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Keywords: Energy taxes, Consumer Demand System, Welfare Effects, Equity

JEL Classification: D12, H22, Q48

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Distributional and Welfare Impacts of Renewable Subsidies in Italy*

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April 27, 2016

Abstract

We empirically assess the distributional impacts and welfare effects of policies to incentivize renewable electricity production for the case of Italy. We use data from the Household Budget Survey between 2000 and 2010 to estimate a demand system in which energy goods' shares of expenditure are modelled using different empirical approaches. We show that the general Exact Affine Stone Index (EASI) demand system provides more robust estimates of price elasticities of each composite good than the commonly used Almost Ideal Demand System (AIDS). The estimated coefficients are used to perform a welfare analysis of the Italian renewable electricity production incentive policy. We show that different empirical approaches give rise to significantly different estimates of price elasticities and that methodological choices are the reasons for the very high elasticites of substitutions estimated using similar data by previous contributions. We find no evidence of regressivity of the incidence of the Italian renewable incentive scheme in the period under consideration. The renewable subsidies act as a middle-class tax, with the higher welfare losses experienced by households in the second to fourth quintiles of the expenditure distribution.

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1 Introduction

Transitioning towards a low-carbon and high-efficiency economy is one of the key ambitions of EU policy. To this end, member states have put in place a comprehensive policy framework. This includes climate and energy targets for 2020 and 2030, the endorsement of the European Strategic Energy Technology Plan as a vehicle to accelerate low carbon technology development and large scale deployment, and a carbon price through the Emissions Trading System. Most recently, the outcomes of the COP21 in Paris confirmed that many countries will follow suit on the path towards decarbonization.

The development and diffusion of low carbon energy sources is particularly important in the electricity sector, which is among the biggest contributors to CO2 emissions and has high mitigation potential. According to the reports of the Intergovernmental Panel on Climate Change (IPCC, 2001, Edenhofer et. al 2014), renewables are expected to continue expanding, particularly in case of climate policies. Achieving policies consistent with 2°C would require a more than doubling of renewable energy by mid century.

Electricity from renewable energy sources (RES-E) plays a crucial role in the decarbonization of the energy sector. However, RES-E costs are still comparatively higher than that of fossil incumbent technologies for electricity production, making it impossible to decarbonize without regulatory intervention. Energy and carbon taxes are among the instruments which are advocated and implemented in a number of countries to support the diffusion of renewables and other low carbon technologies. Taxes are price-based instruments which are arguably more cost-effective than quantity-based instruments in terms of emission reductions. The total costs of reaching a specific environmental target are minimized because each polluter is free to choose the most efficient way to comply with a given policy measure. Indeed, many European countries have implemented energy-related incentive schemes long before the establishment of the EU ETS: the Netherlands in 1988, Finland in 1991, Norway and Sweden in 1991, Denmark in 1992, and Italy and Germany in 1999. Incentives to the development of renewable energy sources has been particularly generous in Europe, and play a key role in major economies industrial and energy policies such as Germany's "Energiewende".

A large literature has focused on the efficiency impact of clean energy subsidies, compared to market based policy instruments. However, the distributional impacts of RES incentives have received much less attention. This is an important shortcoming since energy policies are often accompanied by equity considerations. Concerns on the distributional impacts of environmental and energy policies arise from a widespread fear of their regressive nature. First, a tax which might disproportionately burden the weakest segments of society might not be in the interest of governments which support a greener economy coupled with sustainable development and growth. Second, the political appeal of a tax measure depends on its consequences in terms of competitiveness for industries and distributive impact for households. While a number of theoretical analyses address the issue of optimal taxation policy to deal with environmental externalities and distributional effects, the empirical assessment of environmental and energy tax policies is more limited (see, *inter alia*, Bull and Hassett, 1994; Metcalf, 1999; Speck, 1999; Parry et al., 2005; Fullerton, 2009). Importantly, most of the papers have looked into carbon and energy taxes, and have not estimated the incidence of RES incentives empirically (Borenstein and Davis, 2015). Given the predominance of RES subsidies over carbon taxation in present day energy policies, this is an important shortcoming.

In this paper, we measure the distributional impact and welfare effects of the renewable energy subsidies for the specific case of Italy. Italy provides a good case study since it has implemented one of the most generous subsidy programs, which has led to a massive deployment of renewable installations. For example, solar PV capacity increased 15 fold between 2009 and 2013. With a current installed capacity of almost 20GW, Italy ranks third in the world. Part of the incentives to RES-E production are costs borne by end users who pay a tariff component called A3, which acts as a "para-fiscal tax" levied on electricity consumption and whose revenue is earmarked to finance different subsidy schemes promoting renewables.[1] Providing empirical evidence on whether and to what extent fiscal schemes to support RES-E might undermine households welfare, especially the one of the poorest, is crucial given that the debate about net benefits and incidence of such incentives is very much at the center for academics, policy makers and industrialists.[2]

Our empirical analysis uses household expenditure data from the Italian Household Budget Survey[3] between 2000 and 2010. We aggregate the numerous expenditure categories in our data set into four commodity groups, namely electricity, heating fuels, transport (both private and public), and all other goods.[4] We improve on previous

[1] A3, represents the greatest share (approximately 90%) of the so-called "oneri generali del sistema elettrico", which are costs also devoted to financing special tariff regimes and R&D, besides covering other small duties.

[2] We point out that this study is centered on the quantification of money-metric welfare effects of the policy under scrutiny, and does not pretend to give an exhaustive analysis of non-monetary and long-term benefits of the same policy.

[3] A representative survey of Italian households made of repeated cross sections.

[4] These commodity groups are selected so as to allow for substitution between goods on which the policy we are analyzing might produce a different impact, while keeping their number as small as possible. Indeed, some of the demand system estimation approaches we employ require that the number of commodity groups be limited to four.

contributions (i.e., Tiezzi, 2005 and Martini, 2009) in three ways.

First, we deal with geographical price heterogeneity of energy goods by using regional rather than national price indexes for the disaggregated goods in our analysis. Specifically, we build regional price indexes for electricity, heating fuels and transport and are thus able to account for region specific changes in the price of goods in our analysis.

Second, we compare estimated elasticities from three parametric, locally flexible demand models: the Almost Ideal Demand System (AIDS) *à la* Deaton and Muellbauer (1980) embedding demographic characteristics *à la* Lewbel (1985), AIDS embedding demographic characteristics *à la* Poi (2002) and the Exact Affine Stone Index' (EASI) implicit Marshallian demand system, as recently proposed by Lewbel and Pendakur (2009).[5] These three models share some nice properties: they are easy to estimate, allow for linear price effects which may depend on observable characteristics, and the implicit Marshallian demand functions upon which they are built can be independent of implicit utility, as in homothetic demand systems. However, the EASI demand system overcomes two main concerns related to AIDS models which were used in previous contributions on the topic: the first is that model error terms cannot be interpreted as random utility parameters that represent unobserved heterogeneity; the second is that AIDS models are are constrained by Gorman-type rank restrictions (Gorman, 1981), meaning that Engel curves cannot have significant curvature and variations across the different goods.[6] Conversely, in the EASI model unobserved preference heterogeneity is captured through parameters that act as error terms in the estimating equation and as cost shifters in the cost function; Engel curves can potentially have any shape through arbitrary high-order polynomials in real expenditure, and are almost completely unrestricted;[7] price effects can be interacted with all observables; demographic variables enter both through the intercept and the slopes of real expenditures. One of the main contribution of this paper is to apply this methodological advancement to the case of energy. To the best of our knowledge, this is the first attempt to estimate a demand system for Italian households, aimed at measuring the impact of an environmental policy on household consumers, that makes use of the EASI demand system.

[5]We also estimated a Quadratic AIDS *à la* Banks et al. (1997), but this model does not perfectly fit our data: it estimates income elasticities with little economic sense and it is therefore excluded from our ultimate analysis.

[6]In the AIDS and QUAIDS models, independent of the potential number of Engel curves in the demand model, they must be expressed as linear combinations of at most three functions of expenditure. The EASI demand system, instead, is designed to overcome Gorman-type restrictions, and can potentially fit a demand system made of any number of commodity groups.

[7]In our specific case, the EASI demand system is estimated with each share modeled as a three-order polynomial in real expenditure, and including price effects interacted with observables. See Section 3.

Third, we perform a full-fledged incidence analysis of the Italian RES-E support scheme by using the estimated parameters to compute welfare losses for households in the different quintiles of the expenditure distribution. Specifically, we use the estimated parameters from the EASI model to compute the equivalent income between 2000 and 2010, i.e. the income level that ensures implicit utility levels to be the same when evaluated at two prices vectors – namely real prices and simulated ones obtained by discarding the percent amount attributable to RES-E incentives. Comparing equivalent income to average income in the sample, we are able to quantify a total average household welfare loss of about 12 Euros per month in ten years, which is about 0.6% in monetary terms. The analysis is replicated for quintiles of the expenditure distribution to assess any regressivity of the RES-E support scheme.

Our contribution to the literature on the distributional incidence of environmental policies on households is twofold. We show that the choice of a particular demand system model (and specifically of different ways to embed demographics in AIDS) is a key factor for a correct and plausible estimation of short-run elasticities and can change the magnitude of elasticities rather significantly. This might explain previous, divergent results for the Italian case.[8] In particular, all the estimated models indicate that electricity and heating fuels are necessity goods, while transport is borderline necessity. Own-price elasticities are negative, as required by demand theory. However, AIDS with demographic scaling *à la* Lewbel (1985) provides estimates of own-price elasticities which are quite high in magnitude (approximately equal to one), suggesting that consumers respond elastically to price changes. This result is in line with what Tiezzi (2004) and Martini (2009) find by estimating an AIDS and Quadratic AIDS (Banks et al., 1997) respectively – though with a slightly different timeframe and grouping of goods. Conversely, AIDS with demographic scaling *à la* Poi (2002) and EASI models estimate price elasticities that are more in line with expected household consumption behavior. In particular, own-price elasticities indicate that demand for electricity appears to be very inelastic whilst demand for transport is most elastic.[9]

On the assessment of the incidence of RES-E support schemes, we use the results from the EASI model and show that the second, third and fourth quartile of households are most affected. This implies that for the specific case of Italy, renewable incentives between 2000 and 2010 were not regressive in the traditional sense of the term, but rather acted as a "middle-income" class tax.

[8] And not, for instance, to the use of national rather than regional price data.

[9] Note that this is often interpreted as preliminary evidence that RES-E incentives are to some extent regressive.

The remainder of this paper is organized as follows. Section 2 synthesizes key details of the Italian policy in support of RES-E production. Section 3 provides a brief review of the technicalities that pertain to estimating flexible demand systems. Section 4 describes the data used to estimate our models, and presents the price and income elasticities estimated through different demand models. Section 5 discusses the welfare analysis of the Italian RES-E incentives scheme based on the EASI estimates, analyzing the extent to which the distribution of incomes is impacted. Section 6 concludes.

2 Italian Policy in support of RES-E production

The most challenging goals of the Italian domestic energy policy are complying with the European 20-20-20 energy and climate commitments and reducing energy import dependence. Since 1992 Italy has put in place an ambitious policy plan – initially aimed at reinforcing its energy independence – that has brought the country to be a leading producer of RES-E. After the electricity liberalization in 1999, incentives to RES-E production have increased, and recent reforms introduced by the 2008 Budget Law and the July 6, 2012 Ministerial Decree established a more complex and consistent set of rules that reshape the role of RES-E in the energy sector, implying a bigger impact of these incentives on end users. At present, renewable incentives provided under the Italian legislative regime rank among the highest global subsidies for RES-E.[10]

Since 2007, a feed-in tariff has been introduced to support solar photovoltaic (PV) electricity production that is paid based on the amount of energy produced and dispatched, and it is granted for twenty years. Since 2002, all energy plants fuelled by other types of RES qualify to participate in an incentive regime based on green certificates (GCs), which are issued by the Italian public energy manager (GSE), traded among operators on a dedicated market, and sold to GSE at a fixed price. Pursuant to the July 6, 2012 Ministerial Decree, from 2016 onwards the GC regime will be replaced by a feed-in-tariff calculated on the basis of the average electricity sale price during the relevant year. The transition from the GC to the feed-in-tariff regime is made possible through an incentive formula based on years of business activity and electricity sale price. Furthermore, a new incentive regime for renewable generating plants that entered into operation from January 1, 2013 has been introduced; it includes a cap on national spending for renewables incentives. In particular, for the years from 2013 onwards a maximum of 5.8 billions Euros in public funds can be used to support renewable plants. However, the cap does not apply to solar PV installations. Appendix A describes details

[10] http://tinyurl.com/q5fo68g

of the reforms just mentioned.

Incentives in support of RES-E production are mainly financed through a tariff component, called A3, which constitutes about the 90% of the so called "oneri generali di sistema" for which end users pay in their bills proportional to electricity consumption. Besides RES-E production costs, the A3 component also covers some functioning costs of the GSE and costs related to incentivizing "sources equated to renewables" (SER). SER-using plants are fueled by combined heat and power, waste-to-energy, and fossil sources from small isolated deposits. These enjoy incentives included in the so-called "CIP6" sub-component, as established in the CIP Resolution 6/1992.[11]

The A3 tariff component has worryingly increased in the last years: its revenues were about 4.8 billions Euros in 2009, 11 billlions in 2012, and are expected to reach 13 billions in 2013 (Italian Authority for Electricity and Gas, Reports PAS 3/10, PAS 6/11, 56/2012/I/com, and recommendation PAS 1/11). Indeed, since 2009, the Italian Authority for Electricity and Gas (AEEG, henceforth) has stressed the importance of modifying RES incentive schemes, defining the actual ones as "improper" and "unequal" with respect to the different contributive capacity of households, and "causing market distortions". AEEG points out that Italian "energy-industrial-environmental policy measures (e.g., the development of a RES production chain) should be financed through a proper fiscal tax – along the same lines as any other social cost" (cf. recommendation PAS 1/11, pg. 4).

Another important development was the introduction of the so-called "Bonus Elettrico" in 2007. Fearing the negative impact of rising electricity (and gas) prices on the lower end of the income distribution, the Interministerial Degree of 28/12/07 (D.I., 28/12/07) allowed low income households[12] a compensation for electricity expenses. Such compensation was calculated on the basis of the number of household components, with reference to a consumption and power levels in line with domestic use, and would reduce the electricity bills of the average user by roughly 20%. The introduction of the

[11]The 2007 and 2008 Financial Laws have enforced Directive 2001/77/CE, and ordained that funds devoted to supporting the (all Italian) SER are reduced. More details on the Italian institutional framework and the policy milestones can be found in Appendix B.

[11]AEEG estimates that such a para-fiscal burden determines one third of the average household electricity expense in the period from January 2009 to January 2013, eroding the role of market in shaping electricity price of about 10% (`http://www.autorita.energia.it/it/inglese/annual_report/relaz_ue.htm`)

[12]Low income households are identifyied using the ISEE ("Indicatore della Situazione Economica Equivalente", or Indicator of Equivalent Income, defined on the basis of income, assets and property, and composition of the household). The Bonus Elettrico was guaranteed from the 1st of January 2008 to all familes with ISEE lower than Euros 7,500. Note that the Bonus Elettrico was also extended to families whose components could prove severe health conditions which require extensive use of medical machinery powered by electricity.

"Bonus Elettrico" affects the last two waves of our data, but the results we present here are robust to dropping the more recent data.

3 Demand System Estimation

The first step in our analysis is to estimate a demand system to quantify price elasticities of RES-E incentives and their welfare effects over the income distribution of Italian households.

Price elasticities are a first indicator of how consumers change their consumption patterns and how elastic their response is when commodity prices change. The welfare analysis is then completed using expenditure functions associated with the estimated demand system. For this reason, choosing the best-fitting, flexible and feasible demand system to estimate is of crucial importance for pursuing a sound welfare analysis.

In this Section, we provide a brief overview of technical details, advantages and limits of the estimated demand systems. Appendix B presents a more detailed treatment of all the demand models.

3.1 Almost Ideal Demand Systems and Demographics

The Almost Ideal Demand System model of Deaton and Muellbauer (1980) estimates a system of equations of expenditure shares defined as follows (assuming an additive zero-mean error term associated with each equation):[13]

$$\omega_i = \alpha_i + \sum_{j=1}^{k} \gamma_{ij} \ln p_j + \beta_i \left[\ln y - \ln a\left(\mathbf{p}\right)\right]$$

where ω_i is the expenditure share of good i, p are prices, y represents household total expenditure, and $\ln a\left(\mathbf{p}\right)$ is the translog function:

$$\ln a\left(\mathbf{p}\right) = \alpha_0 + \sum_{i=1}^{k} \alpha_i \ln p_i + \frac{1}{2} \sum_{i=1}^{k} \sum_{j=1}^{k} \gamma_{ij} \ln p_i \ln p_j,$$

Axioms of choice are satisfied when adding up, homogeneity, and Slutsky symmetry are satisfied, i.e. when

[13] AIDS can be easily derived from the most general form, the Quadratic AIDS of Banks et al. (1997). Appendix A presents the Quadratic AIDS (Banks et al., 1997) for expositional clarity. In our analysis, we estimated a Quadratic AIDS both with and without demographic scaling, but income elasticities obtained showed little economic sense. It was therefore excluded from our ultimate analysis.

$$\sum_{i=1}^{k}\alpha_i = 1,\ \ \sum_{i=1}^{k}\beta_i = 0,\ \ \sum_{i=1}^{k}\gamma_{ij} = 0,\ \ \text{and}\ \ \gamma_{ij} = \gamma_{ji}.$$

In the original AIDS models,[14] heterogeneity in individual preferences is not modelled since allowing for heterogeneous preferences in a flexible demand system is quite cumbersome. This is a very restrictive approach, given that heterogeneous preferences are very likely to play a crucial role in shaping demand. One way to overcome this limit is to assume that differences in preferences can be to some extent related to socio-demographic characteristics of the household. The effects of demographic characteristics on consumption patterns have been widely explored, and the literature on the introduction of demographic effects in theoretically-consistent AIDS models is quite large. We use two approaches to account for socio-demographic characteristics in our AIDS model: demographic scaling as suggested by Lewbel (1985) and demographic scaling as suggested by Poi (2002).

Lewbel (1985) embeds r demographic variables z as taste-shifters in the share equations, i.e. as α_i terms in the $\ln a(\mathbf{p})$ expression, thus overcoming the estimation problems associated with the proliferation of parameters:

$$\ln a(\mathbf{p}) = \alpha_0 + \sum_i \left(\alpha_i + \sum_{h=1}^{r}\alpha_{ih}z_h\right)\ln p_i + \frac{1}{2}\sum_{i=1}^{k}\sum_{j=1}^{k}\gamma_{ij}\ln p_i \ln p_j;$$

$$\omega_i = \alpha_i + \sum_{h=1}^{r}\alpha_{ih}z_h + \sum_{j=1}^{k}\gamma_{ij}\ln p_j + \beta_i\left[\ln y - \ln a(\mathbf{p})\right]$$

the new adding-up conditions being:

$$\sum_{i=1}^{k}\alpha_i = 1,\ \ \sum_{i=1}^{k}\alpha_{ih} = 0.$$

Conversely, Poi (2002) embeds the r characteristics in a vector $\mathbf{z}$ through a scaling function in the expenditure function of the household (see Appendix B for details), giving rise to the following expenditure share equations:

[14]Notice that because of the translog price index $\ln a(\mathbf{p})$, the set of expenditure share equations requires non-linear estimation also in the AIDS case.

$$\omega_i = \alpha_i + \sum_{j=1}^{k} \gamma_{ij} \ln p_j + \left(\beta_i + \eta^T \mathbf{z}\right) \ln \left[\frac{y}{\bar{y}_0\left(\mathbf{z}\right) a\left(\mathbf{p}\right)}\right]$$

$$c\left(\mathbf{p}, \mathbf{z}\right) = \prod_{j=1}^{k} p_j^{\eta_j^T \mathbf{z}}.$$

The new parameters restrictions being:

$$\sum_{j=1}^{k} \eta_{hj} = 0 \quad \text{for} \quad h = 1, \ldots, r.$$

Both AIDS models are estimated through a system of non-linear equations by feasible generalized non-linear least squares (FGNLS). Details about estimation and calculation of income and price elasticities are reported in Appendix A.[15]

AIDS models, despite being relatively easy to estimate and for this reason widely used, entail empirical and theoretical limitations. Allowing for unobserved preference heterogeneity in demand systems has been shown to be very important: observables like prices, expenditure and household demographics explain no more than half the variation in budget shares.[16] However, in AIDS models error terms cannot be interpreted as random utility parameters representing unobserved heterogeneity. Furthermore, such parametric models are characterized by Engel curves that are additive in functions of expenditure and are therefore constrained by Gorman's (1981) rank restriction: independent of the number of Engel curves in the model, they must be expressed as linear combinations of at most three functions of expenditure (in the Quadratic AIDS, most general model). [17]

[15]Note that due to cumbersome computation, Poi's estimation program is not designed to derive elasticity standard errors.

[16]Lewbel (2008) comments: "This matters in part because another of Allen and Bowley's (1935) findings remains true today, namely [...] demand function models still fail to explain most of the observed variation in individual consumption behavior."

[17]Gorman's (1981) concept of Engel curve "rank" is shown to have implications for specification, separability, and aggregation of demands (Lewbel, 1995). Although price-independent generalized logarithmic (PIGLOG) preferences, from which the AIDS is derived, ensure consistent aggregation across households, and the number of commodity groups depends on the variety of tax treatments, one should try to keep the number of composite goods as small as possible (less or equal than four).

3.2 Exact Affine Stone Index Demand System

The EASI model is an attempt to overcome the shortcomings associated with AIDS models, while keeping the desirable feature of being "easi-ly" estimable. Lewbel and Pendakur (2009) introduce the concept of *implicit Marshallian demand functions* (IMDFs), which are Hicksian demands with the unobserved utility level substituted out. They show that a demand system built upon IMDFs is linear in the parameters, can incorporate unobserved heterogeneity, is not limited by the Gorman-type restrictions, and can accommodate highly non-linear forms of the Engle curves.[18]

Assuming the most general functional form of the expenditure function proposed by Lewbel and Pendakur (2009), which includes all two-way interactions among expenditure y, the set of demographic charachteristics $\mathbf{z}$ and the vector of prices $\mathbf{p}$, gives rise to the following Implicit Marshiallian budget shares (see Appendix B):

$$\omega_i = \sum_{q=1}^{s} \beta_{iq} \upsilon_q + \sum_{h=1}^{r} g_{ih} z_h + \sum_{j=1}^{r} \sum_{h=1}^{r} \alpha_{ijh} z_h \ln p_j + \sum_{i=1}^{k} \beta_{ji} \ln p_i \upsilon + \sum_{h=2}^{r} h_{ih} z_h \upsilon + \varepsilon_i; \quad (1)$$

$$\upsilon = \frac{\ln y - \sum_{i=1}^{k} \omega_i \ln p_i + 1/2 \sum_{i=1}^{k} \sum_{j=1}^{k} \alpha_{ijh} z_h \ln p_i \ln p_j}{1 - 1/2 \sum_{i=1}^{k} \sum_{j=1}^{k} \beta_{ij} \ln p_i \ln p_j}.$$

where u is the utility level attained at prices $\mathbf{p}$, ε a vector of error terms that include unobservable preference heterogeneity and $\upsilon = \upsilon(\omega(\mathbf{p}, u, \mathbf{z}, \varepsilon), \mathbf{p}, y, \mathbf{z}) = \upsilon(\omega, \mathbf{p}, y, \mathbf{z})$ is the implicit utility function is defined which and depends only on observable data. [19]

Strict monotonicity and concavity of the expenditure function ensure regularity conditions of the demand system to be satisfied. In our analysis, the EASI model has been estimated with an order three of the income polynomial [20].

As argued above, the EASI model is superior to the AIDS model in two respects. First, it overcomes Gorman-type restrictions of the AIDS modelby potentially allowing for a very large number of disaggregated groups of goods. Second, total expenditure might be jointly determined with the budget shares of the specific commodities in the demand model; such endogeneity cannot be easily handled in the case (such as ours)

[18]However, inequality constraints are imposed on the model by cost function monotonicity and concavity, restricting the range of possible parameter values and those of observables for which demands satisfy regularity conditions.

[19]The implicit Marshallian demand system is defined as $\omega = \omega(\mathbf{p}, \upsilon, \mathbf{z}, \varepsilon)$, which is simply the Hicksian demand system with υ substituted for u. υ corresponds to an affine function of the Stone index deflated by the log nominal expenditure.

[20]Results with orders of the income polynomial from one to ten are available upon requests

were there is no access to income information, rather expenditure data is used. The EASI model overcomes this problem by making use of internal instruments to address the issue of endogeneity. The approach developed by Lewbel and Pendakur (2008) hinges on the development of implicit Marshallian demands, which econometrically include the dependent variable on both sides of the equation, suffering from endogeneity. This econometric problem is solved in the model by relaxing the restriction that Marshallian budget share equations have an explicit solution. Therefore, the EASI model internally overcomes the econometric biases due to endogeneity.

As regards estimation methods, in order to account for the endogeneity of v, Pendakur (2008) and Lewbel and Pendakur (2009) suggest an iterative linear 3SLS estimator, i.e. a special case of a fixed-point based estimator by Dominitz and Sherman (2005). The reader is cross-referred to Lewbel and Pendakur (2009) for the functional form of budget share, quantity, real expenditure and observable demographics' elasticities, including price ones.

4 Data and Elasticities of Demand

4.1 Data and Model Specification

The data set used in our analysis includes independent cross-sections of the Italian Household Budget Survey (*Indagine sui consumi delle famiglie italiane*, IHBS henceforth) for the period 2000-2010. IHBS is conducted by the Italian Central Statistics Office (ISTAT) and is representative of the Italian population. Each cross-section is composed of about 24,000 records corresponding to households interviewed. [21] Each year the survey collects very detailed categories of household expenditure. For each day of one week, sampled households are asked to fill in a daily questionnaire and keep a diary of household members' expenditure. Following classical approaches, all expenditures are converted into a monthly equivalent: weekly expenditures are multiplied by

[21] Samples are drawn through a two-stage sampling procedure: primary sampling units (PSUs) are municipalities, and the ultimate sampling units are the households. Municipalities are divided into self-representative (chief towns of provinces or municipalities with more than 50,000 inhabitants) and non self-representative (municipalities with less than 50,000 inhabitants). PSUs are stratified such that every self-representative municipality forms a stratum and is included in the survey every month. Non self-representative municipalities are stratified by region, altimetric zone and main economic activity; from each stratum, three municipalities are drawn that are included in the survey for once in three months. Thus, the sample is made of all self-representative municipalities and 134 non self-representative municipalities. Once the PSUs have been drawn, the households are systematically drawn from the ISTAT's lists of each municipality.

the temporal coefficient equal to the number of weeks in one month (4.28).[22]

In all our demand systems, total expenditure equals the amount spent on electricity, heating fuels, transport and all other goods, which represent the commodity groups our demand system is built upon.[23] These were chosen to ensure both that the groups make sense as functional product groups and to allow for substitution between goods on which the para-fiscal taxation scheme we are analyzing might produce an impact.[24] As explained in the previous section, the EASI model allows for a very large number of disaggregated groups of goods to be estimated, but for comparability we opt for the same specification in both the AIDS and EASI models. Observations with expenditure above and below three standard deviations from the average were dropped to control for outliers.

Prices are proxied by the series of average prices and elementary consumer price indices at the region-month level during the period analyzed, except for the commodity group that includes all the rest of goods, the price of which is assumed to be proxied by the national price index at the monthly level.[25] This is a significant improvement with respect to Tiezzi (2005), which only includes national level prices. Specifically, as regards the commodity groups of electricity, we constructed a Jevons index[26] from average electricity prices relative to Piemonte region in December 1998 (our cross-section by time benchmark). The Jevons index of heating fuels is build using information on the price of gas in cylinder and domestic use fuel. Finally the Jevons index of transport

[22]This way to proceed is well known to produce unbiased estimates under regular assumptions.

[23]Note that the budget shares are calculated including both the main place of residence ("prima residenza") of the household and any other secondary place of residence ("seconda residenza").

[24]It is assumed that the utility obtained from any good – therefore its demand – is unaffected by the amount of working time and externalities from expenditure on certain goods are not allowed.

[25]Note that our analysis assumes that all households are subject to the same contract in terms of electricity power, namely the standard 3kW contract for domestic use.

[26]The month-to-month Jevons index is defined as the unweighted geometric mean of the price ratios, which is identical to the ratio of the unweighted geometric mean prices:

$$P^{0:t} = \Pi \left(\frac{p_{it}}{p_{i0}} \right)^{1/n} = \frac{\Pi \left(p_{it}\right)^{1/n}}{\Pi \left(p_{i0}\right)^{1/n}}.$$

The chained month-to-month indices link together the monthly changes by successive multiplication. The direct indices compare the prices in each successive month directly with those of the reference month, December 1998.

Notice that the Jevons index depends only on the price ratios and is unaffected by the price level. Also, it is transitive, meaning that the chained monthly indices are identical to the corresponding direct indices. This property is important in practice, because chain indices link together the month-on-month indices. One general property of geometric means should be noted when using the Jevons index. If any one observation out of a set of observations is zero, their geometric mean is zero, whatever the values of the other observations. The Jevons index is sensitive to extreme falls in prices. This is why extreme price movements have been carefully checked; none has been registered in our case.

goods at the regional level is built using the Jevons index of public transport and private transport. The latter includes information on the price of LPG, fuel and gasoline and taxi fares. For the fourth group ("All Other Goods") it was impossible to construct an index having cross-sectional and time-series variation: due to the big variety of goods included, we could not recover the average prices of single consumption goods to construct a region-by-month index comparable in both the dimensions.

Finally, a set of demographic characteristics available in the dataset allows us to capture household heterogeneity, especially important in the AIDS-type models where unosberved heterogeneity is not modelled. Specifically, we include the number of adult household members, number of children below six years, age and education of the reference person in the household, as well as seasonal and geographic dummies (these last ones include four main sub-regions of the Italian peninsula, namely North-west, North-east, Middle and South).

Our sample is composed of 244,435 observations over the years 2000-2010. Table 1 presents some descriptive statistics for the full sample as well as average values of the different quintiles of the income distrubution. On average, monthly expenditures at the household level are around 2,300 Euros, with a minimum of roughly 1,400 and a maximum of just above 8,000 Euros. Electricity, gas and transport expenditures account for 2 percent, 3 percent and 5.5 percent of household monthly expenditures, respectively. On average, each household is composed of 2.5 individuals, and the average age of the household head is 57. About a fourth of the households is headed by a person with a primary school degree, around 30 percent by a person with some Junior High Education, and only 19 percent have some college education or higher. The Northeast of the country contains about 15 percent of observations, while the South accounts for one third of households. Focusing on the different quintiles of the expenditure distribution, the quintile dispersion ratio (i.e. the share of the average expenditures of the richest 20 percent of the sample divided by the average expenditures of the bottom 20 percent) is roughly 5.5. On average, households in the first quintile have a higher share of electricity and gas expenditures, and a lower one for transport expenditures. They are smaller in size and, as expected, are more likely located in the Southern regions and headed by a person with low education levels. Also note that over the sample period, the inequality in our sample slightly decreased, with the Gini coefficient going from around 0.33 in 2000 to less than 0.31 in 2010.

4.2 Estimated Elasticities

In this section we focus on elasticities obtained using parameter estimates of the AIDS and EASI models. Behavioral responses to the para-fiscal policy measure can be evaluated *ex ante*, by looking at price elasticities of demand for electricity. They tell us the percentage reduction in the demand of the taxed good following a 1% increase in its price. Elasticities can thus be thought of as a preliminary measure of the regressivity of the environmental policy under scrutiny.[27]

In Table 2 we report estimated total expenditure elasticities, as well as compensated price elasticites, derived from AIDS with demographic scaling *à la* Lewbel (1985) (AIDS 1), AIDS with demographic scaling *à la* Poi (2002) (AIDS 2), and EASI of degree three, respectively. [28] These estimates can be interpreted as short-run elasticities. Own-price elasticities appear on the diagonal and cross-price ones off the diagonal. A common feature of the three estimated models is that the income elasticities indicate electricity and the energy aggregate as necessity goods, while the transport aggregate is borderline necessity and the commodity group including all the rest of goods and services is a luxury good.

Our first result is best illustrated comparing the own-price elasticities estimates from the three models. Own-price elasticities are negative, as required by demand theory, but Table 2 shows that the choice of the demand system model, and in particular the way to account for observables, results in important discrepancies in the estimated values. In the AIDS with demographic scaling *à la* Lewbel (1985) all own-price elasticities are quite high in magnitude (close to one), suggesting that consumers respond substantially to price changes for all commodity groups in our demand system. This result is in line with what Tiezzi (2004) and Martini (2009) find by estimating an AIDS and a Quadratic AIDS with demographic scaling *à la* Lewbel (1985), respectively, using the same source (though for different years and with slightly different grouping). Their

[27]For the AIDS models, elasticities are evaluated at the mean prices and mean total expenditure (cf. Appendix A). For the EASI model the best specification is the one with a polynomial of degree three in income: moments higher than two of the income polynomial were significant up to three. We present results of this specification; the rest of estimation results are available from the authors upon request. Furthermore, Hicksian demand and real expenditure semielasticities are computed as derivatives of the budget shares with respect to log prices and log nominal total expenditure. Then, given estimated model parameters, Marshallian elasticities are derived from the semielasticities for each individual, plugging in observed Marshallian demands or estimated residuals and averaging the result out. Details about the algebraic form of such semielasticities and elasticities are reported in both the paper by Lewbel and Pendakur (2009) and the technical web appendix of the same paper.

[28]The AIDS model estimation provides both compensated and uncompensated price elasticities. The EASI model provides non-compensated semi-elaticities and compensated price elasticities. We report here only the compensated elasticities for both the AIDS and EASI models.

argument to justify such high responsiveness is that high own-price elasticities might reflect the presence of a significant part of electricity demand due to "luxury utilization" (such as air conditioning and some electrical appliances), as well as the existence of a high margin for energy saving.

Conversely, the AIDS with demographic scaling *à la* Poi (2002) and the three-degree EASI models estimate price elasticities that are very close in magnitude and much more in line with expected consumption behavior in such commodity groups. In particular, the direct price elasticities show that electricity demand of the average household is significantly inelastic: the compensated AIDS own-price elasticity is -0.046 while the EASI one is -0.020. Whether the AIDS or the EASI specification is to be considered more fitting, both results show the importance of specifying a demand model that does not impose separability and thus allows for the estimation of the full complement of cross-price elasticities.

The low own-price elasticity for electricity estimated using the AIDS with demographic scaling *à la* Poi (2002) and the EASI models, can be taken as preliminary evidence that the average Italian household will likely not vary its electricity consumption, despite the price increase due to the incentivizing policy. Hence, the position of the poorest households in the expenditure distribution is likely more vulnerable than that of the richest, given their tighter budget constraint. The demand for heating fuels and transport is more elastic to price changes, perhaps suggesting that some room exists in these sectors for future energy saving. The effect of a given policy on average consumption patterns can be studied observing the cross price elasticities. The change in demand of heating fuels and transport due to a change in the price of electricity is quite low (AIDS2: -0.054, 0.074; EASI: -0.128, 0.148). Thus, focusing on the average Italian household, the Italian policy incentivizing RES-E production does not seem to significantly affect the consumption pattern of other polluting goods.

However, the results obtained from the estimation of elasticities on the full sample may hide important differences for different households along the expenditure distribution. Given the evidence on the different performance of the demand system models estimated on the full sample shown above, in the rest of the paper we focus on the EASI model and present own-price elasticity, cross-price elasticity and income elasticity estimates for the different quintiles of the expenditure distribution. Results are shown in Table 3. Starting with electricity, we find low own price elasticities across quintiles. In all case, the elasticity has an absolute magnitude which never exceeds 0.1. Elasticities are particularly low for the lower four quintiles (-0.023,-0.021,-0.03,-0.007).

The fifth quintile displays a higher elasticity, at -0.079. This might reflect a level of education and a disposable income which allows responding more to changes in prices, for example by purchasing more efficient appliances. It is important to keep in mind that heating and cooking is done with natural gas in Italy. Electricity is needed essentially for operating appliances. The penetration of air conditioning during the period observed is still very low, except for the higher quintile. The estimates we present indeed suggest that poor households as well as the middle class may find it harder to react to electricity price changes, and hence that they will be disproportionately burdened by increases in electricity prices.

We observe a similar behavior when looking at heating fuels, though the magnitude of the elasticities is much higher than for electricity, as already noted. Elasticities are lower, especially in the first quintile of the distribution. Transport exhibits an opposite distributional behavior, with higher elasticities for lower incomes. The own-price elasticity of "All Other Goods" is close to minus one for all household types, but slightly lower for poorer households. Focusing on the cross-price elasticity beween electricity and heating fuels, we note that for the poorest households an increase in the price of electricity negatively impacts the consumption of heating fuels to a much greater extent than in rich households (cross price elasticities are estimates at -0.177 and -.008, respectively).

5 Welfare Analysis and Distributional Effects of Italian RES-E Incentives

In the previous Section we discussed preliminary evidence of a possible distributional impact of an increase of electricity prices for poor Italian households. A full-fledged welfare analysis, however, needs to take into consideration the changes in spending behavior across all purchased goods, which will be determined not only by changes in the patterns of electricity consumption but also with respect to all the other goods purchased by the household. To provide such evidence, we present an incidence analysis making use of the estimates derived from the EASI model. The welfare measure that we use to evaluate the impact of RES-E incentive policy on household wellbeing is the equivalent income, [29] which is defined as the income level, eq_h, that ensures the utility levels are the same when evaluated at two prices vectors:

$$v\left(\mathbf{p}_c, y_h\right) = v\left(\mathbf{p}_r, eq_h\right) \tag{2}$$

[29] We made use of the user-written R-project package `easi` by Hoareau et al. (2012) to estimate the equivalent income.

where $v(\cdot)$ is the indirect utility function, y_h is the actual level of income[30], $\mathbf{p}_r$ is the reference price, and $\mathbf{p}_c$ is a different price vector, and prices, $\mathbf{p}_c$. In our specific case, which makes use of an EASI demand system estimation approach (and cost structure) and relies on expenditure data from the IBHS, equivalent income is defined as:

$$eq_h = \exp(\ln y_h + \sum_{i=1}^{k} \omega_i \ln p_{ci} + \frac{1}{2} \sum_{i=1}^{k} \sum_{j=1}^{k} \alpha_{ij} \ln p_{ci} \ln p_{cj} +$$
$$- \frac{1}{2} \sum_{i=1}^{k} \sum_{j=1}^{k} \alpha_{ij} \ln p_{ri} \ln p_{rj}).$$

Hence, the equivalent income is the monthly income level which ensures that the implicit utility enjoyed by the household is the same in the two scenarios: the reference one (simulated prices) and the current one (actual prices). The simulated price vector is simply obtained by discarding the A3 tariff component included in actual prices from 2004 to 2010 while assuming that other commodity prices do not vary. We refer to AEEG data, reported in Figure 1, to quantify the percentage price variation due to the reform. Notice that simulated electricity prices are the same as actual ones between 2000 and 2003, due to lack of data. Such an analysis is performed on the whole sample and on subsamples selected according to quintiles of real expenditure.

Estimating the percentage monthly average welfare loss over the period analyzed requires to compare the estimated equivalent income with the average monthly real income in the sample.[31] To ascertain the distributive effects of RES-E incentive policy, we thus make use of estimated coefficients of the EASI model with actual prices, compare them with those estimated using simulated prices, and compute the equivalent income as explained above. Results are presented in Table 4. We quantify a total average household welfare loss of about 11.5 Euros per month over the period 2000-2010, which corresponds to a monetary loss of roughly 0.5%.

The incidence analysis over quintiles of the expenditure distribution reveals that the Italian RES-E incentive policy does not embed regressive impacts, as traditionally depicted. The incidence of welfare loss, defined as a percentage, across quintiles that

[30]In our case, this is equal to nominal total expenditures as the IBHS contains only information on expenditures and note income

[31]It is important to stress that we do not need to analyze the impact of the policy distinguishing between different household types, given that the arguments of the household cost function in EASI models are scaled to reflect heterogeneity in household demographics and that the EASI models also accounts for unobserved heterogeneity.

resembles an inverted U instead of the more conventional regressive incidence. Notably, a welfare loss of about 6.5 Euros for the first quintile and 38.6 Euros for the last quintile correspond in both cases to 0.8% of welfare. In practice, the burden borne by the poorest and the richest households is approximately the same. Conversely, the three middle quintiles experience a welfare loss that in percentage terms is almost double. As a result, one can argue that the RES-E support policy (and its mitigating measures) in Italy brought households at the lowest extreme of the distribution closer to those in the middle of the distribution, while it brought those at the upper extreme further from the median households and at the same distance with respect to the poorest (cf. figures reported in Table 4, columns "Quintile 2" to "Quintile 4").

While the results obtained in the incidence analysis show that in the specific case of the Italian RES-E incentives do not produce significant distortions along the income distribution, it is important to note that this does not say there are no effects on welfare, quite the contrary, just that they are not regressive. The lack of regressivity of the RES-E incentive scheme for Italy that emerges from our analysis is in contrast with the general expectation of regressivity in energy taxes. This may be due to different reasons. First, note that in our case we use expenditure data, and not income data, from the IBHS. Data on expenditure better represents lifetime income, which is the preferred statistics to be used in the estimation of demand systems, as households tend to smooth consumption over their lifetime. The use of expenditure rather than income data has been proven to reduce the regressivity of estimates (for instance, Poterba 1991). Second, higher regressivity emerges from analyses which do not take into account the full behavioral response that a price change in electricity induces in household consumption. In our case, the use of demand system estimates fully captures the behavioral response of households, and thus likely reduces the estimated regressivity of the RES-E schemes that could emerge from more basic analyses (such as the ones of Verde and Pazienza, 2016). Finally, the presence of the "Bonus Elettrico", namely the compensation measure designed for low-income households and discussed in Section 2, may have contributed to mitigating any negative distributional impact linked with the RES-E recovery mechanism (and for that matter with any electricity price increase) on poorer households.

6 Conclusions

This paper tests whether the Italian policy supporting the production of (RES-E) had negative distributional impact and welfare effects. In Italy, part of the incentives to RES-E production are costs borne by end users who pay a tariff component called A3, which acts as a “para-fiscal tax” levied on electricity consumption and whose revenue is earmarked to finance different subsidy schemes promoting renewables. To explore this question, we use household expenditure data from the Italian Household Budget Survey between 2000 and 2010. We improve on previous analysis of the topic (and specifically on the few focusing on the Italian case) by using regional prices in our estimation, by comparing estimated elasticities from three parametric, locally flexible demand models, and by using the more robust results to perform a full-fledged incidence analysis of the Italian RES-E support scheme. Specifically, we use the estimated parameters to compute welfare losses for households in the different quintiles of the expenditure distribution using the equivalent income metric, i.e. the income level that ensures implicit utility levels to be the same when evaluated at two prices vectors – namely real prices and simulated ones obtained by discarding the percent amount attributable to RES-E incentives.

We provide two main results. First, on the methodological side, we show that in the case at hand, the choice of a specific demand system estimation techniques on which to base the incidence analysis can give rise to profoundly different estimates. We thus argue that previous unconvincing results can be explained due to a methodological choice. Second, using robust estimates of own-price, cross-price and income elasticities for the quintiles of the expenditures distribution in the IBHS does not provide any evidence of regressive impacts. Rather, what emerges is that the RES-E incentive in Italy acted mainly as a middle-class tax, with welfare losses of the second to fourth quintile being estimated as double those of both the bottom and top quintile.

Our results should not be interpreted as suggesting distributional neutrality of renewable energy subsidies. We have shown that the central quintiles are more heavily hit by the incentive policy. Moreover, subsidies program create additional distributional impacts in terms of adoption of renewable technologies. In a recent contribution, Borenstein (2015) shows that adoption of solar PV is dominated by the wealthiest, high electricity consuming households. The value of installing solar PV was thus greater for the higher-income households. We leave this question to future research.

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Appendix A

Italian institutional framework

This Appendix provides details on the Italian institutional framework, which includes several incentive schemes have been used for promoting RES-E in Italy since 1992 and the process of liberalization of the Italian Electricity Market which started in 1999.

FIGURE 2

Note: Figure displays the timeline of Italian policies to incentivize RES-E

The "CIP6" incentive program

In the years 1992-1999, until the enactment of Legislative Decree 79/1999 introducing electricity liberalization in Italy – that enforced the Directive 1996/92/EC – Italian policy promoting and supporting renewable energy sources was based on the so called "CIP6" incentive program. It provided a direct incentive for producers, which could sell electricity from renewable energy sources (RES-E) to the monopolist, ENEL, at a fixed price, higher than the market price.[32] ENEL recovered the difference in prices through electricity bills, shifting the costs on to end users.

Specifically, the CIP's (Comitato Interministeriale Prezzi) Resolution 6/1992 set prices of RES-E for plants which started their business activity after January 30, 1991, according to two criteria established by Law 9/1991:[33]

- "avoided costs" criterion (electricity withdrawal costs should not exceed ENEL production costs of the same amount of energy); avoided costs include costs relative to plants, management and maintenance, and combustible (yearly updated);
- "incentivized costs" criterion (incentivizing for higher costs of technologies used, in order to allow for recouping invested capital faster); incentives are paid out during the first eight years of business.[34]

Set prices varied depending on whether plants supplied the whole power or a given share (A type), or just their exceeding power (B type).

The CIP Resolution 6/1992 referred to:

a) renewable sources: solar, wind, hydraulic, geothermal, wave-motion and waste reclamation;

b) "sources equated to renewables": combined heat and power, recovery of exhaust heat and industrial waste;[35]

[32] ENEL was monopolist of the Italian electricity sector up to 1999. Law 22/1991, item 22, defined the juridical regime of renewable energy production plants, remitting to CIP (Comitato Interministeriale dei Prezzi) setting the prices at which producers could supply RES-E to ENEL. In practice, such law ordained that energy production through renewables was liberalized, and decreed that energy unused by the same producers should be sold to ENEL at "incentivized prices". After 1998 the Regulatory Authority for Electricity and Gas (AEEG) replaced CIP, which was suppressed.

[33] The Ministerial Decree of January 24, 1997 extended incentives to existing renewable energy power plants, to those currently underway and to proposals advanced towards ENEL (as described in Law 481/1995, paragraph 7, item 3) within November 19, 1995.

[34] Agreements have a variable time lenght, up to 15 or 20 years.

[35] The 2007 and 2008 Financial Laws have enforced Directive 2001/77/CE, devoting less funds in support to the (all Italian) "sources equated to renewables" from the CIP6 incentive scheme. Waste-to-energy plants were also excluded from the CIP6 scheme following the Legislative Decree 172/2008.

c) standard sources: fossil fuels and others.

Law 481/95 instituted the Regulatory Authority for Electricity and Gas (AEEG) that replaced the CIP since 1998.

The most important measures taken by AEEG in these respects are:

- Resolution 108/1997 that modifies prices of supplying "excess electricity";
- Resolutions 82/1999 and 62/2002 that set prices of electricity produced by streamflow hydro plants up to 3 MW;
- Resolution 81/1999 that updates prices set in the CIP Resolution 6/1992 for plants which started their business after January 1, 1997.

Such a feed-in tariff system of subsidy only applies to plants built during the period in which the system was in force, but is no longer applicable to new plants, although a new version of the feed-in tariff system is now applicable to photovoltaic plants.

Electricity Liberalization

Legislative Decree 79/1999, the so called "decreto Bersani", introduced electricity liberalization in Italy. Item 2, paragraph 12 dictates the relinquishment of rights and obligations of buying RES-E from ENEL to GRTN (Gestore della Rete di Trasmissione Nazionale), now called GSE (Gestore dei Sistemi Energetici).[36] Since January 1, 2001 GSE withdraws the "excess electricity" of RES-E production, as defined in the mentioned Law 9/1991, which is supplied by producers at prices set by AEEG. Electricity is then sold by GSE in the electricity market, according to what is decided by the Ministry for Economic Development year by year. The difference between costs borne by GSE and revenues from sales in the market is a cost borne by end users, who pay for those in the electricity bills through some tariff components, called A2-A6. These are used to recover costs, called "oneri generali di sistema", borne for the "sake of the whole

[36] "Gestore dei Sistemi Energetici - GSE S.p.A." was previously called "Gestore della Rete di Trasmissione Nazionale S.p.A.", then "Gestore dei Servizi Elettrici S.p.A." The company changed its name for the first time on November 1, 2005, after the transfer of part of its assets (management of the national transmission grid) to Terna S.p.A. Since then, GSE has become increasingly focused on support schemes for renewables and on governance of the Group, and its name has reflected its evolving mission.

The sole shareholder of GSE is the Ministry of Economy and Finance, which exercises its rights in consultation with the Ministry of Economic Development. GSE is the parent company of three subsidiaries: "Acquirente Unico" (AU), "Gestore dei Mercati Energetici" (GME), and "Ricerca sul Sistema Energetico" (RSE) – this last one is active in research in the electricity and energy sectors, as well as in projects of strategic interest.

electricity system" and selected by the Government or the Parliament. Their amount is established by the Regulator and varies according to utility types. Revenues collected are managed through accounts opened at the "Cassa conguaglio per il settore elettrico", the public technical body of the accounting of energy systems.

Tradable Green Certificates (TGCs)

The incentive is based on the issue of Tradable Green Certificates (TGCs) evidencing the production of RES-E. The scheme runs as follows. Each TGC is granted by GSE to producers of renewable energy that conform to the specific criteria of qualification as eligible plants ("Impianto Alimentato a Fonti Rinnovabili" – IAFR), based on their net output for each 1 MWh produced, having started their operation after April 1, 1999.[37] TGCs may be purchased (either in one-to-one transactions or on the market) for satisfying the requirements imposed on conventional producers (non-renewable electricity producers) by Legislative Decree 79/1999, Item 11: since 2002, electricity producers or importers are imposed a duty (renewable requirement) to introduce a minimum amount equal to 2% of the electricity produced by RES-E plants that have started their operation after April 1, 1999 (quota). Between 2004 and 2006 such a percentage has been increased by 0.35% per year, while the yearly increase has been 0.75% between 2007 and 2012. The market for TGCs is therefore created by the demand from producers and importers who do not produce sufficient electricity from renewable sources to satisfy the renewable requirement quota, as well as by purchasing TGCs from other producers. The respective quota of the renewable requirement of each producer or importer is calculated on the basis of the production or import in the previous year, net of cogeneration, the plant's auxiliary services consumption, exports and a deduction of 100 GWh. TGCs are valid for three years: those issued in respect of electricity generation in a given year (reference year) may be used towards compliance with the obligation also in the following two years. For example, TGCs issued in relation to RES-E produced in 2006 can satisfy the renewable requirement in relation to non-renewable energy produced in 2006, 2007 and 2008. TGCs not used by their expiry date are purchased by the GSE at a predetermined price from time to time.

[37]The number of certificates issued is proportional to the electricity generated by the plant/system and varies depending on the type of renewable source used (new, reactivated, upgraded, renovated system/plant).

Conto energia

"Conto Energia" is a particular type of incentive based on the feed-in tariff system, and is dedicated to photovoltaic plants. They can enjoy, as an alternative to the TGCs, a subsidised tariff paid by the GSE for each unit produced, as provided by the Ministerial Decree of February 19, 2007 and by the Resolution of AEEG 90/2007. The tariff is paid for 20 years from the start of the commercial operation of the plant and its amount varies depending on its characteristics (whether on the ground or totally or partially integrated with a building). The incentive is available up to a global maximum amount of 1200 MW installed, of which approximately 63 MW have so far been installed, hence room is left for large investments in this field.

2008 Budget Law

An in-depth review of the incentive system for RES-E has been introduced by Law 244/2007 (Budget Law 2008) – together with Legislative Decree 159/2007 converted with amendments to Law 220/2007 – for plants starting their commercial operation from January 1, 2008 (except photovoltaic plants which enjoy the "Conto Energia" alternative option).

The most significant changes are the following:

- the incentive is differentiated based on the type of renewable sources used;
- an alternative to TGCs scheme, differentiated by type of source, is the all-inclusive feed-in tariff (tariffa onnicomprensiva), a national scheme applicable to RES-E plants (excluding solar ones) which have a nominal real power of less than 1 MW (200 MW for on-shore wind plants); the tariff is granted over a period of 15 years, during which its rate remains fixed and based on the amount of electricity fed into the grid, for all plants commissioned by December 31, 2012;
- no energy subsidy is applicable to those plants that started their operation after December 31, 2008 if they have enjoyed other types of public subsidy.

The TGCs regime has been partly revised as follows:

- the duration of the new TGCs is extended from 12 to 15 years;
- GSE may issue TGCs for an amount equal to the one of renewable energy purchased by the GSE under the CIP6 scheme, for its own use, as well as for offsetting fluctuations in the annual production of renewable energy or insufficient offers of

TGCs on the market (but subject to certain reconciliation obligations every three years).

From 2008 on, the GSE may sell such certificates on the electricity market at a price per MWh equal to the difference between: (i) a reference value, initially set at €180/MWh ($257/MWh); and (ii) the yearly average price at which IAFR plants sold electricity to local network operators during the previous year, to be assessed by AEEG. The reference price may be adjusted every three years by the GSE in order to ensure that the production of renewable energy is properly incentivized.

Should the total offer of TGCs exceed their demand on the market, as a consequence of a failure to increase the renewable requirement, the GSE is obliged to purchase every year any unused TGC at a price equal to the average price of TGCs recorded on the electricity market during the previous year.

Future policies

On July 6, 2012 a Ministerial Decree (the decree, henceforth) about renewable energy incentives was enacted. The decree implements the criteria indicated in Decree 28/2011, and sets out a new incentive scheme for wind-farms, hydro-electrical plants, geo-thermal power plants, biomass, biogas, bio liquids, depuration gas, landfill gas plants, waste treatment plants and wave power plants, which are new, totally rebuilt, refurbished or enlarged; possess a minimum power capacity of 1kW; and will be operational by January 1, 2013.[38]

The decree establishes a ceiling equal to 5.8 billion Euros in public funds for year 2013 (the "2013 Cap") which can be used to support the development of renewable plants. This ceiling does not relate to incentives for solar photovoltaic plants, which are determined by a separate legislative decree. Moreover, the decree sets a cap on public funds which can be used for the refurbishment and rebuilding works of existing plants, and establishes three alternative ways to gain access to the incentives, described below.

Enrollment in the Register of Qualified Plants

Application to enrol GSE maintains a "Register of Qualified Plants" (the Register). Enrolment in the Register is mandatory for plants with less than 5MW capacity (less than 10MW if the plant is hydro-electric or less than 20MW if the plant is geothermal). The application to enrol is submitted to the GSE by the plant's owner and

[38]Incentives relating to solar photovoltaic plants are not covered by the decree.

must contain the plant's authorisation, a valid grid interconnection proposal and a self-declaration about the mandatory requisites to be enrolled in the Register. GSE sets a time period during which all applications must be submitted; following that period it publishes a list of the enrolled plants. These are listed in the Register according to the criteria provided in paragraph 10 of the Decree which gives priority, *inter alia*, to:

- plants which have been constructed by agricultural companies;
- plants using biological products;
- plants which have been enrolled in the previous register/s or which have been already been granted the authorisation or that have entered into operation, as well as smaller plants.

Deadline for getting into operation Once enrolment in the Register is confirmed, the plant must get into operation within a period of 16 to 36 months, depending on the type of plant. Failure to comply with this obligation results in the incentive being reduced by 0.5 percent a month, up to 12 months. After 12 months of delay have past, the plant and its owner are not ent incentive. Moreover, if the owner of the plant re-applies for the incentive, it is entitled a reduced incentive (i.e., 15% of its current value).

Deadline for the enrolment procedure As regards the 2013 cap, GSE publishes technical guidance on the functioning of the Register and the method for enrolment; 15 days later a notice is published regarding the start of the first enrolment procedure. For subsequent years, GSE publishes the relevant notice within March 31 of each year. Each procedure shall include an overall cap which is applicable to the relevant year.

Participation in a Descending Auction The option to participate in a descending auction applies to renewable plants that exceed the threshold capacity for enrolment indicated above. If an existing plant is enlarged, the capacity of the plant is determined by the difference between capacities prior to and post the enlargement.

Here follows a brief description of the descending auction procedure.

Auction notice The GSE publishes an auction notice 30 days before the start of a 60-day period during which offers may be submitted. The same deadlines for the enrolment auction notice apply.

Application for participation The application for participation in the auction must be submitted to the GSE together with other documentation as specified in Annex 3 of the Decree, together with a self-declaration of the applicant stating that the owner of the plant meets the requisites for participation.

Participants' requisites The main requirements for participation in the auction are listed below; other requirements may be imposed by the GSE.

The applicant must :

- have the plant's authorisation certificate (or, in specific cases, concession or environmental impact assessment decree);
- have a valid grid interconnection proposal;
- be able to show financial and economic soundness of the owner of the plant, which can be demonstrated by providing a declaration from a bank, or giving evidence of a capacity of a 10 percent minimum equity of the costs of the project;
- provide a temporary financial guarantee (and definitive guarantee in case of awarding of the auction);
- demonstrate that it is in compliance with the requirements indicated in public contract codes (i.e., Italian Legislative Decree 163/2006, paragraph 38).

Ranking The ranking list is based on the best reduction of the reference value offered. The reference value must be based on the values indicated by the Decree for each source of energy (i.e. wind, geothermal power, biomass etc); offers containing a reduction of less than 2 percent of the auction base are excluded from the calculation.In case of two or more equal offers, other priority criteria, contained in paragraph 15 of the decree apply (e.g., based on technologies). Rankings are published by GSE within 60 days from the end of the auction procedure.

Getting into operation Plants awarded incentives by auction participation must be operative within 28 to 40 months, depending on the type of plant. Delays result in a reduction of the incentive by 0.5 percent per month, up to a maximum of 24 months. Once this deadline is exceeded, the plant does not get any incentive (and the utlimate guarantee is withdrawn by the GSE). For those plants subject to refurbishment, rebuilding and/or enlargement works, a procedure similar to the auction must be issued by the GSE.

Direct access The direct access option applies to very small plants as defined in paragraph 4 of the decree, and include, among others: wind farms with less than 60kW capacity, hydro-electric plants with less than 50kW capacity, and wind farms, hydro and biomass plants having double the above-mentioned capacities.

Incentives

Plants enrolled in the Register As regards plants enrolled in the Register, the amount of the incentive for each kind of source, as stated in Annex 1 of the decree, depends on the date in which the plant gets into operation. A value is set which applies to all the new plants getting into operation in 2013; for the following years, a yearly reduction of 2 percent applies. For those existing plants subject to refurbishment/rebuilding or enlargement works, a special value for the incentive is established on the basis of the values indicated in Annex 1 divided by a coefficient (greater than 1) which depends on the kind o work and the sources of energy, as indicated by Annex 2 of the decree. Only plants enrolled in the Register that fall within the national cap are granted the incentive

Plants awarded by a descending auction Descending auctions envisage offers below the reference value set by the auctioneer. The reference value is represented by the applicable incentive at the date on which the plant starts to be operative. The yearly reduction of 2 percent apply from 2016 onwards. The minimum value of the incentive, however, cannot be lower than a 30 percent discount of the reference value. Only plants that fall within the national cap indicated above are granted the incentive.

Period that the incentive is paid In all cases, the incentive is paid starting from the date the relevant plant is "commercially operative", which is the date that the owner of the plant starts to sell energy produced by the plant; this may be different than the date the plant is connected to the grid. The period in which the owner is entitled to receive the incentive depends on the source of energy used at the plant (e.g., for off-shore wind farms it is 25 years and for hydro power plants it is 25-30 years, based on the capacity of the plant; for tidal waves plants having a maximum capacity of 5MW, the period is 15 years; for geo-thermal power plants with a maximum capacity of 1MW, it is 25 years).

Temporary incentive regime during the interim period Paragraph 199 of the decree sets out the rules underlying the incentive scheme during the transitional period between the old green certificate regime (applicable until 2015) and the new regime. Plants which received authorization by or before July 11, 2012 and which get into operation from that date up until April 30, 2013 (extended to May 30, 2013 for waste treatment plants), are entitled an incentive after 2015, calculated according to this equation:

$$Incentive = x \times (180 - esp) \times 0,78.$$

1. x is equal to 1 for those plants which got into operation within December 31, 2007, or equal to the coefficient for those which got into operation after this date (i.e., 180− National Energy Price) established by paragraph. 2(148) of the 2007 Budget Law (L. 244/2007); and

2. esp is the electricity sale price, as established each year by the AEEG (for biomass and biogas plants, the price is the 2012 sale price and for bio liquids plants the price is the 2009 sale price).

Moreover, for the years 2012-2015, GSE is obliged to issue the relevant green certificates to the operators every three months and withdraw them at the price established by Decree 28/2011. The GSE then withdraws the green certificates two times per year.

Special rules for biomass, biogas, bio liquids and waste treatment plants For biomass, biogas, bio liquids and waste treatment plants, the decree establishes special rules concerning compliance with the "sustainable criteria" in order to control of the quality and quantity of raw materials used. As regards waste treatment plants, only some categories of waste are admitted as renewable sources.

Premiums In addition to the public incentives, the decree introduces a new system of premium payments for certain categories of plants, including biomass, bio liquid and bio gas plants. For example, premiums are available to:

- biomass plants having between 1MW and 5MW capacity if the owner can demonstrate the plant reduces greenhouse gases emissions;

- biomass plants which are fuelled by certain predefined types of biomass, as listed in Table 1-B of the decree;

- biomass plants which comply with certain strict air emission standards, defined in the decree;

- biomass, bio liquids and biogas plants which are part of high capacity cogeneration technology plants that are connected to a heating district network;
- bio gas cogeneration plants which permit the recovery of nitrogen for agricultural purposes.

Moreover, paragraph 28 of the decree states special rules for the thermo-dynamic solar plants which get into operation from 2013, introducing a more advantageous incentive regime and some additional technical provisions to supplement the existing legislative regime.

Agreement with GSE For all plants receiving incentives under the new scheme provided by the decree, the owner of the plant must provide the GSE with specific documents within 30 days from the date the plant gets into operation. Then, within the following 90 days, the GSE executes an agreement with the relevant plant owner and pay the incentive monthly or through instalments every two or more months if the amount does not exceed the thresholds set by the GSE in its guidelines. The decree establishes that certain operating costs of the GSE must be reimbursed by the recipients of the incentives. The standard agreement must be sent by the GSE to AEEG for its review within 3 months from the date the decree enters into force.

Price of electricity and “mercato tutelato”

The electricity liberalization in Italy started in 1999 and was concluded in 2007, when the electricity market was open to all classes of consumers, therefore also to residential consumers (households). Before 2007 domestic consumers had access only to the so called “mercato vincolato”, i.e. a sort of captive market. After 2007, the “mercato vincolato” has become “mercato tutelato”, but it is now a choice whether to buy in the free market or in the “mercato tutelato”. The majority of domestic consumers still chooses the “mercato tutelato”.

Liberalization Milestones:

- 1999 - The free market was open to end users with levels of consumption at least equal to 30 GWh per year and a minimum volume of consumption of 2GWh per year for each firm belonging to an “electricity purchase consortium”;[39]

[39] The “decreto Bersani” law is unique in allowing small and medium enterprises to access the market through “electricity purchase consortia”, instead of directly.

- January 2000 - Thresholds varied to 20 GWh per year and 1 GWh per year;
- January 2002 - Thresholds varied to 9 GWh per year and 1 GWh per year;
- May 2003 - Thresholds varied to 100.000 KWh per year (consortia were abolished);
- July 1, 2004 - All but residential consumers have access to the market (no limits of consumption);
- July 1, 2007 - All can access the market.

Directive 2003/54/CE is especially concerned with public service obligations and customer protection; specifically, "Member States shall ensure that all household customers, and, where Member States deem it appropriate, small enterprises, (namely enterprises with fewer than 50 occupied persons and an annual turnover or balance sheet not exceeding EUR 10 million), enjoy universal service, that is the right to be supplied with electricity of a specified quality within their territory at reasonable, easily and clearly comparable and transparent prices. To ensure the provision of universal service, Member States may appoint a supplier of last resort." Also, "Member States shall take appropriate measures to protect final customers, and shall in particular ensure that there are adequate safeguards to protect vulnerable customers, including measures to help them avoid disconnection."

In Italy such a directive has been enforced through Decree Law 73/2007, that allows two systems of customer protection: "Servizio di maggior tutela" for residential consumers as well as firms connected to low-tension networks with less than 50 employees and total yearly proceeds up to 10 mln Euros, as these are "captive" classes of consumers different from commercial consumers; "Servizio di salvaguardia" for all other customers, to help them avoid disconnection. Acquirente Unico - AU (single buyer) is responsible for the supply of electricity for the captive market. It shall buy electricity at best conditions and shall hedge market prices through long term contracts.[40] Distributors' costs

[40] "Acquirente Unico S.p.A. (AU) is a subsidiary of the Gestore dei Servizi Energetici-GSE S.p.A. Group. AU is vested by law with the mission of procuring continuous, secure, efficient and reasonably-priced electricity supply for households and small businesses.

AU buys electricity in the market on the most favourable terms and resells it to distributors or retailers of the standard offer market ("mercato di maggior tutela") for supply to small consumers who did not switch to the open market.

Since the full opening-up of the electricity market on 1 July 2007, under Law-Decree no. 73 of 18 June 2007, AU has been purchasing electricity to cover the requirements of the standard offer market, i.e. household and small business consumers (connected at low voltage, with less than 50 employees and a yearly turnover not exceeding € 10 million) who did not choose a new provider in the open market.

AU buys electricity on the basis of demand forecasts and resells it to standard offer retailers in are passed through to electricity suppliers for the captive market (both dispatching and energy cost). They recover all these costs from end customers. Their tariff is regulated, unique for the whole country, updated every 3 months for the energy costs, and reflects: AU wholesale energy acquisition costs, Transmission and Distribution costs, Average regulated supply costs. In our study we consider the yearly average price of electricity for Italian households (taxes included) in the "mercato tutelato".

Appendix B

In this Appendix, we provide an in-depth discussion of the (Q)AIDS and EASI demand system Models.

6.1 Almost Ideal Demand Systems

The original AIDS model of Deaton and Muellbauer (1980) is easily derived from the most general form of AIDS, the Quadratic AIDS of Banks et al. (1997). We present the Quadratic AIDS for expositional clarity. In our analysis, we estimated a Quadratic AIDS both with and without demographic scaling, but income elasticities obtained showed little economic sense. We therefore opted for excluding the Quadratic AIDS as a possible demand estimation model to describe our data.

Consider a consumer's demand for a set of k good categories. The Quadratic AIDS of Banks, Blundell, and Lewbel (1997) is based on the indirect utility function

$$\ln v\left(\mathbf{p}, y\right) = \left\{ \left[\frac{\ln y - \ln a\left(\mathbf{p}\right)}{b\left(\mathbf{p}\right)} \right]^{-1} + \lambda\left(\mathbf{p}\right) \right\}^{-1}, \tag{3}$$

where y represents household total expenditure, $\mathbf{p}$ is a vector of prices, and $\ln a\left(\mathbf{p}\right)$

accordance with its mission and with the directions given by AEEG.

The ways in which AU procures electricity are specified in the Decree of the Minister of Productive Activities of 19 December 2003. Under the Decree, AU may:

- make OTC contracts (off the power exchange) for a volume not exceeding 25% of the overall yearly forecast demand of the captive market;
- participate in procedures for allocation of transmission capacity in order to import electricity from abroad and, based on its allocated capacity, make contracts with foreign suppliers;
- procure electricity in the electricity market in order to cover the remaining requirements, after making financial contracts to hedge the risk of price volatility.

After buying electricity, AU resells it to standard offer retailers in accordance with the directions given by AEEG, at prices permitting AU to cover its recognised costs and balance its accounts". (`http://www.acquirenteunico.it/`)

is the translog function

$$\ln a(\mathbf{p}) = \alpha_0 + \sum_{i=1}^{k} \alpha_i \ln p_i + \frac{1}{2} \sum_{i=1}^{k} \sum_{j=1}^{k} \gamma_{ij} \ln p_i \ln p_j,$$

while $b(\mathbf{p})$ is the Cobb-Douglas price aggregator

$$b(\mathbf{p}) = \prod_{i=i}^{k} p_i^{\beta_i},$$

and

$$\lambda(\mathbf{p}) = \sum_{i=1}^{k} \lambda_i \ln p_i.$$

Axioms of choice are satisfied when adding up, homogeneity, and Slutsky symmetry are satisfied, i.e. when

$$\sum_{i=1}^{k} \alpha_i = 1, \quad \sum_{i=1}^{k} \beta_i = 0, \quad \sum_{i=1}^{k} \gamma_{ij} = 0, \quad \sum_{i=1}^{k} \lambda_i = 0, \quad \text{and} \quad \gamma_{ij} = \gamma_{ji}.$$

Applying Roy's identity to (3) we can express the model in expenditure share form, which is the equation system to be estimated (assuming an additive zero-mean error term associated with each share equation):

$$\omega_i = \alpha_i + \sum_{j=1}^{k} \gamma_{ij} \ln p_j + \beta_i \ln \left[\frac{y}{a(\mathbf{p})} \right] + \frac{\lambda_i}{b(\mathbf{p})} \left\{ \left[\frac{y}{a(\mathbf{p})} \right] \right\}^2.$$

When $\lambda_i = 0$ for all i, the quadratic term drops out and we obtain the Deaton and Muellbauer's (1980) AIDS specification.[41]

6.1.1 Demographics

In the original AIDS models, heterogeneity in individual preferences is not modelled since allowing for heterogeneous preferences in a flexible demand system is quite cumbersome. This is a very restrictive approach, since heterogenous preferences are very likely to play a crucial role in shaping demand. One way to overcome this limit is to assume that differences in preferences can be to some extent related to socio-demographic

[41] Notice that because of the translog price index $\ln a(\mathbf{p})$, the set of expenditure share equations requires non-linear estimation also in the AIDS case.

characteristics of the household. The effects of demographic characteristics on consumption patterns have been widely explored, and the literature on the introduction of demographic effects in theoretically-consistent AIDS models is quite large. Three main approaches are identifiable: demographic scaling, demographic translating and the Gorman procedure. Demographic scaling means modifying the arguments of the household cost function so that prices and total expenditure are scaled to reflect heterogeneity in household demographics. Strictly speaking, scaling means adjusting prices and total expenditure to reflect equivalence scales (Lewbel, 1985; Pollak et al., 1981), which results in a demand system where price and income coefficients depend on demographics. Demographic translating consists in allowing the constant term in a demand equation to depend on demographics, so that only preferences are allowed to vary according to household characteristics, while the other behavioral parameters (price and expenditure coefficients) are constant across households. The Gorman procedure is basically a combination of these two approaches (see also Blundell, Pashardes, and Weber (1993)).

We have opted for the demographic scaling approach in two different flavors. A first possible way of embedding r demographic variables while overcoming the estimation problems associated with the proliferation of parameters is to let them enter as taste-shifters in the share equations, i.e. as α_i terms in the $\ln a(\mathbf{p})$ expression, as suggested by Lewbel (1985):

$$\ln a(\mathbf{p}) = \alpha_0 + \sum_i \left(\alpha_i + \sum_{h=1}^{r} \alpha_{ih} z_h \right) \ln p_i + \frac{1}{2} \sum_{i=1}^{k} \sum_{j=1}^{k} \gamma_{ij} \ln p_i \ln p_j;$$

$$\omega_i = \alpha_i + \sum_{h=1}^{r} \alpha_{ih} z_h + \sum_{j=1}^{k} \gamma_{ij} \ln p_j + \beta_i \ln \left[\frac{y}{a(\mathbf{p})} \right] + \frac{\lambda_i}{b(\mathbf{p})} \left\{ \left[\frac{y}{a(\mathbf{p})} \right] \right\}^2,$$

the new adding-up conditions being:

$$\sum_{i=1}^{k} \alpha_i = 1, \ \sum_{i=1}^{k} \alpha_{ih} = 0.$$

Another way of allowing for scaling demographic characteristics in AIDS models is Poi's (2002) extended technique *à la* Ray (1983). Denoting the vector of r characteristics with $\mathbf{z}$ and $C^H(\mathbf{p}, u)$ being the expenditure function of a reference household, each household cost function is:

$$C(\mathbf{p}, \mathbf{z}, u) = y_0(\mathbf{p}, \mathbf{z}, u) \cdot C^H(\mathbf{p}, u)$$

where the scaling function $y_0(\cdot)$ is given by

$$y_0(\mathbf{p}, \mathbf{z}, u) = \bar{y}_0(\mathbf{z}) \cdot \theta(\mathbf{p}, \mathbf{z}, u).$$

$\bar{y}_0(\cdot)$ is parametrized as

$$\bar{y}_0(\mathbf{z}) = 1 + \rho^T \mathbf{z}$$

and $\theta(\cdot)$ as

$$\ln \theta(\mathbf{p}, \mathbf{z}, u) = \frac{\prod_{j=i}^{k} p_j^{\beta_j} \left(\prod_{j=i}^{k} p_j^{\eta_j^T \mathbf{z}} - 1 \right)}{\frac{1}{u} - \sum_{j=1}^{k} \lambda_j \ln p_j}.$$

Thus the expenditure share equations will be

$$\omega_i = \alpha_i + \sum_{j=1}^{k} \gamma_{ij} \ln p_j + \left(\beta_i + \eta^T \mathbf{z}\right) \ln \left[\frac{y}{\bar{y}_0(\mathbf{z})\, a(\mathbf{p})} \right] + \frac{\lambda_i}{b(\mathbf{p})\, c(\mathbf{p}, \mathbf{z})} \left\{ \left[\frac{y}{\bar{y}_0(\mathbf{z})\, a(\mathbf{p})} \right] \right\}^2$$

$$c(\mathbf{p}, \mathbf{z}) = \prod_{j=1}^{k} p_j^{\eta_j^T \mathbf{z}}.$$

New restrictions to the parameters in order the demand system to satisfy the adding up property are $\sum_{j=1}^{k} \eta_{hj} = 0$ for $h = 1, \ldots, r$. As before, if $\lambda_i = 0$ we face the AIDS model.

AIDS models are estimated through a system of non-linear equations by feasible generalized non-linear least squares (FGNLS). Details about estimation and calculation of income and price elasticities are reported in Appendix A.

Note that we estimated the AIDS and Quadratic AIDS using Poi's (2002) method – through a self-written Stata program by the same author – and obtained parameter and price elasticity estimates similar for both models; however, income elasticities (or more precisely total expenditure eleasticities) computed by Quadratic AIDS were not in line with economic theory, therefore suggesting that such a model is not a good fit for the case at hand. The same result was obtained with no demographics.

AIDS Models Elasticities

Uncompensated price and income elasticities of AIDS and Quadratic AIDS are presented. Those are computed as follows:

$$\epsilon_{ij} = -\delta_{ij} + \frac{1}{\omega_i}\left[\gamma_{ij} - \beta_i\left(\alpha_j - \sum_k \gamma_{kj}\ln p_k\right)\right] \tag{4}$$
$$\nu_i = \frac{\beta_i}{\omega_i} + 1$$

$$\epsilon_{ij} = -\delta_{ij} + \frac{1}{\omega_i}\left\{\gamma_{ij} - \left[\beta_i + \frac{2\lambda_i}{b(\mathbf{p})}\left(\ln\frac{x}{a(\mathbf{p})}\right)\right]\left(\alpha_j + \sum_k \gamma_{kj}\ln p_k\right) - \frac{\lambda_i\beta_j}{b(\mathbf{p})}\left[\ln\frac{x}{a(\mathbf{p})}\right]^2\right\} \tag{5}$$
$$\nu_i = \frac{1}{\omega_i}\left[\beta_i + \frac{2\lambda_i}{b(\mathbf{p})}\left(\ln\frac{x}{a(\mathbf{p})}\right)\right] + 1$$

$$\epsilon_{ij} = -\delta_{ij} + \frac{1}{\omega_i}\left\{\gamma_{ij} - \left[\beta_i + \frac{2\lambda_i}{b(\mathbf{p})}\left(\ln\frac{x}{a(\mathbf{p},\mathbf{z}^h)}\right)\right]\left(\alpha_j\left(\mathbf{z}^h\right) + \sum_k \gamma_{kj}\ln p_k\right) - \frac{\lambda_i\beta_j}{b(\mathbf{p})}\left[\ln\frac{x}{a(\mathbf{p},\mathbf{z}^h)}\right]^2\right\} \tag{6}$$
$$\nu_i = \frac{1}{\omega_i}\left[\beta_i + \frac{2\lambda_i}{b(\mathbf{p})}\left(\ln\frac{x}{a(\mathbf{p},\mathbf{z}^h)}\right)\right] + 1$$

where δ_{ij} is the Kronecher delta. Specifically, equations (4) show elasticities for AIDS, which do not differ depending on the inclusion of taste-shifter characteristics; equations (5) and (6) show elasticities for the Quadratic AIDS model in the plain and demographic scaling versions, respectively.

The Slutsky's equation allows us to compute compensated price elasticities as

$$\epsilon_{ij}^{COMP} = \epsilon_{ij} + \nu_i\omega_i$$

Using Poi's (2002) method, uncompensated price elasticities in the most general formulation (Quadratic AIDS with demographics) are computed as

$$\epsilon_{ij} = -\delta_{ij} + \frac{1}{\omega_i}\left\{\gamma_{ij} - \left[\left(\beta_i + \eta^T\mathbf{z} + \frac{2\lambda_i}{b(\mathbf{p})\,c(\mathbf{p},\mathbf{z})}\ln\left(\frac{y}{\bar{y}_0(\mathbf{z})\,a(\mathbf{p})}\right)\right)\right] \times \right.$$
$$\left.\left(\alpha_j + \sum_s \gamma_{js}\ln p_s\right) - \frac{\left(\beta_i + \eta^T\mathbf{z}\right)\lambda_i}{b(\mathbf{p})\,c(\mathbf{p},\mathbf{z})}\left[\ln\left(\frac{y}{\bar{y}_0(\mathbf{z})\,a(\mathbf{p})}\right)\right]^2\right\}$$

and income elasticity for good i is:

$$\nu_i = 1 + \frac{1}{\omega_i}\left[\beta_i + \eta^T \mathbf{z} + \frac{2\lambda_i}{b(\mathbf{p})\,c(\mathbf{p},\mathbf{z})}\ln\left(\frac{y}{\bar{y}_0(\mathbf{z})\,a(\mathbf{p})}\right)\right].$$

AIDS Models Estimation

The AIDS models are estimated through a system of non-linear equations by feasible generalized non-linear least squares (FGNLS). It can be viewed as a nonlinear variant of Zellner's seemingly unrelated regression model (Zellner 1962; Zellner and Huang 1962; Zellner 1963) and is therefore commonly called nonlinear SUR or nonlinear SURE. Formally, the model is

$$\begin{aligned} y_{i1} &= f(\mathbf{x}_i\beta) + u_{i1} \\ &\cdots \\ y_{iN} &= f(\mathbf{x}_i\beta) + u_{iN} \end{aligned}$$

The errors for the ith observation may be correlated, so fitting the m equations jointly may lead to more efficient estimates. Moreover, fitting the equations jointly allows us to impose cross-equation restrictions on the parameters. By estimating demand system parameters by iterated feasible generalized non-linear least-square estimation we assume that each of the share equation is associated with an additive zero-mean error term. For this model, iterative FGNLS estimation is equivalent to maximum likelihood estimation with multivariate normal disturbances.

As regards Poi's version of the models, we make use of the user-written Stata command `-quaids-` by Brian Poi (2012). Such a command, that makes use of iterated FGNLS as well, computes income, compensated and uncompensated price elasticities at means of all the variables or for individual observations in the dataset, even though no option exists which allows us to retrieve elasticities' standard errors, due to cumbersome computation.

6.2 Exact Affine Stone Index Demand System

AIDS models, despite being relatively easy to estimate and for this reason widely used, entail empirical and theoretical limitations. Allowing for unobserved preference heterogeneity in demand systems has been shown to be very important: observables like prices, expenditure and household demographics explain no more than half the variation in budget shares. For instance, Lewbel (2008) comments: "This matters in part because another of Allen and Bowley's (1935) findings remains true today, namely [...] demand function models still fail to explain most of the observed variation in individual consumption behavior.". However, in AIDS models error terms cannot be interpreted as random utility parameters representing unobserved heterogeneity. Furthermore, such parametric models are characterized by Engel curves that are additive in functions of expenditure and are therefore constrained by Gorman's (1981) rank restriction: independent of the number of Engel curves in the model, they must be expressed as linear combinations of at most three functions of expenditure (in the Quadratic AIDS, most general model). The EASI model is an attempt to overcome these shortcomings, while keeping the desirable feature of being "easi-ly" estimable like AIDS ones. Lewbel and Pendakur (2009) introduce the concept of *implicit Marshallian demand functions* (IMDFs), which are Hicksian demands with the unobserved utility level substituted out. They show that a demand system built upon IMDFs is linear in the parameters, can incorporate unobserved heterogeneity, is not limited by the Gorman-type restrictions, and can accommodate highly non-linear forms of the Engle curves.

Let $e(\mathbf{p}, u, \mathbf{z}, \varepsilon)$ be the expenditure function, with $\mathbf{p}$ denoting the price vector, u the utility level attained at prices p, $\mathbf{z}$ the set of demographic characteristics, and ε a vector of error terms that include unobservable preference heterogeneity. Hicksian budget share functions, derived applying Shepard's lemma, are $\omega = \omega(\mathbf{p}, u, \mathbf{z}, \varepsilon) = \nabla_p e(\mathbf{p}, u, \mathbf{z}, \varepsilon)$. The implicit utility function is defined as $\upsilon = \upsilon(\omega(\mathbf{p}, u, \mathbf{z}, \varepsilon), \mathbf{p}, y, \mathbf{z}) = \upsilon(\omega, \mathbf{p}, y, \mathbf{z})$ and depends only on observable data. The implicit Marshallian demand system is defined as $\omega = \omega(\mathbf{p}, \upsilon, \mathbf{z}, \varepsilon)$, which is simply the Hicksian demand system with υ substituted for u. υ corresponds to an affine function of the Stone index deflated by the log nominal expenditure.

The most general functional form of the expenditure function proposed by Lewbel and Pendakur (2009), which includes all two-way interactions among y, $\mathbf{z}$ and $\mathbf{p}$, is one that lends itself to be conveniently implemented in empirical work:

$$\ln e(\mathbf{p}, u, \mathbf{z}, \varepsilon) = \upsilon + \sum_{i=1}^{k} y_i(\upsilon, \mathbf{z}) \ln p_i + \frac{1}{2} \sum_{i=1}^{k} \sum_{j=1}^{k} \alpha_{ij}(\mathbf{z}) \ln p_i \ln p_j \tag{7}$$
$$+\frac{1}{2} \sum_{i=1}^{k} \sum_{j=1}^{k} \beta_{ij} \ln p_i \ln p_j \upsilon + \sum_{i=1}^{k} \varepsilon_i \ln p_i.$$

where

$$y_i(\upsilon, \mathbf{z}) = \sum_{q=1}^{s} \beta_{iq}\upsilon_q + \sum_{h=1}^{r} g_{ih}z_h + \sum_{h=2}^{r} h_{ih}z_h\upsilon, \tag{8}$$

and

$$\alpha_{ij}(\mathbf{z}) = \sum_{h=1}^{r} \alpha_{ijh}z_h. \tag{9}$$

Implicit Marshiallian budget shares are calculated by applying Shepard's lemma and are given by

$$\omega_i = \sum_{q=1}^{s} \beta_{iq}\upsilon_q + \sum_{h=1}^{r} g_{ih}z_h + \sum_{j=1}^{r}\sum_{h=1}^{r} \alpha_{ijh}z_h \ln p_j + \sum_{i=1}^{k} \beta_{ji} \ln p_i \upsilon + \sum_{h=2}^{r} h_{ih}z_h\upsilon + \varepsilon_i \tag{10}$$

$$\upsilon = \frac{\ln y - \sum_{i=1}^{k} \omega_i \ln p_i + 1/2 \sum_{i=1}^{k}\sum_{j=1}^{k} \alpha_{ijh}z_h \ln p_i \ln p_j}{1 - 1/2 \sum_{i=1}^{k}\sum_{j=1}^{k} \beta_{ij} \ln p_i \ln p_j}.$$

Strict monotonicity and concavity of the expenditure function ensure regularity conditions of the demand system to be satisfied.

As regards estimation methods, in order to account for the endogeneity of υ, Pendakur (2008) and Lewbel and Pendakur (2009) suggest an iterative linear 3SLS estimator, i.e. a special case of a fixed-point based estimator by Dominitz and Sherman (2005). The reader is cross-referred to Lewbel and Pendakur (2009) for the functional form of budget share, quantity, real expenditure and observable demographics' elasticities, included price ones.

Appendix C

A utility-based approach used to specify the demand model's integrability, as in the AIDS case, allows exact welfare measurement. An attractive measure of the welfare impact is the compensating variation (CV): the change in income a household would require in order to be made indifferent between the original price vector (at the original income level) and the new price vector. This is calculated as $\exp(\log e(\mathbf{p}_0, u) - \log e(\mathbf{p}_1, u))$ where $e(\mathbf{p}_0, u)$ is simply the original log income y^0. Thus:

$$CV = y^0 - \exp\left(a(\mathbf{p}_1) + \left(\log y - a(\mathbf{p}_0)\,\frac{\mathbf{p}_0}{\mathbf{p}_1}^{\beta_1}\right)\right)$$

The exact measure of welfare that results from the AIDS expenditure function can be directly computed from the model's estimated parameters. Notice that CV is not independent of income, different from the case of random utility and other models that impose restrictions on income effects to facilitate welfare measurement.

in the case of the EASI mode, the welfare measure we for our incidence analysis is the equivalent income, which is defined as the income level, eq_h, that ensures the utility levels are the same when evaluated at two prices vectors, i.e.:

$$v\left(\mathbf{p}_c, y_h\right) = v\left(\mathbf{p}_r, eq_h\right) \tag{11}$$

where $v\left(\cdot\right)$ is the indirect utility function, $\mathbf{p}_r$ is the reference price, and $\mathbf{p}_c$ is a different price vector. By inverting the indirect utility function, we obtain the equivalent income in terms of expenditure function: $eq_h = e\left(\mathbf{p}_r, \mathbf{p}_c, y_h\right)$. In practice, eq_h is the equivalent income of household h that faces the price vector $\mathbf{p}_c$, with a level of nominal income y_h. The equivalent income is the level of income, at the reference price $\mathbf{p}_r$, that offers the same utility level than that obtained with the income level y_h and the price system $\mathbf{p}_c$. The function $e\left(\mathbf{p}_r, \mathbf{p}_c, y_h\right)$ is increasing with respect to $\mathbf{p}_r$ and y_h, decreasing with $\mathbf{p}_c$, concave and homogeneous of degree one with respect to the reference price, and has continuous first and second derivatives in all its arguments. Consider the cost function (7) in the EASI class, where υ is replaced by u . From (8) and (9), we have:

$$y_i\left(\upsilon, \mathbf{z}\right) = \omega_i\left(\mathbf{p}, u, z\right) - \sum_{j=1}^{k} \alpha_{ij} \ln p_j - \sum_{j=1}^{k} \beta_{ij} \ln p_j u. \tag{12}$$

By substituting (12) in (7), we have:

$$\ln e\left(\mathbf{p}, u, \mathbf{z}\right) = u\left(1 - \sum_{i=1}^{k}\sum_{j=1}^{k} \beta_{ij} \ln p_i \ln p_j\right) + \sum_{i=1}^{k}\left(\omega_i\left(\mathbf{p}, u, z\right) - \sum_{j=1}^{k} \alpha_{ij} \ln p_j\right) \ln p_i$$
$$+\frac{1}{2}\sum_{i=1}^{k}\sum_{j=1}^{k} \alpha_{ij} \ln p_i \ln p_j.$$

The contemporary situation is characterized by nominal total expenditures, y_h and prices, $\mathbf{p}_c$. This configuration achieves a level of utility $\overline{u}$:

$$\overline{u} = \frac{\ln y_h - \sum_{i=1}^{k} \omega_i \ln p_{ci} + \frac{1}{2}\sum_{i=1}^{k}\sum_{j=1}^{k} \alpha_{ij} \ln p_{ci} \ln p_{cj}}{1 - \frac{1}{2}\sum_{i=1}^{k}\sum_{j=1}^{k} \beta_{ij} \ln p_{ci} \ln p_{cj}}. \tag{13}$$

The reference or *ex ante* situation is characterized by nominal total expenditures equal to the equivalent income, eq_h, and prices, $\mathbf{p}_r$: this configuration also achieves a level of utility $\overline{u}$. We can calculate this equivalent income eq_h by solving

$$\ln e\left(\mathbf{p}_r, u, \mathbf{z}\right) = \ln eq_h = \overline{u}\left(1 - \frac{1}{2}\sum_{i=1}^{k}\sum_{j=1}^{k}\beta_{ij}\ln p_{ci}\ln p_{cj}\right) \tag{14}$$

$$+\sum_{i=1}^{k}\left(\omega_i\left(\mathbf{p}_r, u, z\right) - \sum_{j=1}^{k}\alpha_{ij}\ln p_{rj}\right)\ln p_{ri} + \frac{1}{2}\sum_{i=1}^{k}\sum_{j=1}^{k}\alpha_{ij}\ln p_{ri}\ln p_{rj}$$

By substituting (13) in (14), we obtain:

$$eq_h = \exp(\ln y_h + \sum_{i=1}^{k}\omega_i \ln p_{ci} + \frac{1}{2}\sum_{i=1}^{k}\sum_{j=1}^{k}\alpha_{ij}\ln p_{ci}\ln p_{cj} +$$

$$-\frac{1}{2}\sum_{i=1}^{k}\sum_{j=1}^{k}\alpha_{ij}\ln p_{ri}\ln p_{rj}).$$

The CV is a monetary measure that quantifies the amount needed to compensate the household of their welfare loss in terms of total average monthly expenditure over ten years; the equivalent income, instead, is the monthly income level which ensures that the implicit utility enjoyed by the household is the same in the two scenarios: the reference one (simulated prices) and the current one (actual prices). In this case, estimating the percentage monthly average welfare loss over the period analyzed requires to compare the estimated equivalent income with the average monthly real income in the sample. It is important to stress that we do not need to analyze the impact of the policy distinguishing between different household types, given that the arguments of the household cost function in AIDS and EASI models are scaled to reflect heterogeneity in household demographics; in the EASI case unobserved heterogeneity is also accounted for. CV estimation after AIDS was only possible in the demographic scaling à la Lewbel case, as the user-written program of Poi (2002) does not allow us to use post estimation commands and apply the delta method in Stata, despite that being the preferred AIDS model. For this reason and due to the fact that EASI is our benchmark model, we report only results of the equivalent income estimation.

TABLE 1

Descriptive Statistics

Variable	Mean	St. Dev.	Min	Max	Quintiles (Mean Values)				
					q1	q2	q3	q4	q5
Electricity share	0.020	0.014	0	0,076	0.030	0.023	0.020	0.016	0.012
Heating Fuels share	0.031	0.030	0	0.154	0.035	0.034	0.032	0.030	0.024
Transport share	0.055	0.046	0	0.207	0.034	0.060	0.065	0.063	0.051
All the Rest of Goods share	0.894	0.054	0.726	1	0.900	0.883	0.883	0.891	0.913
Total Expenditure	2317.643	1394.932	375.428	8143.100	840.828	1427.594	1976.919	2732.437	4590.735
Number of Members	2.475	1.186	1	10	1.652	2.238	2.568	2.822	3.049
Age of reference person	57.107	16.901	16	85	67.07	58.047	54.736	53.388	52.962
Number of children below 6 years of age	0.120	0.376	0	4	0.043	0.108	0.141	0.155	0.150
Education of reference person: PhD	0.005	0.071	0	1	0.002	0.002	0.004	0.006	0.012
Education of reference person: Bachelor	0.075	0.263	0	1	0.019	0.047	0.067	0.094	0.145
Education of reference person: Some college degree	0.011	0.103	0	1	0.005	0.009	0.011	0.012	0.015
Education of reference person: High-school	0.232	0.423	0	1	0.100	0.198	0.253	0.288	0.318
Education of reference person: Diploma	0.060	0.237	0	1	0.028	0.054	0.066	0.074	0.076
Education of reference person: Junior high-school	0.295	0.456	0	1	0.223	0.317	0.331	0.319	0.278
Education of reference person: Primary school	0.268	0.442	0	1	0.451	0.317	0.243	0.189	0.145
Education of reference person: None	0.056	0.228	0	1	0.173	0.055	0.027	0.017	0.011
Northwest	0.237	0.425	0	1	0.180	0.214	0.234	0.263	0.293
Northeast	0.148	0.355	0	1	0.104	0.128	0.147	0.169	0.192
Middle	0.281	0.449	0	1	0.224	0.265	0.293	0.308	0.311
South	0.334	0.472	0	1	0.493	0.393	0.326	0.261	0.204
Number of observations		244,435			46,441	49,065	50,202	51,152	47,575

Note: Period 2000-2010; Total expenditure is expressed in Euros

TABLE 2

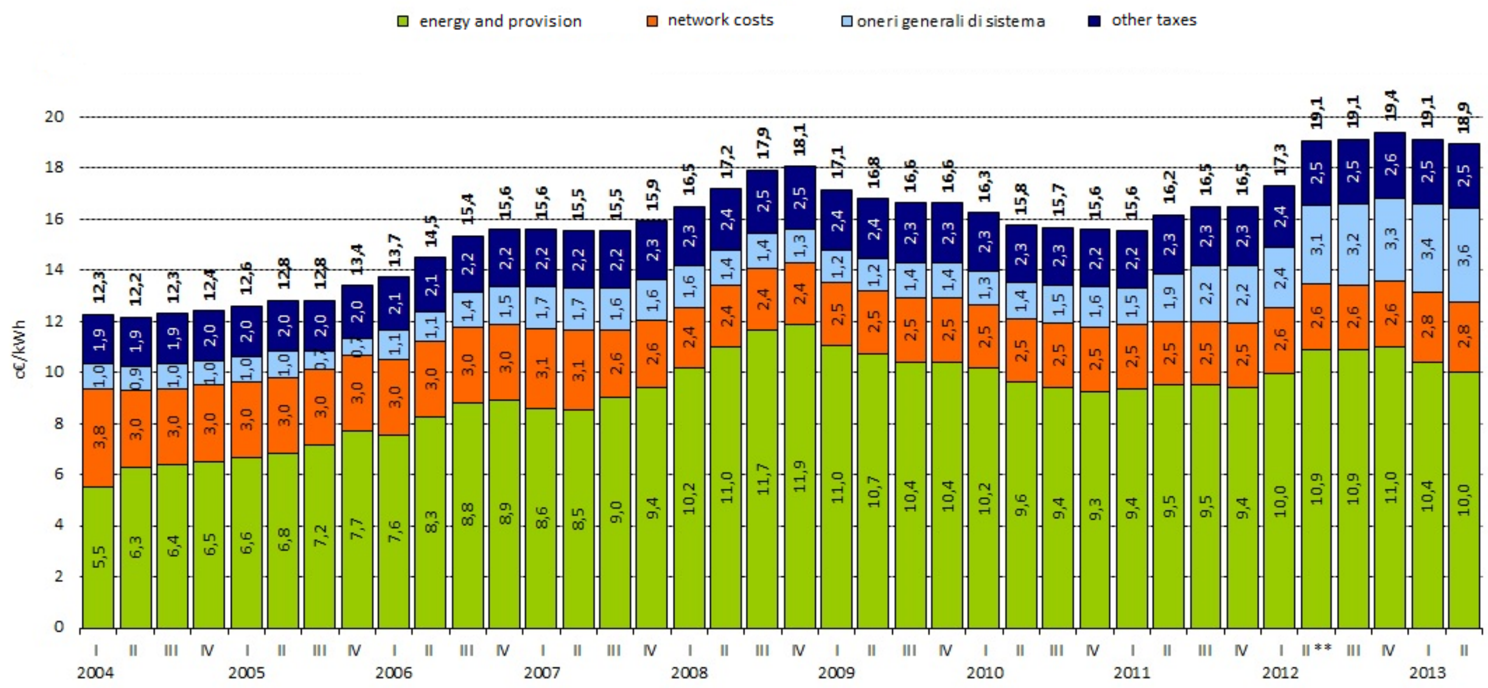
	Compensated Price Elasticities				Income Elasticities
	Electricity	Heating Fuels	Transport	Other	
	AIDS 1				
Electricity	-0.994	0.006	0.054	0.880	0.415
Heating Fuels	0.008	-0.973	0.055	0.894	0.708
Transport	0.008	0.021	-0.946	0.895	1.006
Other	0.009	0.031	0.058	-0.102	1.023
	AIDS 2				
Electricity	-0.046	-0.083	0.201	-0.072	0.305
Heating Fuels	-0.054	-0.842	0.095	0.801	0.634
Transport	0.074	0.053	-1.064	0.937	0.918
Other	-0.002	0.028	0.058	-0.084	1.029
	EASI				
Electricity	-0.020	-0.074	0.050	-0.024	0.384
Heating Fuels	-0.128	-0.843	0.003	-0.004	0.693
Transport	0.148	0.022	-1.102	0.001	0.974
Other	-0.483	0.199	0.064	-1.001	1.026

Note: Estimated Compensated Price Elasticities and Income Elasticities from AIDS and EASI models are reported. AIDS 1 refers to the model with demographic scaling à la Lewbel (1985), and AIDS 2 refers to the model with demographic scaling à la Poi (2002). Observations with total expenditure and shares above and below three standard deviations of the mean were dropped to control for outliers. Demographic variables included are: household size, number of children below 6 years of age, seasonal dummies, macro-regions dummies, and reference person educational dummies (8 categories from PhD to elementary school). Elasticities are evaluated at mean prices and mean total expenditure. Period 2000-2010.

TABLE 3					
		EASI			
QUINTILE 1	Electricity	Energy	Transport	Other	Income
Electricity	-0.023	-0.144	0.131	-0.032	0.452
Heating Fuels	-0.177	-0.688	-0.053	-0.004	0.898
Transport	0.155	-0.030	-1.209	0.004	2.062
Other	-0.651	-0.063	–0.591	-0.953	0.982
QUINTILE 2	Electricity	Energy	Transport	Other	Income
Electricity	-0.021	-0.095	0.037	-0.025	0.451
Heating Fuels	-0.153	-0.894	0.006	-0.001	0.764
Transport	0.116	0.037	-1.142	0.005	1.280
Other	-0.527	0.172	-0.149	-0.983	1.004
QUINTILE 3	Electricity	Energy	Transport	Other	Income
Electricity	-0.030	-0.054	0.031	-0.023	0.405
Heating Fuels	-0.106	-0.830	-0.014	-0.004	0.577
Transport	0.122	0.000	-1.093	0.003	1.028
Other	-0.513	0.281	0.051	-1.004	1.027
QUINTILE 4	Electricity	Energy	Transport	Other	Income
Electricity	-0.007	-0.027	0.022	-0.021	0.268
Heating Fuels	-0.069	-0.957	0.040	-0.005	0.462
Transport	0.098	0.108	-1.060	-0.003	0.760
Other	-0.338	0.453	0.250	-1.029	1.048
QUINTILE 5	Electricity	Energy	Transport	Other	Income
Electricity	-0.079	-0.036	0.060	-0.017	0.209
Heating Fuels	-0.088	-0.911	-0.004	-0.003	0.288
Transport	0.253	0.007	-0.979	-0.007	0.381
Other	-0.299	0.717	0.580	-1.049	1.064

Note: Estimated Price Elasticities from EASI with a third order polynomial in real expenditure and price effects interacted with observables are reported by quintiles of the distribution of total expenditure. Observations with total expenditure and shares above and below three standard deviations of the mean were dropped to control for outliers. Demographic variables included are: household size, number of children below 6 years of age, seasonal dummies, macro-regions dummies, and reference person educational dummies (8 categories from PhD to elementary school). Period 2000-2010.

FIGURE 1



Note: Electricity price and its components (expressed as c€/kWh) applied to a standard consumer, i.e. household with 3 kW employed and 2.700 kWh consumed yearly. Source: Italian Authority for Energy and Gas

TABLE 4

Welfare Analysis and Distributional Effects (2000-2010)						
	Average Household	Q1	Q2	Q3	Q4	Q5
Reference income	2317.643	840.828	1427.594	1976.919	2732.437	4590.735
Estimated equivalent income	2329.580	848.560	1449.983	2017.604	2783.967	4626.246
Welfare loss in Euros	11.937	7.7319	22.389	40.685	51.53	35.511
Welfare Loss %	0.514%	0.915%	1.556%	2.037%	1.868%	0.771%

Note: Computation made in terms of average monthly total expenditure over the years 2000-2010

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