of 2004.

The proposed taxation scheme hits transport fuels the most, although Italy is already one of the OECD countries where transport fuels are most heavily taxed. Households' costs are increased not only by the higher price of heating fuels, but, also, by the indirect effect on households of the higher costs of electricity production. The law provides a lower tax rate on natural gas for households living in disadvantaged areas of the country. The heaviest tax burden is on Coal used for electricity production, which should cause a reduction in the use of this fuel in thermoelectric energy production, although this kind of energy generation exhibits the lowest unit cost of production. More generally, the proposed scheme seems to provide incentives to promote substitution of natural gas for fossil fuels in the domestic and energy sector and a substitution of unleaded petrol for other fuels in the transport sector.

As said before, the green tax reform has been introduced in a revenue-neutral context. The explicit goal of the reform is to exploit a double-dividend: to promote environmental improvement and, at the same time, to reduce the tax wedge on labour costs. In the 6 years of the reform revenues of 6987.66 Million/Euro are projected,<sup>13</sup> coupled with a 12 million tons reduction of CO<sub>2</sub>, representing about 12% of the target reduction (to be achieved by 2010) in CO<sub>2</sub> emissions for Italy set out in the Kyoto Protocol. The revenue for the first year (1999) of the reform's implementation has been 1125.88 Million/Euro. The largest share (60.5%) of this revenue, 681.21 Million/Euro, was used for cutting social security contributions, thus reducing the tax wedge on labour costs by 0.82%.<sup>14</sup> 31.1% of it, 352.74 Million/Euro, was targeted on compensation measures including a tax credit for lorry hauliers, a reduction in the Diesel-oil duty and a reduction in taxation of heating fuels for the poorest and coldest areas of the country. Finally, 8.4% of the revenue, 154.94 Million/Euro, was devoted to

(footnote continued)

of productivity. In this case the basic prices of the energy industries are largely unaffected except in as much as their labour costs and own use of electricity and fuels are taxed.

<sup>9</sup>Comitato Interministeriale per la Programmazione Economica.

<sup>10</sup>To be achieved on 1 January 2005.

<sup>11</sup>The  $k$  coefficient is calculated for each sector by referring to the most used product in that sector: petrol for transports, methane for the civil and industrial sector, for instance.

<sup>12</sup>Such structure is also applied to energy products used in the industrial sector, but the rates are reduced when applied to the production of electric power since in Italy electricity is already taxed as output. In this area the tax rate is calculated by applying the component proportional to the environmental impact only with a very limited increased coefficient.

<sup>13</sup>This is the projected revenue published in the report issued by the technical committee in charge of illustrating the new fiscal measure to the Council of Ministers. See, also, Rapporto CER/Centro Europa Ricerche n. 1/1999, pp. 28–30. Roma, Vetro Editore. The expected revenue for 1999 was 1125.87 Million/Euro and 1172.36 Million/Euro for the following 5 years, assuming consumption levels and composition unchanged with respect to 1999 levels.

Euros instead of Lire will be used henceforth. The exchange rate Lire/Euro is 1936.27 Lire for 1 Euro.

<sup>14</sup>This has been achieved through removal of some social security contribution, through halving the social contributions due by young entrepreneurs in the handcraft and commercial sector and through transfer on the account of the state budget (*fiscalizzazione*) for 3 years of the social contributions due by firms for the labour force recruited in the Southern regions by the end of 2001.

Table 2  
Price changes due to the carbon tax

	Unit of measurement	Excise level in 1998	Price levels in 1998	Excise levels in 2005	Price levels in 2005	% Price variation
<i>Transport fuels</i>						
Unleaded petrol	Lire/l	1022.28	1846	1150.25	1974	7
Diesel oil (transports)	Lire/l	747.47	1355	905.86	1513	12
LPG (transports)	Lire/kg	597.64	866	400	668	–23
Natural gas (transports)	Lire/m <sup>3</sup>	0	650	200	850	31
<i>Domestic fuels</i>						
Diesel oil (domestic)	Lire/l	747.47	1336	905.86	1494	12
LPG (domestic)	Lire/kg	325.4	600	400	675	12
Natural gas (domestic)	Lire/m <sup>3</sup>	332	1002	349	1019	2
Heavy fuel oil (domestic)	Lire/kg	45	725	423.05	1103	52
<i>Industrial use and energy production</i>						
Natural gas (industrial use)	Lire/m <sup>3</sup>	20	295	40	315	7
Natural gas (electricity production)	Lire/m <sup>3</sup>	0	200	8.5	209	4
Coal (electricity production)	Lire/kg	0	99	41.84	141	42
Heavy fuel oil (energy production)	Lire/kg	28.4	190	41.26	203	7

Source: Tabarelli and Bianchi (1998).

interventions improving environmental efficiency of energy use. The difference between the expected Carbon tax revenue and the above expenditures (about 67.14 Million/Euro) was covered through the increase in the excise on unleaded petrol already decided in 1996 and confirmed in the Financial Law for 1999.

The Carbon tax was formally adopted on 15 January 1999. In 1999 the increase in the excise rates has been equal to 20% of the total increase to be applied as of 1 January 2005. Eleven months after entering into force, in November 1999, the tax progression was suspended due to fears that on top of the surge in world oil prices, the ecotax would impose unacceptable inflationary pressures (ENDS, 2000a). At the same time, a government decree let the retail prices of petrol and diesel fell by an average of 30 Lire per litre thus compensating for the Carbon tax. The tax was re-applied in June 2000 at levels slowly higher than those in force in 1999. During 2001 and 2002 the tax levels were maintained at the 2000 levels. The Government in 2001 has extended the tax rebates already allowed for petrol and diesel fuels to natural gas and diesel used for domestic heating (ENDS, 2000b). At the same time, pressures have been growing to abolish it, especially from government representatives (Tax News Update, 2002) and the industrial associations (ENDS, 2002). A committee of Italian MPs has also recommended its abolition in a review of national energy policy issued in April 2002. Meanwhile Italy has ratified, together with the other members of the EU, the Kyoto Protocol on the 31st of May 2002 even though its greenhouse gases emissions have risen by 5.6% from 1990 to 2001 and carbon dioxide emissions from the transport sector alone have increased by 22.8% since 1990 levels (ENDS, 2002).

#### 4. True-cost-of-living indices and the compensating variation

Our aim is to assess the welfare effects of price increases determined by the introduction of the Carbon tax on different households and also to assess its distributive effects, i.e. how households at different levels of income and with different demographic profiles are affected. In order to do that we calculate, first, True-Cost-of-Living (TCOL) index numbers and then the Compensating Variation. A TCOL index number compares the cost of achieving a given level of welfare before a price increase with the cost of achieving the same level of economic welfare after the price increase and measures how much extra income is needed to get back to the original welfare level (Deaton and Muellbauer, 1980a, p. 170). If  $u^0$  is the base level of welfare, the corresponding true index of the cost of living is given by:

$$P(p^1, p^0, u^0) = \frac{c(u^0, p^1)}{c(u^0, p^0)} = \text{TCOL}, \quad (1)$$

where  $c(u^0, p^1)$  is the minimum cost of reaching utility  $u^0$  at the price vector  $p^1$ , whereas  $c(u^0, p^0)$  is the minimum cost of reaching  $u^0$  at prices  $p^0$ . TCOLs represent a more precise measure of the welfare change caused by a change in prices than the Laspeyres index number, because they allow for substitution possibilities in the bundle of goods consumed holding utility constant, whereas the Laspeyres index number measures the change in the cost of living assuming that the same bundle of goods will be bought before and after the price change. The money metric measure of a welfare change corresponding to TCOLs is the Compensating Variation

Table 3  
AID parameters—three stages least-squares estimation (1985–1996)<sup>a</sup>

	ALIM (food and beverages)	PASTI (outdoors meals and drinks)	GAS (domestic fuels)	BENZI (transport fuels)	SETRA (public transports and services)	RESTO (all other expenditures)
$C_{1j}$	0.10221 (0.01782)	-0.14329 (0.01056)	-0.05358 (0.00766)	0.03120 (0.00840)	0.00012 (0.00238)	0.06334 (0.02373)
$C_{2j}$		-0.08206 (0.01514)	-0.00358 (0.00609)	0.03164 (0.00684)	-0.00024 (0.00273)	0.19755 (0.02019)
$C_{3j}$			-0.00157 (0.00511)	0.02660 (0.00380)	0.00269 (0.00144)	0.02944 (0.00879)
$C_{4j}$				-0.02545 (0.00492)	-0.00222 (0.00106)	-0.06175 (0.01133)
$C_{5j}$					0.00707 (0.00020)	-0.00741 (0.00524)
$C_{6j}$						-0.22117 (0.00524)
$B_I$	-0.16258 (0.00843)	0.03549 (0.00736)	0.02599 (0.00520)	-0.01040 (0.00432)	-0.00233 (0.00135)	0.11383 (0.00945)
Number of observations =	720					
$R^2$	0.894	0.859	0.704	0.496	0.296	
DW	1.554	1.796	1.690	1.800	2.012	

<sup>a</sup>Standard errors in parenthesis. The  $c_{ij}$  parameters have been obtained as:  $c_{ij} = -(t'_{ij} - \alpha_i \alpha_j + \alpha_i \delta_{ij})$  and standard errors have been computed using the Delta Method implemented through the ANALYZ command of TSP 4.4.

(CV) defined as the minimum amount by which a consumer would have to be compensated after a price change in order to be as well off as before (Deaton and Muellbauer, 1980a, p. 186). In this case, instead of having ratios as with the TCOL index number, we have sums of money expressed as the difference in costs of reaching the same utility level at two different price vectors. As it is well known, the CV is the area between the compensated or Hicksian demand curve and the price before and after the change. Hicksian demands are the derivatives of the cost function, therefore integration gives the difference in costs of reaching the same indifference curve at two different price vectors (Deaton and Muellbauer, 1980a, p. 186). Since the compensated or Hicksian demand curve shows the relationship between the price and quantity demanded at constant levels of utility, CV is a precise measure of the change in welfare following a price change. If we define CV as:  $CV = c(u^0, \mathbf{p}^1) - c(u^0, \mathbf{p}^0)$ , this can be easily obtained from a TCOL as:

$$c(u^0, \mathbf{p}^0)[\text{TCOL} - 1] = c(u^0, \mathbf{p}^1) - c(u^0, \mathbf{p}^0) = CV. \quad (2)$$

To calculate the TCOL in (1) we need to know the parameters of the cost function  $c(u, \mathbf{p})$ , which can be obtained through estimation of a complete system of demand equations. This has been specified as an Almost Ideal Demand System (AIDS) (Deaton and Muellbauer, 1980b). Details on the specification and estimation of the demand system and on the data used can be found in the appendix. The values of the AID system's parameters to be used later for calculation of the TCOLs are shown in Table 3 together with their standard errors, the coefficient of multiple determination and the Durbin Watson statistic.

## 5. TCOLs calculation

The estimated parameters of the demand system have been used to produce TCOLs (see Eq. (A.5)). These have been calculated from January 1985 (1) till December 2000 (12). For each of the five households' profiles considered (see Appendix A for details), TCOLs have been calculated for five different welfare levels  $\ln y$ .<sup>15</sup> These have been chosen as follows. Indicating with  $\ln \bar{y}$  the mean of the monthly 1995 total expenditure of each family type ( $h = N1, \dots, N5$ ) and with  $\ln y_n$  ( $n = 1, \dots, 5$ ), the chosen level of welfare, for each of the five households' profiles of our sample we have chosen the following values of the expenditure distribution:

$$\begin{aligned} \ln y_1^h &= \ln(0.25\bar{y}); & \ln y_2^h &= \ln(0.75\bar{y}); \\ \ln y_3^h &= \ln \bar{y}; & \ln y_4^h &= \ln(1.25\bar{y}); \\ \ln y_5^h &= \ln(2.75\bar{y}) \end{aligned}$$

indicating very low to very high welfare levels. These reflect the real expenditure distribution in the sample used. This specification of different welfare levels for each type of households will be used to assess the distributive effects of this fiscal reform.

In order to simulate the increase in prices due to the introduction of the Carbon tax we have build up two different price indices for the two aggregates under consideration: transport fuels (BENZI) and domestic fuels (GAS). Only the prices of leaded and unleaded petrol, heating oils and natural gas have been modified, in the transport fuels aggregate, to keep track of the tax, although the Law specifies increases in the prices of

<sup>15</sup>At the normalisation point, the welfare level  $u$  is equal to the logarithm of total expenditure  $y$ .

additional products which have not been taken into account here due to lack of data. In the baseline simulation, the prices for the taxed products, supplied by Unione Petrolifera (the Italian Oil Firms Union), have been modified to phase out the Carbon tax and obtain the baseline price time series. The consumption price is given by:  $p_{it} = (ip_{it} + \alpha_{it})(1 + \gamma)$  where  $p_{it}$  is the industrial price of product  $i$  in month  $t$ ;  $\alpha_{it}$  is the excise duty on product  $i$  at time  $t$  and  $\gamma$  is the value added tax (VAT) rate calculated as a fixed percentage of the sum of the other two components of the price structure.<sup>16</sup> We have thus obtained the baseline monthly time series of prices to be used in the simulations, which have been normalised with respect to the mean 1995 price. A second time series has been obtained as follows. We have simulated the introduction of the Carbon tax for 4 years, choosing as the starting month January 1997 (although we use the tax system valid from January 1999, as provided by the Law) and have carried out the simulation till December 2000, because for this period data on prices were available. The monthly prices have been increased linearly, by 20% per year of the total rise to be achieved at the end of the fourth year, as indicated by the Law. We have thus obtained two time series of monthly prices for each taxed product, normalised with respect to the mean 1995 price. These are the same up until December 1996 and start diverging from January 1997.<sup>17</sup> Since we have squeezed the price increases to four rather than 6 years (as provided by the Law), the simulation is likely to produce welfare changes that might be higher than what would result from a linear price increase over 6 years.

### 5.1. The compensating variation (welfare effects)

After having obtained TCOLs for the two different scenarios:  $a$  and  $b$  ( $a$ =no Carbon tax scenario;  $b$ =Carbon tax scenario), we have calculated monthly CV for each type of household and each welfare level, from 1997 (1) till 2000 (12) as defined in (2). CV is a money metric measure of welfare and can be defined as the level of income necessary to compensate the consumer for a price change in order to be as well off as he was before the change in price. The difference in the CV calculated for the two scenarios  $a$  and  $b$  thus indicates the amount of income that, after the introduction of Carbon taxation (scenario  $b$ ), would allow

households to enjoy the same level of welfare they would have had without the fiscal reform (scenario  $a$ ). This is given by:

$$CV_{n,b}^{h,t} - CV_{n,a}^{h,t} = (TCOL_{n,b}^{h,t} - TCOL_{n,a}^{h,t})y_n^{h,t},$$

where  $CV_{n,b}^{h,t}$  is the CV of household  $h$ , at time  $t$ , at the welfare level  $n$ , calculated according to scenario  $b$ ;  $CV_{n,a}^{h,t}$  is the CV of the household  $h$ , at time  $t$ , at the welfare level  $n$ , calculated according to scenario  $a$  and  $y_n^{h,t}$  is the welfare level  $n$  of household  $h$  at month  $t$ . So we get 25 different welfare changes per month: one for each household type,  $h$ , and welfare level,  $n$ .

In order to have an aggregate measure of the welfare change, the number of households in each household and expenditure class has been multiplied by a coefficient (also published by ISTAT) that allows to convert the sample used into the existing population, i.e. into the real number of households of that type and of households in that class of expenditure living in Italy in 1995. Table 4 shows the annual aggregate welfare losses (expressed in Million/Euro '95) calculated for each of the 4 years of the simulation (1997–2000) for each household profile and welfare level. For the poorest group of families, the annual welfare loss goes from 0.52 Million/Euro '95 in 1997 to 5.27 Million/Euro '95 in 2000, at the target level of taxation; whereas for the richest group the annual loss amounts to about 21 Million/Euro '95 in 1997 and to 213.55 Million/Euro '95 in 2000. The large drop one can observe in the welfare loss for the 5 AD and  $\ln y_5$  in Table 4 is due to the fact that the 5th household type was the less represented among those considered in this work. Data shown in Table 4 can be used to make a tentative comparison between the expected cumulated revenue from the Green Reform, i.e. about 6987.66 Million/Euro as explained in Section 3, and the cumulated loss of the 5 household types under consideration up to the year 2000, whereas Table 5 can be used to assess the distributive impact. In Table 4, summing over household types and years, we get 2320.44 Million/Euro '95 amounting to, roughly, 33.3% of the expected cumulated revenue from the Carbon tax. The aggregate welfare loss seems to be significant and to amount to a considerable portion of the expected cumulated revenue from the reform. However comparisons of the estimated welfare loss with the projected cumulative revenue from the Carbon tax must be taken with care, because only 5 household's profiles are accounted for in our simulations, although they are the most representative ones. Moreover, the projected cumulative revenue of 6987.66 Million/Euro is calculated assuming constant consumption levels over the 6 years of implementation, which probably causes the expected revenue from increased taxation to be rather large. The last five rows in Table 4 show the annual aggregate welfare loss per welfare level and the last column in the table indicates the share of the

<sup>16</sup>Oil price rises in the year 2000 have boosted the associated VAT revenues and the Italian government has used this additional revenue to cut the excise on oil products between 30 and 50 Lire per litre (OECD, 2000, p. 24).

<sup>17</sup>In other words, given the baseline time series of prices, the price rises due to the Carbon tax have been implemented starting from January 1997 and until December 2000. We could not simulate the price increases from January 1999 and onwards for 6 years, because monthly prices were available only up until December 2000.

Table 4  
Aggregate welfare losses per year (Million/Euro 1995)

	Years				Sum over the 4 years and percentage values	
	1997	1998	1999	2000		
<i>Household type</i>						
1 AD	29.39	59.86	91.21	122.97	303.42	13.1
2 AD	55.11	112.12	170.64	229.77	567.64	24.5
3 AD	66.67	135.72	206.38	277.80	686.58	29.6
4 AD	55.11	112.17	170.27	229.00	566.60	24.4
5 AD	19.11	38.89	58.93	79.33	196.20	8.5
Sum over all household types	225.43	458.77	697.42	938.82	2320.44	100.0
<i>Welfare levels</i>						
ln $y_1$	0.52	1.03	1.60	2.12	5.27	0.2
ln $y_2$	38.89	78.86	119.04	160.51	397.26	17.1
ln $y_3$	72.82	148.07	224.86	302.70	748.45	32.3
ln $y_4$	92.60	188.71	287.56	386.93	955.86	41.2
ln $y_5$	20.61	42.04	64.35	86.56	213.55	9.2

Table 5  
Monthly welfare loss (year 2000) as a percentage of mean 1995 expenditure per household profile and welfare levels

Household type	Welfare levels				
	ln $y_1$	ln $y_2$	ln $y_3$	ln $y_4$	ln $y_5$
1 AD	0.44	0.57	0.67	0.75	0.85
2 AD	0.47	0.59	0.68	0.76	0.85
3 AD	0.43	0.54	0.63	0.70	0.79
4 AD	0.41	0.51	0.59	0.65	0.73
5 AD	0.40	0.50	0.58	0.64	0.72

cumulated loss for each household profile and welfare level over the total welfare loss. As we have already pointed out, the large drop we can observe for the ln  $y_5$  profile is likely to be due to the number of the families with that profile living in Italy in 1995.

### 5.2. The distributive impact

Since we are also interested in evaluating the distributive effects of Carbon taxation we have calculated, in Table 5, the mean monthly welfare loss in the year 2000 (at the target rate of Carbon taxation) per household type and welfare level as a percentage of the mean monthly 1995 expenditure level. Contrary to what has been found in other similar studies, the tax burden is progressively distributed across households at different welfare levels. Thus, the presumed regressivity of Carbon taxation is not sustained here. This might be due to the fact that the reform has mainly hit transport fuels, whereas heating fuels' prices have increased relatively less. As Smith (2000) has pointed out, this effect might also be due to households in the lowest expenditure levels not owning a car. Indeed, in the

British study, when only car-owning households are taken into consideration, the distributive effect is reversed. Fig. 1 shows the progressivity of Carbon taxation in Italy more clearly. Moreover, it can also be observed from Fig. 1 and Table 5, that the tax burden seems to affect mainly households with one and two adults and decreases for larger families. This could be explained by the fact that the tax burden due to car ownership, for instance, is more distributed as the number of household members' increases, because the number of car owned does not increase linearly with the number of households' member.

### 5.3. Effectiveness of the carbon tax

Behavioural responses to the fiscal reform can be evaluated ex ante, by looking at the price elasticities of demand for transport and domestic fuels. They tell us the percentage reduction in the demand of the taxed goods following a 1% increase in their price. Elasticities can be thought of as a preliminary measure of the environmental effectiveness of the fiscal reform, because they indicate the capacity of the environmental tax to achieve the goal of reducing emissions of the pollutive substances. From the demand system in (10) we can easily calculate the matrix of Marshallian (non-compensated) price elasticities of demand and the vector of income elasticities as:

Marshallian elasticities :

$$e_{ij} = \frac{c_{ij}}{w_i} - b_i \frac{w_j}{w_i} + \frac{b_i}{w_i} b_j \ln \left( \frac{y}{P^*} \right) - \delta_{ij}$$

with  $\delta_{ij} = 1$  for  $i = j$  and  $\delta_{ij} = 0$  for  $i \neq j$ .

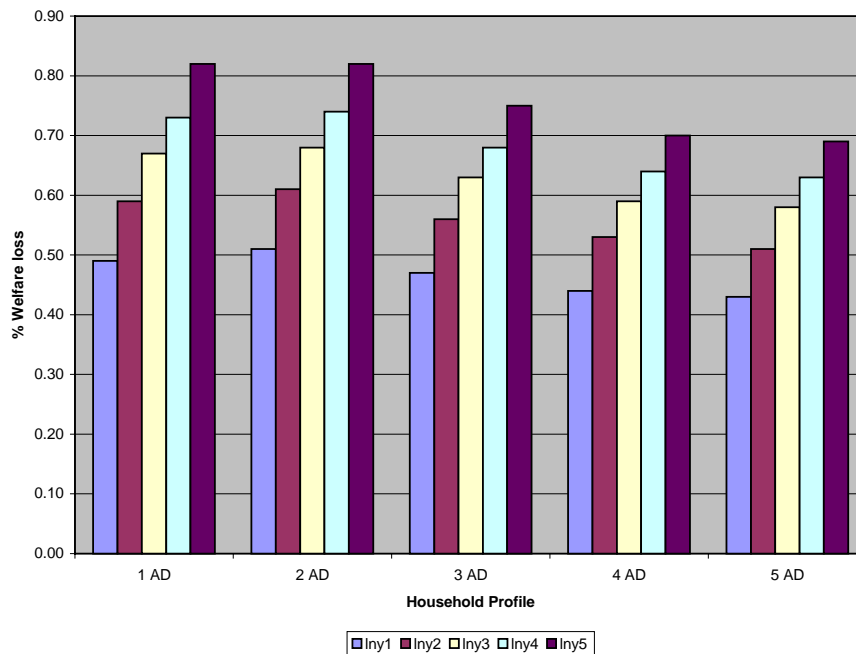


Fig. 1. Monthly welfare loss (year 2000) as % of mean monthly 1995 expenditure.

Income elasticities :

$$e_i = \frac{b_i}{w_i} + 1.$$

These are shown in Table 6A and B together with the estimated budget shares. Elasticities have been calculated at the sample mean (over 720 observations) and standard errors are computed using the Delta Method<sup>18</sup> implemented through the ANALYZ command of TSP4.4.

The direct price elasticities show that the demand for domestic fuels (GAS) and transport fuels (BENZI) turns out to be significantly elastic:  $-1.057$  and  $-1.282$ , thus signalling that the Carbon tax can be effective in reducing carbon emissions. The demand for transport fuels is even more elastic than that of domestic fuels. This result suggests that Carbon taxation in the transport sector could play a significant role in the future Italian environmental policy, especially after the Kyoto Protocol ratification of 31 May 2002.

The effect of the tax on the consumption pattern can be studied observing the cross price elasticities. The third and fourth rows of Table 6A are the relevant ones. The change in demand of food, outdoors meals, public transports and other goods due to a change in the price of domestic fuels is low ( $-0.135$ ;  $-0.068$ ;  $0.323$ ;  $0.383$ ;  $0.053$ ). The demand for domestic fuels appears to be complementary to transport fuels, although this elasti-

city is also low ( $0.311$ ). The same sort of changes in the consumption pattern is shown when the price of transport fuels changes ( $0.137$ ;  $0.367$ ;  $0.489$ ;  $-0.276$ ;  $-0.160$ ). Thus, whereas the tax might be effective in reducing the consumption of the polluting goods, it does not significantly affect the consumption pattern.

As to the income elasticities of demand, domestic fuels turn out to be a luxury good ( $1.523$ ), whereas the demand for transport fuels increases less than proportionally with respect to the increase in income:  $0.880$ .

## 6. Final considerations

In this paper, we have calculated the welfare loss due to the Carbon/Energy Tax introduced in Italy at the beginning of 1999 by the Centre-Left coalition, which allows for gradual increases in the prices of most fossil fuels over 6 years. The reform hits mainly transport fuels and heating fuels, through increases in the excise rates of these products to be achieved with a smooth transition from 1999 to 2005. Heating fuels are taxed relatively less and, in addition, the generated revenues are partly recycled by compensating households living in climatically disadvantaged regions for the increased burden of taxation.

Only gross welfare costs to households are calculated assuming no revenue recycling. This is equivalent to the Fiscal Revenues from the reform being discarded, but helps identifying the crude distributional impact of the tax.

<sup>18</sup>The method linearises non-linear functions around the estimated parameter values and calculates standard errors of the estimated parameters.

Table 6

*(A) Marshallian elasticities at the sample mean*

	ALIM	PASTI	GAS	BENZI	SETRA	RESTO
ALIM	−0.528 (0.054)	−1.995 (0.140)	−1.252 (0.158)	0.398 (0.099)	0.122 (0.328)	0.057 (0.054)
PASTI	−0.395 (0.032)	−2.091 (0.195)	−0.112 (0.124)	0.373 (0.078)	−0.009 (0.374)	0.421 (0.045)
GAS	−0.137 (0.023)	−0.068 (0.077)	−1.057 (0.101)	0.311 (0.043)	0.383 (0.196)	0.053 (0.019)
BENZI	0.137 (0.024)	0.367 (0.086)	0.489 (0.075)	−1.282 (0.055)	−0.276 (0.141)	−0.160 (0.024)
SETRA	0.003 (0.007)	−0.006 (0.035)	0.050 (0.029)	−0.024 (0.012)	−0.031 (0.027)	−0.018 (0.011)
RESTO	0.411 (0.073)	2.338 (0.266)	0.358 (0.188)	−0.656 (0.134)	−0.869 (0.729)	−1.608 (0.079)

*(B) Income elasticities (IE) and budget shares (BS) at the sample mean*

	IE	BS
ALIM	0.508 (0.025)	0.330
PASTI	1.456 (0.095)	0.078
GAS	1.523 (0.104)	0.050
BENZI	0.880 (0.049)	0.087
SETRA	0.680 (0.184)	0.007
RESTO	1.254 (0.021)	0.447

Standard errors in parentheses.

The welfare effects have been calculated using the Compensating Variation obtained by True Cost of Living index numbers. True Cost of Living Indices measure how much extra income is needed to get back to the original welfare level. The advantage of using True Cost of Living Indices rather than other price indices is that behavioural responses to a price change (i.e. substitutions in the bundle of goods chosen by the household as a consequence of a change in the price of one of the goods) are incorporated, so that the measure of welfare change is more precise. As West and Williams point out in their welfare calculations for the United States (West and Williams, 2002, p. 19): “Omitting demand responses may lead one to substantially overstate the welfare cost of the gas tax. Omitting demand responses also makes the gas tax appear more regressive. Own price gas demand elasticities are relatively similar across most of the income distribution, but gas demand for the top quintile is substantially less elastic. Thus the relative burden of the top quintile is larger under measures that include demand responses making the tax more progressive.”

When information on the expenditure function of households is available (i.e. when data are available on total expenditures, prices and expenditures on the goods among which the demand system is divided) the calculation of exact measures of welfare change, such as the Compensating Variation, is fairly easy and gives more reliable information on the welfare changes and on the distribution of the burden of a price change. The parameters of the True Cost of Living Indices have been obtained through estimation of a complete system of demand using micro-data supplied by the Italian National Statistical Institute from 1985 to 1996.

All the welfare changes are positive, thus representing losses to households rather than gains, as consequences of the reform. One may also observe that the tax burden

seems to affect mainly households with one or two adults and decreases for larger families. This could be explained by the fact that the tax burden due to cars' widespread use, for instance, is more distributed as the number of households increases, because the number of cars owned and used does not increase linearly with the number of households' members. From Table 4 we can see that the aggregate welfare loss (cumulated over the years and taking into account the number of households of each type living in Italy in 1995) is quite substantial and affects Italian households in a non-negligible way. The expected welfare loss to households could be compared to the expected fiscal revenues that could be used, ex post, to compensate households for the increased burden of taxation. However, comparisons with the expected cumulated fiscal revenues are to be taken with care. On one hand, we only consider five households profiles. On the other hand, the projected cumulated revenue has been calculated, by the policy maker, without taking into account behavioural responses, i.e. assuming constant consumption over the 6 years of implementation. In fact consumption, and thus the fiscal revenues, is likely to be reduced as a consequence of increased taxation.

The other relevant result is that variation of welfare losses across different levels of total expenditures does not allow sustaining the presumed regressivity of Carbon taxation, as the cost of living of households in the lowest income groups is not most adversely affected by the tax increases. In fact the effect becomes bigger as we move up the income distribution: i.e. for each household profile, the welfare loss increases with income. This might be due to the fact that the reform has mainly hit transport fuels. If households at the lowest expenditure levels do not own a car the tax burden might be progressive, as noticed by Smith (2000).

Other studies have produced similar results such as Labandeira and Labeaga (1999) for Spain and Symons et al. (2000), for some European Countries, although the methodological framework adopted is different.

As to the environmental effectiveness of the tax reform, price responses seem to play an important role in the Italian case: the price and income elasticities for transport fuels, calculated at the sample mean, are very high. This could be due to the fact that alternative transportation options, other than private cars, are available. In Italy cars have for a long time been a status symbol rather than a necessary means of transportation. Public means of transportation are widespread and rather efficient and distances are much shorter than, for instance, in the United States where the demand for fuels is more inelastic (West and Williams (2002, p. 7), find that the price elasticity of demand for gasoline is in the range  $-0.5$ ,  $-0.7$  except for the top quintile of the income distribution).

Thus, the way people react to policy changes seems to be crucial and behavioural responses should be taken into account when assessing the effects of increased taxation.

We hope that exercises such as this may help providing useful insights, to the policy makers, into the likely effects of environmental policy measures. One of the factors causing great resistance in developed countries to the introduction of Carbon taxes is their presumed regressivity. However, the Italian Carbon tax does not seem to be regressive. This evidence might encourage the use of Carbon taxes as cost-effective instruments of environmental policy, at least in the transport sector, as a way to comply with the Kyoto protocol obligations.

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## Appendix A

### A.1. The Demand System: specification, data and estimation

The system of demand has been specified as an Almost Ideal Demand System (AIDS) (Deaton and

Muellbauer, 1980b). We start from a logarithmic cost function which implies PIGLOG preferences (Deaton and Muellbauer, 1980a, pp. 154–158), i.e. which allows perfect aggregation over consumers:

$$\ln c(u, \mathbf{p}) = \ln a(\mathbf{p})(1 - u) + u \ln b(\mathbf{p}), \quad (\text{A.1})$$

where  $a(\mathbf{p})$  and  $b(\mathbf{p})$  are functions of prices and  $\ln$  indicates the natural logarithm. By adopting the flexible functional forms approach (A.1) can be approximated through a function that, thanks to its large number of parameters, can be considered as a second-order approximation of the true cost function.

Thus letting:

$$\ln a(\mathbf{p}) = \alpha_0 + \sum_i \alpha_i \ln p_i + \frac{1}{2} \sum_i \sum_j c_{ij}^* \ln p_i \ln p_j, \quad (\text{A.2})$$

$$\ln b(\mathbf{p}) = \ln a(\mathbf{p}) + b_0 \prod_i p_i^{b_i}, \quad (\text{A.3})$$

where  $i = 1, \dots, n$  and  $j = 1, \dots, n$  are the number of goods considered, substituting (A.2) and (A.3) into (A.1) and differentiating with respect to the prices,  $\ln p_i$ , we obtain the Hicksian demand functions as shares and substituting the indirect utility function (obtained by inversion of the cost function) into the Hicksian demand functions we obtain Marshallian demand functions as shares of the form:

$$w_i = \alpha_i + \sum_j c_{ij} \ln p_j + b_i \ln \left( \frac{y}{P} \right), \quad (\text{A.4})$$

where  $y$  is total expenditure, the  $P$  price function is defined as:

$$\ln P = \alpha_0 + \sum_i \alpha_i \ln p_i + \frac{1}{2} \sum_i \sum_j c_{ij} \ln p_i \ln p_j$$

and the parameters  $c_{ij}$  are defined as:  $c_{ij} = 1/2(c_{ij}^* + c_{ji}^*) = c_{ji}$ .

These demand functions satisfy integrability, i.e. are consistent with utility maximization, when the following restrictions on the parameters are satisfied:

$$\sum_i \alpha_i = 1, \\ \sum_i b_i = \sum_i c_{ij} = 0 \quad \text{Adding-up,}$$

$$\sum_j c_{ij} = 0, \quad \text{Homogeneity,}$$

$$c_{ij} = c_{ji} \quad \text{Symmetry.}$$

Economic theory also requires the matrix of the substitution effects to be negative semi-definite. When using the cost function specified in (3) the TCOL in (1) takes, after normalisation of the prices in the base year,

the following form:

$$\ln \text{TCOL} = \ln a(p) + \ln y_0 \left( \prod_i p_i^{b_i} - 1 \right), \quad (\text{A.5})$$

where  $\ln y_0 = u_0$ , the reference level of welfare, at the normalisation point.<sup>19</sup> Thus, different TCOLs can be calculated for different levels of welfare, corresponding to different levels of the total expenditure, to assess the distributive effects of changes in the relative prices, and for different households' types.

## A.2. Data

To estimate the demand model we have used monthly time series of households' data for the period 1985(1)–1996(12) taken from the survey *Indagine sui consumi delle famiglie* carried out by ISTAT. The sample used in this work has been obtained from the *non-hierarchical* file, where ISTAT records the micro-data for each of the 12 years under consideration.<sup>20</sup> This file does not include detailed characteristics of any single member of the household surveyed, but one gets information on several different demographic profiles based on the number of components of the households and their age.

Out of these, we have aggregated data for each of the following five household types (in parentheses the mean monthly number of observations is shown) that are those most numerous in the ISTAT survey:

- N1AD (229) = one adult younger than 65 (years of age);
- N2AD (371) = two adults with reference person younger than 65;
- N3AD (390) = three adults;
- N4AD (286) = four adults;
- N5AD (80) = five adults.

For these types we have used, for each variable considered, the mean of the number of observations on each type of household per month. Our demand system is composed of expenditures on the following six consumption goods (besides the monthly income and total expenditure) that have been obtained as aggregates of detailed current expenditures on 66 goods and services.<sup>21</sup>

<sup>19</sup>For a detailed treatment of the True Cost of Living Indices and their derivation from a specific cost function, one may consult Patrizii and Rossi (1991), chapter 5.

<sup>20</sup>Details on the sampling procedure used to collect these data can be found in ISTAT, *Indagine sui consumi delle famiglie. Documentazione tecnica e descrizione del file standard non gerarchico. Anni 1987–1994*.

<sup>21</sup>Aggregation is possible if we assume, as it is usually done, that goods within each group are consistent with the Hicks and Leontief Composite Commodity Theorem (Deaton and Muellbauer, 1980a, pp. 120–121), which asserts that if a group of prices moves in parallel the corresponding group of commodities can be treated as a single good.

- ALIM = food and beverages;
- PASTI = outdoors meals and drinks;
- GAS = domestic fuels (including natural gas, heating oils and other heating fuels);<sup>22</sup>
- BENZI = transport fuels (including leaded and unleaded petrol);
- SETRA = public transports and services;
- RESTO = all other non-durable expenditures and services, including electricity.

We have also included five dummy variables *N1–N5* that classify households' types and 12 dummy variables *M1–M12* associated to the months, although only 4 dichotomy variables related to the household type and 11 associated to the months have been used in order to avoid the dummy variable trap (Greene, 1997, p. 381).

Table 7 shows, for each household profile and at the sample mean, the budget's shares for each of the six macro-goods taken into account, monthly income and monthly total current expenditure. Domestic fuels and transport fuels account for, on average, 5% and 9% of the monthly current expenditures over the period under analysis. While the share of domestic fuels decreases as income and expenditure grow, the budget share allocated to transport fuels increases from 8% to 9% as the number of households goes from 1 to 2 and remains constant thereafter, despite the increase in income and monthly expenditure. This might be due, for instance, to the fact that the number of cars used within a household is likely to increase linearly when we go from a single household to a couple, but not so when the number of households increases further.

## A.3. Prices

Monthly prices vary not only temporally (across months and years), but also longitudinally, i.e. across different types of households, because rather than using a single deflator for each aggregate, we have used different price indices for each of the elementary goods that make up the six aggregates. In other words, expenditures at constant prices for each of the six aggregates have been obtained as:  $Q_{It}^h = \sum_i (p_{i95}/p_{it})(p_{it}q_{it}^h)$ , where  $Q_{It}^h$  is constant prices expenditure on aggregate good *I* of household *h* at time *t*; *i* is the number of elementary goods composing aggregate *I*;  $p_{i95}/p_{it}$  is the '95 deflator for good *i* and  $p_{it}q_{it}^h$  is current expenditure at time *t*, on good *i*, of household *h*. Since different households types spend different amounts on the same good, the implicit prices for each aggregate, obtained dividing current prices expenditures by constant prices expenditures, are different for each house-

<sup>22</sup>Excluding electricity which is instead included in the RESTO aggregate.

Table 7

Budget shares, mean monthly income and total expenditures (in Euro) for the whole sample and for household profile

	Mean values	Standard deviation	Minimum	Maximum	Household profiles (mean values)				
					N1	N2	N3	N4	N5
ALIM (food)	0.33	0.04	0.22	0.43	0.28	0.33	0.35	0.34	0.36
PASTI (outdoors meals)	0.08	0.03	0.03	0.19	0.12	0.08	0.06	0.06	0.06
GAS (domestic fuels)	0.05	0.01	0.01	0.09	0.06	0.06	0.05	0.04	0.04
BENZI (transport fuels)	0.09	0.01	0.06	0.13	0.08	0.09	0.09	0.09	0.09
SETRA (public transport and services)	0.01	0.00	0.00	0.02	0.01	0.01	0.01	0.01	0.01
RESTO (other expenditures)	0.45	0.02	0.37	0.55	0.46	0.44	0.44	0.45	0.45
Income	1610.61	520.06	547.53	2847.61	1009.42	1390.91	1672.63	1932.88	2047.19
Total expenditure	1468.51	488.55	475.30	2860.95	910.89	1257.56	1519.87	1783.15	1871.09

holds' type. The '95 elementary price indices are the components of the Consumer Price Index (1995 = 100) published by ISTAT.

If  $f$  is the family type,  $m$  the month and  $t$  the year considered, our final data have been organised as a sample  $\Phi(f, m, t)$  by lining up monthly data ( $m = 1 - 12$ ) for each year ( $t = 1 - 12$ ), on each family type ( $f = 1 - 5$ ) in vectors of 720 observations ( $12 \times 12 \times 5$ ). The vectors called V1–V6 (for current price values), Q1–Q6 (for constant, 1995, price values) and P1–P6 for the corresponding implicit prices, plus the dummy variables mentioned above, represent the dataset used in this exercise.

#### A.4. Demand model estimation

The AI demand system has been applied to the six groups of expenditures to estimate the parameters necessary to calculate the TCOL in (A.5).<sup>23</sup> Heterogeneous preferences have been modelled using the *linear demographic translating technique* proposed by Lewbel (1985) that implies the introduction, into the demand equations, of two translating intercepts, one for the household type and the other for the months. The translating procedure implies that the translog price index, modified by the demographic characteristics, becomes:

$$\ln a(p, a) = \ln a(p) + \sum_i A_i(a) \ln p_i, \quad (\text{A.6})$$

where  $A_i(a) = \sum_k \alpha_{ik} a_k$  and  $\alpha_{ik}$  are linear parameters in the translating intercepts  $a = a_1 \dots a_k$  (family type and months) and  $\sum_i \alpha_{ik} = 0 \forall k$  by adding up

<sup>23</sup> At an earlier stage we have specified the demand system as a Quadratic Almost Ideal Demand System (QUAIDS, Banks et al., 1997), which allows for non-linear income effects of changes in prices. However, a Likelihood Ratio performed to test the significance of the parameters of the quadratic terms in the equations does not allow rejection of the null hypothesis. The model has therefore been restricted to the AIDS form.

The cost function in (A.1) thus becomes:

$$\ln c(u, p, a) = \ln a(p, a)(1 - u) + u \ln b(p) \quad (\text{A.7})$$

and the estimated demand system is:

$$w_i(p, a, y) = \alpha_i + \sum_k \alpha_{ik} a_k + \sum_j c_{ij} \ln p_j + b_i \ln \left( \frac{y}{P^*} \right), \quad (\text{A.8})$$

where  $\ln P^* = \ln P + \sum_i \alpha_{ik} a_k \ln p_i$ . The values of prices and expenditures have been transformed into logarithms because of the specification of the demand system. All the variables have then been normalised as differences with respect to their sample means. Due to the adding-up restriction we have estimated only five equations, whereas the parameters of the sixth equation can be obtained as a linear combination of the coefficients of the first five equations, according to the demand theory restrictions presented before. Adding-up is automatically satisfied by the AIDS demand system in (A.4), homogeneity and symmetry have been imposed through the parameters' restrictions listed above. Economic theory also requires the imposition of curvature conditions, i.e. the matrix of the Slutsky substitution effects to be negative semi-definite. Here, negativity has been imposed, locally, during estimation through the semi-flexible technique following Diewert and Wales (1988), Moschini (1998) and Ryan and Wales (1998).<sup>24</sup>

<sup>24</sup> The coefficients of the Slutsky matrix,  $S$ , are not constant in the AIDS, but depend on prices and income. However at the normalisation point they become constant, because at this point they are only a function of known parameters. This happens when prices and income are scaled so that they are zero at the normalisation point. If we choose the sample mean as the normalisation point,  $S$  will be negative semidefinite at the sample mean when the Slutsky matrix is reparameterized with the Cholesky decomposition (Lau, 1978) imposing the constraint  $S = -TT'$ , where  $T$  is a lower triangular matrix such that  $t_{ij} = 0$  for  $i < j$ . At the normalisation point, the elements of the Slutsky matrix are:  $s_{ij} = c_{ij} + \alpha_i \alpha_j - \alpha_i \delta_{ij}$ , where  $\delta = 0$  for  $i \neq j$  is the Kronecker delta. Substitution of the above constraint leads to  $c_{ij} = -(t'_{ij}) - \alpha_i \alpha_j + \alpha_i \delta_{ij}$  which can be estimated. The matrix of substitution effects is thus locally concave by construction. When the

In order to have consistent estimates of the parameters of the demand system (A.8) the explanatory variables must be independent from the residuals. This may not happen when total expenditure is endogenous. To test this possibility a Hausman–Wu (HW) test has been used. This is a Likelihood Ratio (LR) test distributed as a  $\chi^2$  with 5 degrees of freedom.<sup>25</sup> The value of the test statistic is very high: 18.08 with a *p*-value of 0.002. We thus reject the null hypothesis of exogeneity of total expenditure and estimate the unrestricted demand system with the method of Three-Stages Least Squares (3SLS),<sup>26</sup> using as instruments all the exogenous variables included in the original demand system plus the estimated value of the log of total expenditure from the auxiliary regression.

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- (footnote continued)
- unrestricted parameter estimates violate concavity, considering a model with a substitution matrix of rank  $K < (n + 1)$  may be useful to achieve convergence of the parameters of the locally concave model (Moschini, 1998, p. 355). This is known as the semi-flexible technique which implies the factorisation of the  $c_{ij}$  coefficients, as above, with a reduction in the rank of the Slutsky matrix. Restricting the rank of the substitution matrix of such a locally concave demand model thus yields the Semiflexible Almost Ideal Demand System (Moschini, 1998) because the price coefficients are estimated with less information. Here the rank of the T matrix has been reduced from 5 to 3, so that the number of  $c_{ij}$  parameters is reduced from 15 to 12.
- <sup>25</sup>The HW test compares the original demand system (where the coefficients of the residuals from the auxiliary regression are set to zero) with the unrestricted model that includes, among the explanatory variables, the residuals of an auxiliary regression. In the auxiliary regression the log of total expenditure is the dependent variable whereas the explanatory variables include all the exogenous variables used in the demand system plus the log of income. See Davidson and McKinnon (1993) for a description of the Hausman–Wu exogeneity test.
- <sup>26</sup>Three-stages least squares is an instrumental variable (IV) method for estimating a system of simultaneous equations where there may be endogenous variables on the right-hand side. See also: Browning and Meghir (1991) and Blundell et al. (1993) for a similar estimation procedure in case of endogeneity of total expenditure.
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