Assessing Equity Effects of Climate Change Policy through the American Consumer Expenditure Survey: New Results on Housing and Transportation

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ABSTRACT

Climate change policies raise crucial equity issues at the world level, between industrialized (and belonging to Annex B) and developing countries, which represents a serious hurdle in defining a cooperative framework for a concerted mitigation policy. But not less serious –and much less addressed- is the domestic equity issue. There are obvious reasons to expect that the cost –before any compensation mechanism or an associated redistributive policy- will vary significantly according to categories of households, in particular to income classes. Indeed, it is well known that the share of energy consumption –either for residential use or in private transportation- is decreasing with income, so that low income groups would bear a relatively higher burden.
A preliminary analysis has be conducted on the basis of the American consumer expenditure survey (CEX) for which a span of 20 years –from 1984 to 2003- is now available, and a database pairing this survey with the Consumer Price Index, and was presented at the NCCR CLIMATE 2005 Seminar held in Interlaken. Welfare costs can then be compared according to income classes, the size of the family, the generation (age of the representative agent) and the region of residence.
New and more detailed results are presented here, namely concerning Private Transportation, by taking into account all categories of outlays, and Housing with alternative specifications of the demand function. A comparison is also performed between econometric estimates with individual and aggregate data. Differences with previous estimations are analyzed and commented.

Keywords: climate change, welfare cost, equity, demand function, Engel curve, Slutsky matrix, separability, additive separability

New concept: Technical Progress in consumption

JEL classification: C8, C31, D1, D58, D6

Climate change policies raise crucial equity issues at the world level, between industrialized (and belonging to Annex B) and developing countries, which represents a serious hurdle in defining a cooperative framework for a concerted mitigation policy. But not less serious –and much less addressed- is the domestic equity issue. There are obvious reasons to expect that the cost –before any compensation mechanism or an associated redistributive policy- will vary significantly according to categories of households, in particular to income classes. Indeed, it is well known that the share of energy consumption –either for residential use or in private transportation- is decreasing with income, so that low income groups would bear a relatively higher burden. Another aspect to cope with is the elasticity of demand for energy: the higher the elasticity, the higher the cost, for a given target of demand decrease, but the smaller the cost for a given price increase.

Households are likely to exhibit different price elasticities in energy consumption, but it is difficult from a simple reasoning to conjecture that, for instance, low income households have smaller price elasticities than high income households. This effect, additional to the pure income effect quoted above, is of the second order (compared to first order) as the Harberger's formula clearly shows. Then it is likely to make a difference only for large price variations, bigger than those that were experienced in the past, except for the short periods of oil crisis. However the contemplation of drastic climate change policies aimed at severely curbing GHG emissions requires such big variations.

Assessing the equity effects of climate change policy –and even its aggregate cost- needs estimating the main characteristics of demand functions, according to the level of income and category of household. It must also be based on the results of scenario policy assessment, as performed with general equilibrium models. The task is then at the crossing of these two fundamental exercises of applied economics, econometric estimation of demand functions, which is of microeconomic nature, and general equilibrium modeling, which is of macroeconomic nature even though based on microeconomic foundations.

As for global general equilibrium assessment, the present work is based on GEMINI-E3 and more precisely on simulations implemented in the framework of the Working Group 21 of the Energy Modeling Forum. It aims at measuring the possibility of –and the gains from- abatement of GES other than $C0_2$. Proceedings of the workshop will be published in a special issue of the Energy Journal. The preliminary results from GEMINI-E3 (the results from other modeling teams are not yet available) will be used here.

The estimation of households' demand functions is a much more difficult and time-consuming task. It first requires the availability of a consistent database, from which the econometric estimations can be performed. Measuring both income effects –Engel coefficients or Engel curves- and price effects –Slutsky coefficients- can only be contemplated with a spatio-temporal database, combining the time and the agent dimensions. The time dimension is necessary to have enough price variance, and the agent dimension to have enough variance on income and households' characteristics. The database must combine –or "pair", according to the statistical language- statistical information on households' expenditures and on consumption prices.

This is not easily available from statistical offices around the world. All the developed countries have exhaustive surveys on consumption prices, though as will be stressed below, few of them offer regional detailed data. Moreover the series are seldom available on a website and easily and freely downloadable.

Concerning households' expenditures, very few countries have asked their statistical office to collect regular and comprehensive information through detailed annual surveys. In the United Kingdom there is the well-known Family Expenditure Survey, but it is not easily and freely downloadable. The most prominent example is the United States with the Consumer Expenditures Survey (known as CEX), which is made by the Bureau of Labor Statistics and now covers 20 years –from 1984 to 2003- with the same format and in particular a constant commodity nomenclature (cf. BLS, 2003).

The BLS is also the statistical unit in charge of the Consumer Price Survey (CPI), which warrants some –but not total- consistency with the CEX (cf. BLS, 2001). Together the two surveys represent a fantastic source of information -consistent and comprehensive- on the American consumer, which appears to be at the present time largely under-exploited. Pairing the two surveys and checking their mutual consistency is a long and fastidious work that has been rendered still more difficult by a change in nomenclature of the CPI from 1998. Retrapolating series of prices for the period prior to 1997 by using "old series" is absolutely necessary in order to benefit from the 20 years span covered by the two surveys but truly represents a painstaking work, which in fact had been largely underestimated at the beginning. But the task has been started and completed, in the framework of the author's current research on approximate aggregation.

The resulting database has been recently put online (www.consumhattan.net). Detailed information is given on its construction and several datasets, in particular those used in the present work, can be downloaded. What is important for our purpose is that the CEX survey reviews American Households according to various characteristics, and in particular the region of residence, the size of the family and the generation (age of the representative person), making it possible to estimate the demand function -and then to measure a welfare cost of any policy- for each category (see in Appendix the nomenclature of categories of households).

The paper follows a previous communication presented at the NCCR CLIMATE 2005 Seminar held in Interlaken March 3-4, 2005 and aims at presenting additional results, based on new and more general estimations of the American households' demand function. It has three sections.

The first section summarizes the previous paper and, by the way, gives a graphical representation of the database. The second section presents new econometric estimations of the demand for residential energy and for energy in transportation.

The third section assesses the sensitivity of these alternative econometric estimations on the measurement of the equity effects, at the domestic level, of a climate change policy as defined by a scenario performed with GEMINI-E3 in the framework of the Energy Modeling Forum WG21.

I The demand for energy of the American consumer

I.1 A Graphical representation

A graphical representation of the database can be made along the two dimensions: on the one hand, longitudinally (according to years or periods), on the other hand transversally (according to classes of income). The second representation can be made for a given year or period, for instance the mean year or period, or for the whole interval of time by pooling data.

The transversal representation features the Engel curve, which varies according to the year and more precisely to the price system. What is relevant in the estimation of the demand function is the mean Engel curve, corresponding to the mean year and then to the average price system (normalized here to unity). It appears –but this has to be substantiated by econometric tests- that pooling data yields a good approximation of the Engel curve, better than the Engel curve of the mean period.

Effectively, the latter is based on a number of points that is too small to be reliable. Besides, there is much more transversal than longitudinal variability. The effect of prices on demand over the considered period is then very limited.

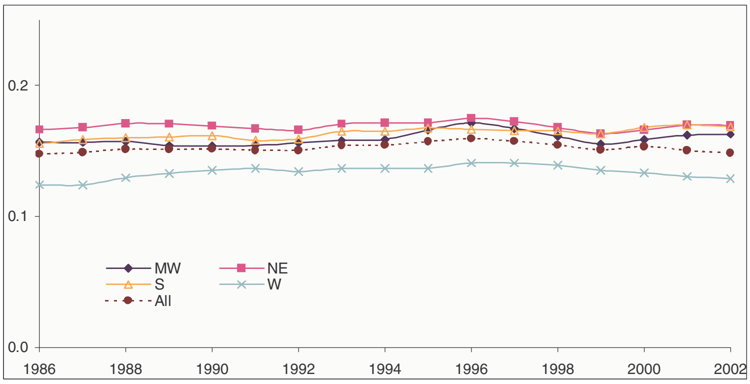
Starting from the Major Functions of Housing and Transportation, energy appears as an item that represents on the average respectively 15.5% and 20% of total expenditure in the concerned function[1],

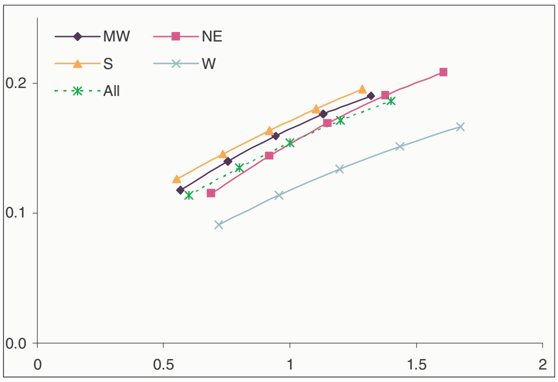
[1] Other items are respectively : Shelter and Household furnishings and operations; Vehicle purchase (incl. insurance) and Other vehicle charges.

Figures below yield a graphical representation, longitudinal and transversal, and according to the characteristics of Region, Size of family and Generation, of the considered energy item:

Energy in Housing

Region





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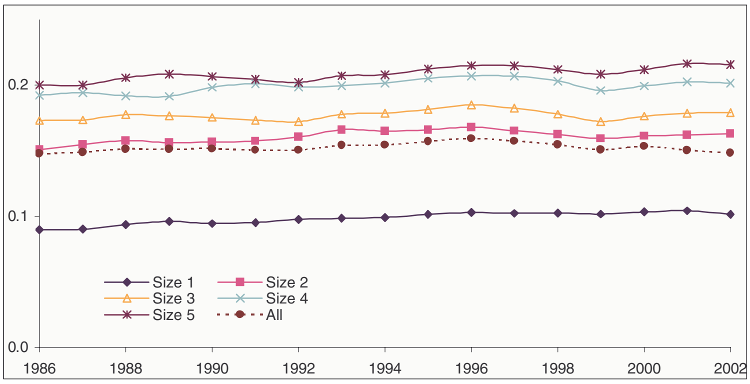
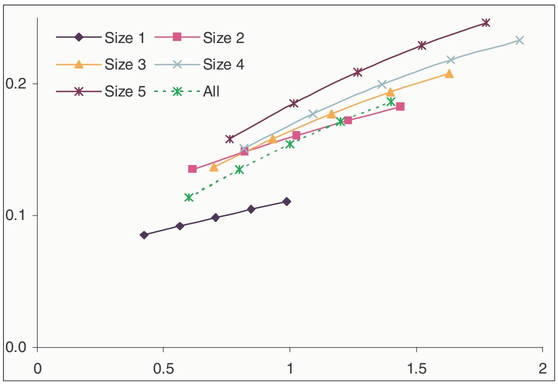
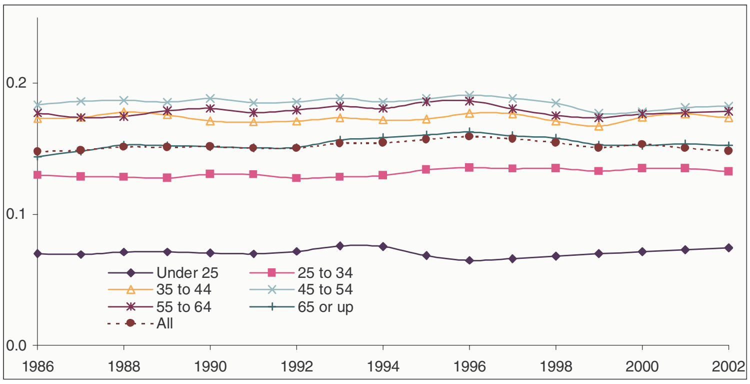
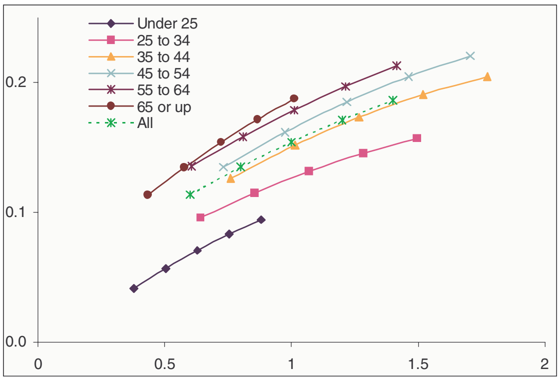


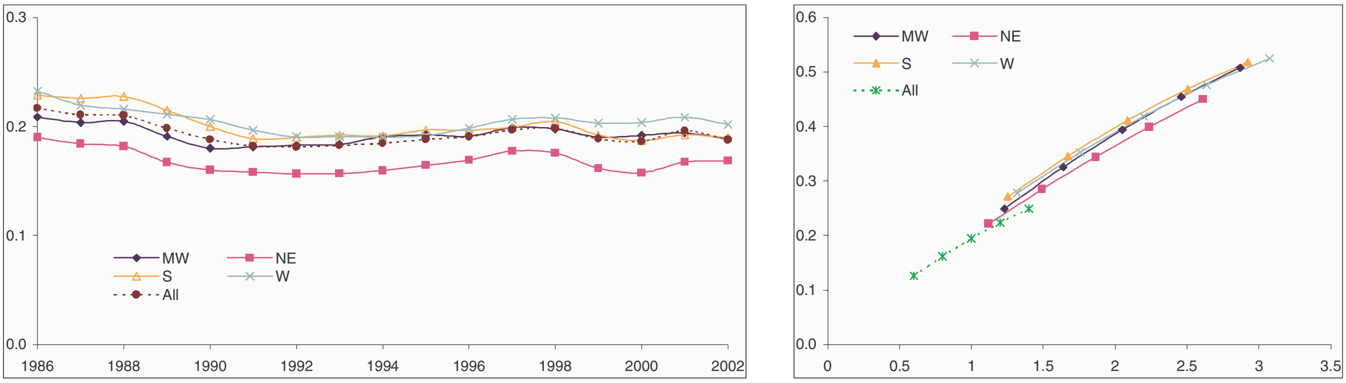


Age





Region



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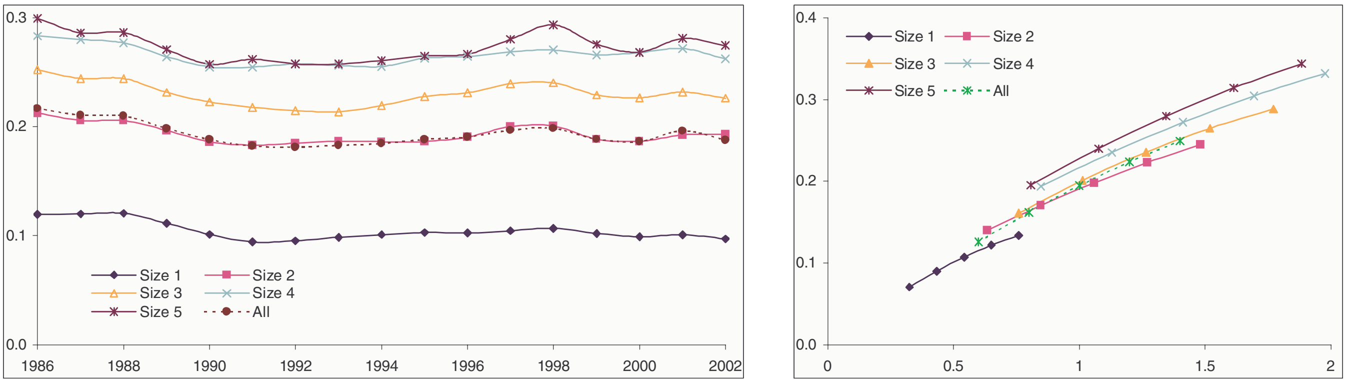
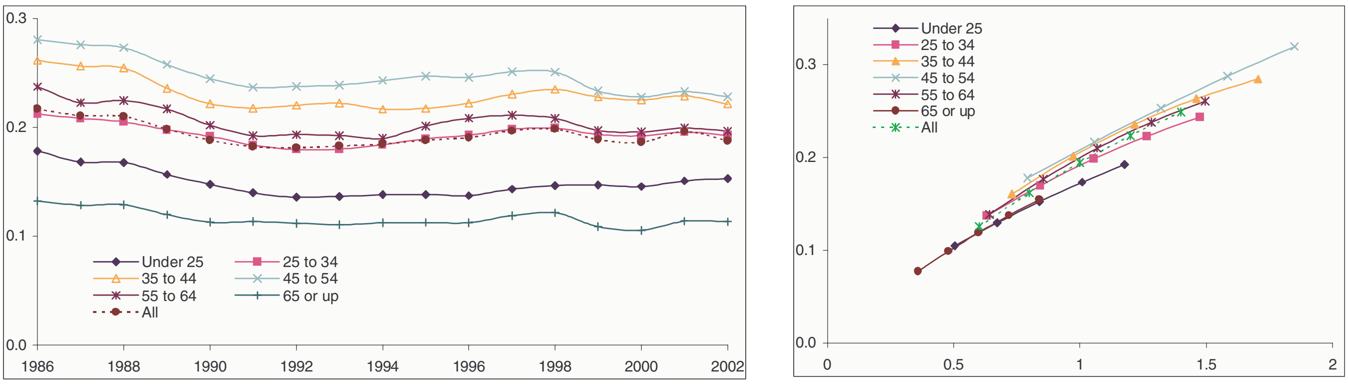


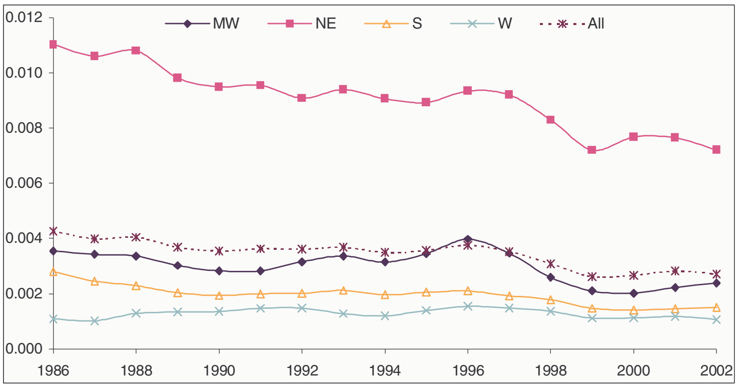
Age

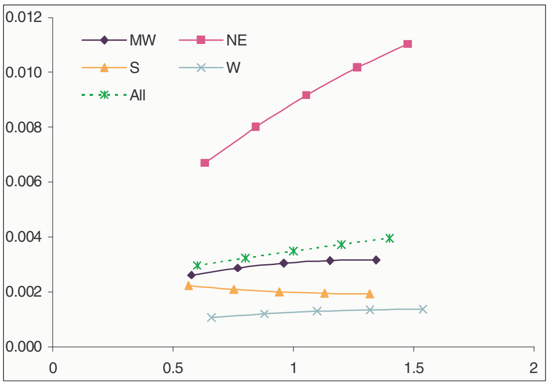


Residential energy (excluding Water and other public services) can in turn be broken down into 3 commodities, Fuel oil and other fuels, Electricity and Natural gas, which can be represented graphically in the same manner than previously:

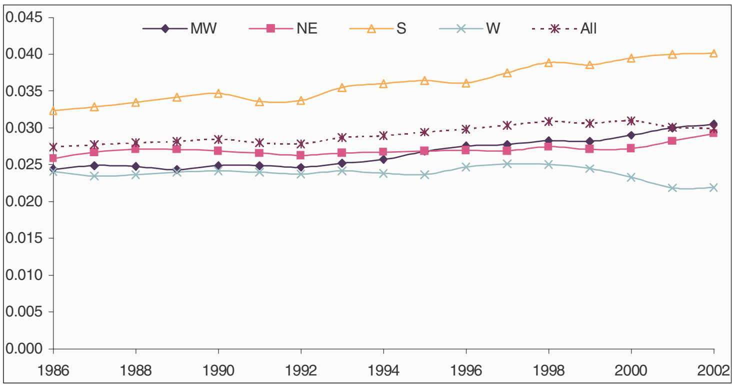
By region

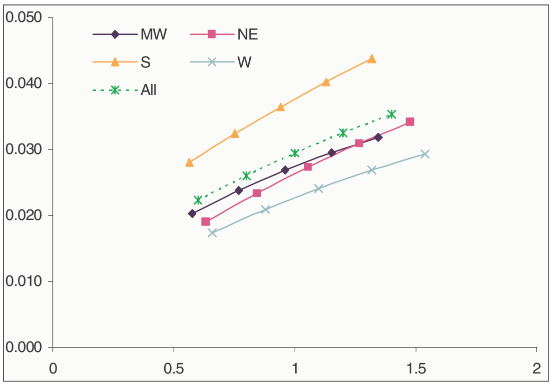
Fuel oil and other fuels



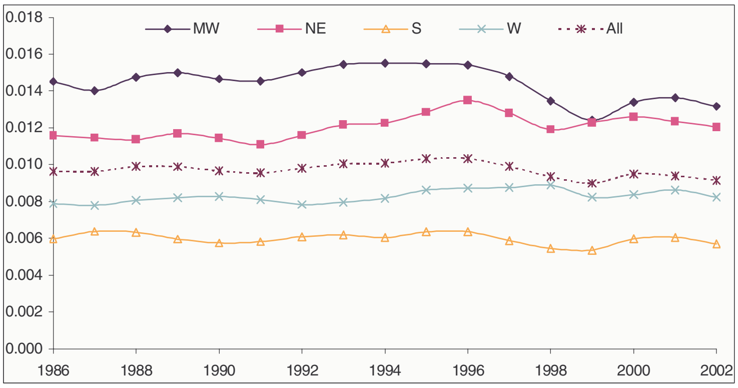


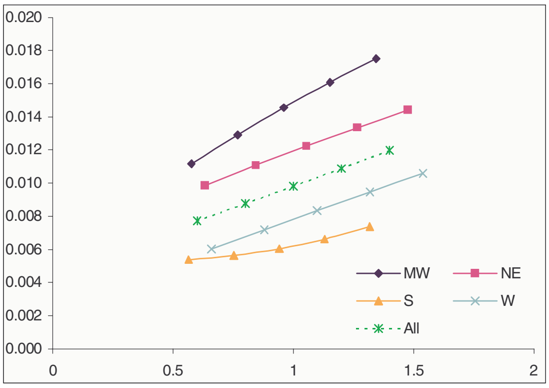
Electricity





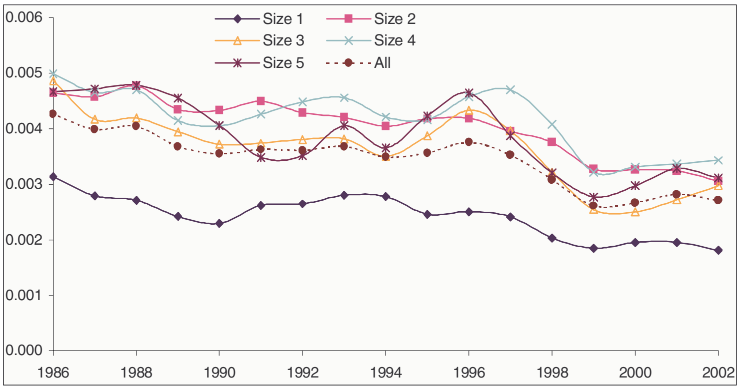
Natural gas

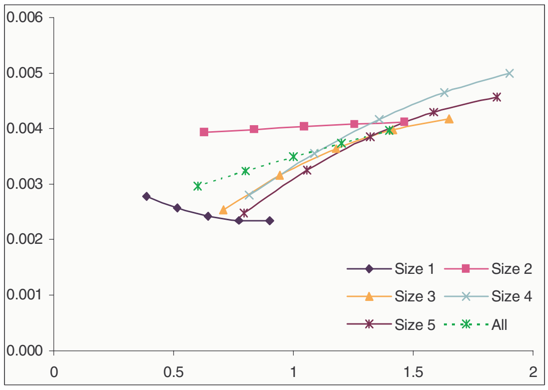




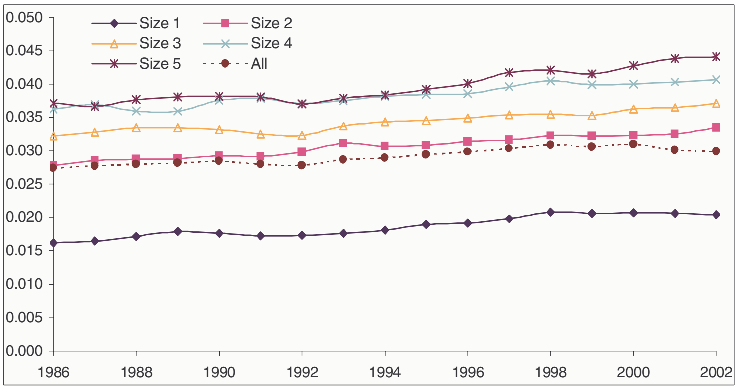
By size

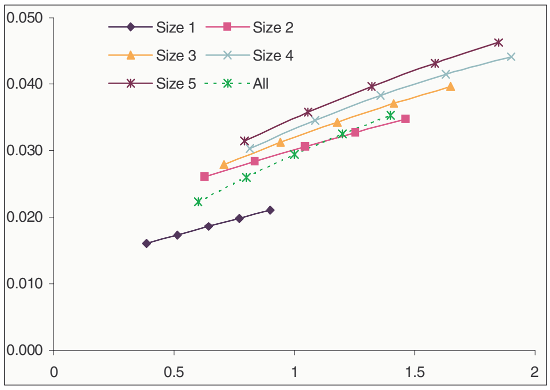
Fuel oil and other fuels



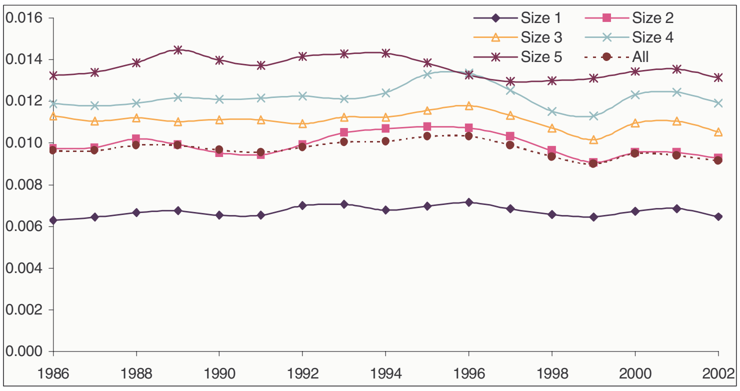


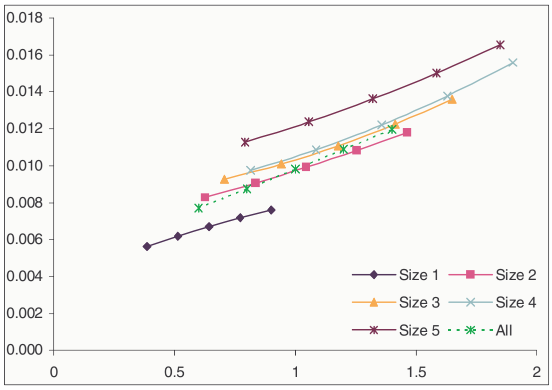
Electricity





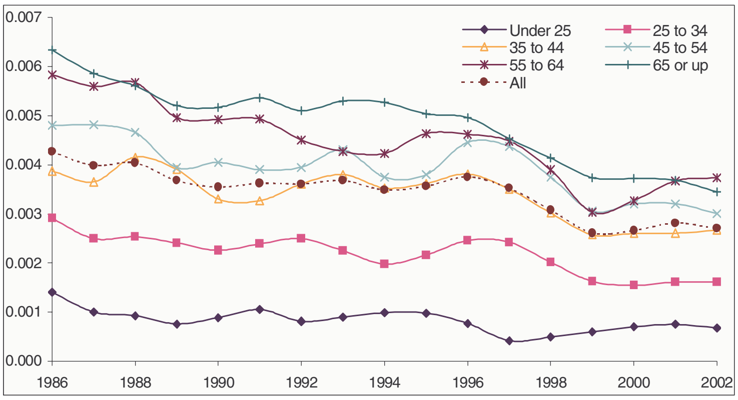
Natural gas

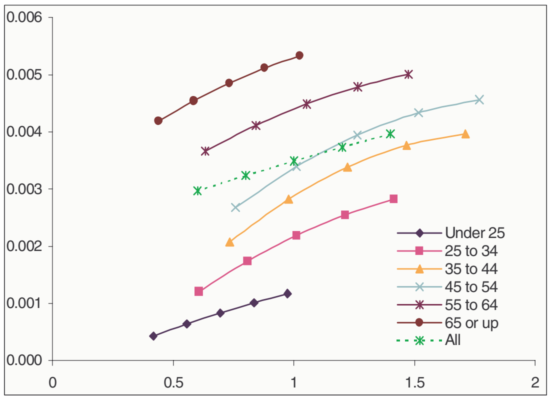




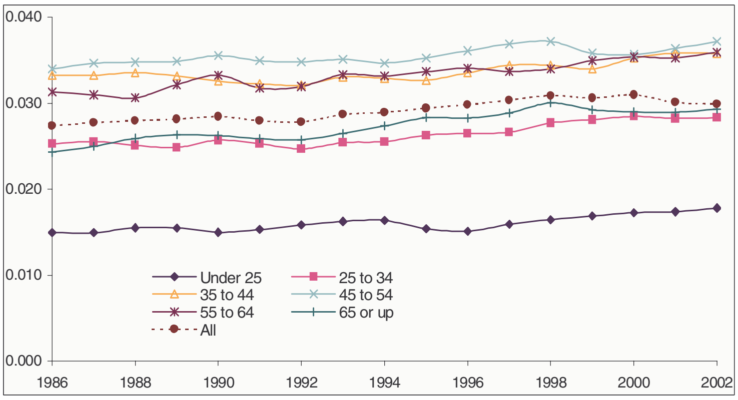
By generation

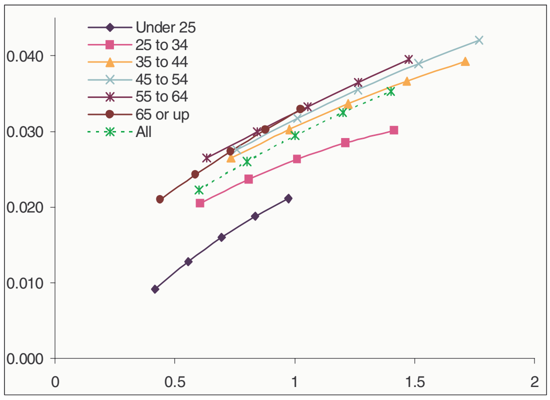
Fuel oil and other fuels



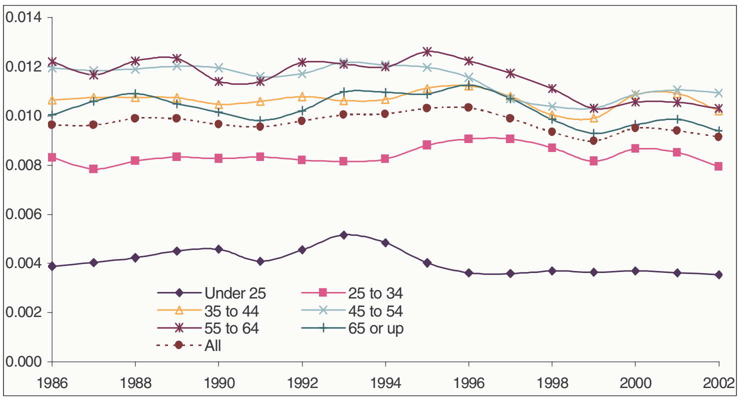


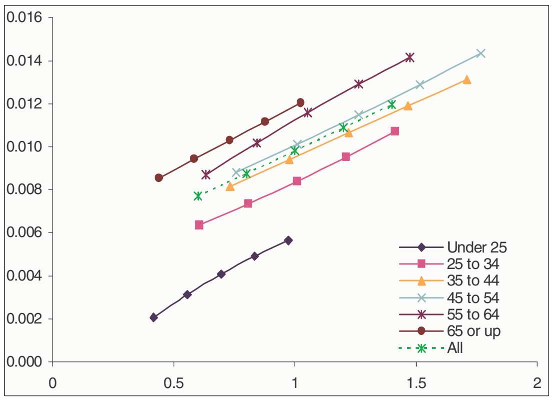
Electricity





Natural gas





Some general comments may be made and some conjectures formulated. First of all it appears that behavior concerning global demand for housing and transportation is not significantly differentiated according to the characteristics of the households[2], large differences appear in energy demand within each function, particularly residential energy. Thus households from the Middle West, of unitary size and under

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[2] Corresponding data and graphs are not reproduced in the present article, and can be found in the paper presented at Interlaken.

25 consume relatively less than the average, while households from the South, big families (size 5) and older generations consume more. As for private transportation, singles and young households consume slightly less while large families and families belonging to the 45 to 54 generation consume slightly more.

By commodity in residential energy, the differences are very important, with the Westerners, young and small families generally at the bottom. For other types of family, the allocation between energy commodities may vary in non negligible proportions, North Easterners consuming relatively more fuel oil and less electricity than the average.

With respect to income, the graphs exhibit mostly concave Engel curves, but while in the residential sector the share of energy decreases constantly with income (more precisely total expenditure in the concerned function), the share of energy increases and then decreases in transportation. But as the share of energy is significantly higher in Housing than in Transportation, the total share decreases constantly with income.

From the longitudinal representations of aggregate demand, it would be very difficult to infer differences in the sensitivity to prices. This is even more the case for residential energy because not only direct but also cross elasticities must be taken into account. Effectively substitutions between forms of energy may be very large.

Equity effects of an increase in energy prices can be conjectured: families allocating a higher share of income to energy will be penalized compared to those allocating a smaller share. On the whole, low income families can be expected to bear a relatively higher share of the cost of a climate change policy, compared to high income families, unless it is associated to a change in the allocation of income resulting from market mechanisms or from an accompanying fiscal policy.

I.2 Estimating the demand function of the American consumer

The comparison of the Engel curves of the various categories of households clearly shows that resorting to an "Adult Equivalent Scales" specification of the utility/demand function is not economically and statistically sound[3]. In order to cope with the different categories, econometric estimation must be performed on each of them.

I.2.1 The general specification of the demand function

The database theoretically allows one to estimate the whole demand function, but the number of independent commodities (53) prevents any attempt of resorting to any general –flexible enough-specification[4]. Separability assumptions –in some cases even additive separability assumptions- are unavoidable, implying a nested structure of the allocation of income to commodities. A natural solution is to conform to the hierarchical nomenclature of the CEX survey, starting from Major Groups or Major Functions, then breaking down into sub-functions, groups of commodities and so on. It is not obvious that this solution is the most efficient[5].

In the present case, two reduced models will be considered, the first one for residential energy and the second one for gasoline and motor oil. In each model, the arguments of the utility or demand function are the considered energy commodities and a "current commodity" representing all the other goods[6].

[3] Anyway the database does not allow to estimate this kind of specification
[4] In particular the Slutsky matrix, which exhibits the direct and cross price effects, has 1348 independent coefficients, but much fewer with separability properties (only one in addition to Engel's coefficients in the case of generalized additive separability)
[5] A great number of econometric experimentations show that it works pretty well, but not systematically (for instance beverages don't appear to be associated with other items of the Food function)
[6] Clearly the current good is not the same in the two models, but the differences are very small.

In order to assess the effects of changes in prices according to the income level of households, the specification must be flexible enough. This is not to be understood as usually in the local sense of the Translog or AIDS specifications (relevant for the individual consumer), but in some "aggregate" sense relevant for aggregate demand or, equivalently, for individual consumers with significantly different incomes, akin to the rank 3 general Gorman[7] specification and in particular the Quadratic Expenditure System of Howe, Pollack and Wales[8]. They represent mathematical developments of the utility function at the third order, at least partially (some third order coefficients being redundant).

Aiming to estimate these "structural" specifications (either the Gorman's general specification or the Quadratic Expenditure System[9]) with individual data would lead to a highly non linear demand model, then not easily manageable with classical econometric tools. This is the reason why we have implemented a linearization procedure based on the relevant parameters to estimate, the Slutsky and Engel coefficients for the average income and their changes in function of income.

It is not possible to detail the procedure in the limited scope of this paper, but the results that will be presented below will show its efficiency[10]. A foremost advantage of the linearization procedure is that it easily allows one to take into account "technical progress" incorporated in each commodity, i.e. change in demand not attributable to the change in prices or income, merely due to the passing of time, akin to incorporated technical progress in a production function.

Technical progress when positive means an "attraction" for the commodity increasing over time, when negative a disaffection. Technical progress in the above sense can represent a true technical progress, for instance when the commodity can be used more efficiently over time (i.e. with a more efficient device or equipment) or, in a very different context, a bias in the measurement of prices[11].

As it is well known that energy is used more and more efficiently over time in developed economies, in the production sector but also by households, a positive effect can be expected for energy commodities, at least some of them. Gasoline in cars seems a very likely example as the unitary consumption by mile has decreased on the average over the considered period, from 1984 to 2003. The general specification of the demand function can then be written:

$$c_i^t = f_i\left(p_j^t e^{-\gamma_j t}, r^t\right)$$

which can be associated to the indirect utility function of the form:

$$V\left(p_i^t e^{-\beta_i t}, r^t\right)$$

A comparison to a specification without technical progress shows the superiority of the former (see Bernard, 2005).

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[7] Gorman, 1981. For a survey on aggregation over individuals, see Stoker, 1993.
[8] Howe, Pollack and Wales, 1979
[9] Very little –if any- econometric work has been performed with these specifications on repeated panel data, in order to estimate simultaneously price and income effects. Most of the work focus on estimating Engel curves (Banks, Blundell and Lewbel, 1997; Lewbel, 2003).
A complete estimation of the demand function has been performed by Jorgenson (1990) but from aggregate data and with a rank 2 specification.
[10] The procedure has been checked on simulation experiments, in the same way as it was performed in the seventies by Fisher and Fisher et alii, and proved efficient.
[11] For energy commodities that are perfectly homogenous goods, no bias can be expected in the measurement of prices.

I.2.2 The demand for gasoline

The demand for gasoline is a very interesting topic for econometric estimation because it can be considered either as a single commodity (together with a "current good" representing all other commodities), or together with other items of private transportation (vehicle purchase and insurance, other vehicle charges, and of course a "current good"). This also offers a favourable opportunity to compare estimations with individual data (i.e. by classes of income) or with aggregated data.

I.2.2.a Gasoline as a single commodity

The results of the econometric estimations will not be presented through the directly estimated coefficients but through parameters of significance for the present analysis, namely the value of the Engel coefficient and the price elasticity for five levels of income: average, average less 40%, average less 20%, average plus 20%, average plus 40%.

Econometric results presented in Table 1 exhibit a positive technical progress, mostly in the range of 1% to 1.5% with two regions (North East and South) and two generations (45-54, 55-64) above and one family size and one generation below.

Estimated (non compensated) price elasticities, at the average income level, are remarkably close and also highly significant. They are in the 0.3 to 0.5 range with the notable exception of the generations Under 25 and 65 or up, i.e. younger and older families which exhibit a much smaller figure, respectively 0.19 and 0.13.

I.2.2.b Gasoline together with other items of private transportation

With four commodities (resp. item 1: vehicle purchase and insurance; item 2: gasoline; item 3: other vehicle charges; item 4: current good of the economy), the econometric estimation concerns, beside the parameters of the Engel curve associated to each commodity, the whole Slutsky matrix representing the price effects. Estimating the demand for private transportation is then much more difficult owing to the requirement that the estimated demand function exhibit the usual convexity properties[12] .Except in one case (households Under 25) this property has been checked to hold. Results of Table 2 yield the central values of the parameters (corresponding to the mean value of income), and their derivatives with respect to income.

Note that a lack of information on regional prices prevents to estimate the demand functions for each of the regions considered previously.

Table 3 compares the results of interest concerning gasoline of the two estimated models. Differences are very small concerning the Engel coefficients –and this could be easily expected-, but bigger concerning technical progress and price elasticity. In particular the complete model gives rather higher elasticities but this is not systematic.

[12] Negative semi-definiteness of the Slutsky matrix

Table 1

	All households	MW	NE	S	W	Size1	Size2	Size3	Size4	Size5	AUnder25	A25-34	A35-44	A45-54	A55-64	A65orup
Technical Progress	1.39%	1.40%	1.79%	1.75%	1.10%	1.58%	1.12%	1.48%	0.85%	1.50%	0.78%	1.10%	1.16%	1.63%	2.23%	1.50%
	(7.0)	(7.0)	(3.5)	(6.7)	(3.2)	(3.1)	(5.7)	(4.6)	(4.7)	(3.8)	(2.4)	(4.7)	(4.3)	(5.9)	(4.4)	(4.2)
Engel(0.6)	0.0510	0.0539	0.0473	0.0540	0.0478	0.0440	0.0479	0.0529	0.0496	0.0579	0.0485	0.0508	0.0497	0.0472	0.0513	0.0461
	(64.9)	(52.4)	(45.4)	(51.3)	(38.7)	(34.2)	(35.2)	(31.9)	(25.5)	(26.0)	(21.5)	(34.9)	(27.1)	(26.8)	(29.3)	(36.8)
Engel(0.8)	0.0432	0.0463	0.0406	0.0458	0.0399	0.0377	0.0388	0.0424	0.0383	0.0464	0.0450	0.0411	0.0390	0.0387	0.0428	0.0413
	(79.7)	(65.4)	(56.9)	(62.2)	(47.8)	(37.5)	(42.8)	(38.7)	(30.6)	(32.2)	(27.6)	(42.7)	(32.6)	(33.3)	(35.5)	(42.4)
Engel(1)	0.0354	0.0386	0.0338	0.0377	0.0320	0.0314	0.0297	0.0318	0.0270	0.0349	0.0414	0.0313	0.0284	0.0302	0.0342	0.0365
	(118.9)	(100.2)	(88.0)	(89.5)	(73.5)	(43.2)	(66.0)	(60.1)	(48.4)	(53.0)	(41.3)	(66.5)	(50.7)	(53.7)	(52.2)	(52.5)
Engel(1.2)	0.0277	0.0309	0.0270	0.0295	0.0242	0.0251	0.0206	0.0212	0.0157	0.0234	0.0379	0.0216	0.0177	0.0216	0.0257	0.0317
	(51.0)	(43.7)	(37.9)	(40.1)	(28.9)	(24.9)	(22.8)	(19.4)	(12.5)	(16.2)	(23.2)	(22.4)	(14.8)	(18.6)	(21.3)	(32.5)
Engel(1.4)	0.0199	0.0232	0.0202	0.0214	0.0163	0.0187	0.0115	0.0107	0.0044	0.0119	0.0344	0.0118	0.0070	0.0131	0.0172	0.0269
	(25.3)	(22.5)	(19.4)	(20.3)	(13.2)	(14.5)	(8.5)	(6.4)	(2.3)	(5.3)	(15.2)	(8.1)	(3.8)	(7.4)	(9.8)	(21.4)
Elast(0.6)	-0.270	-0.108	-0.556	-0.273	-0.431	-0.159	-0.137	-0.345	-0.273	-0.314	-0.152	-0.236	-0.324	-0.291	-0.394	0.234
	(1.9)	(0.6)	(2.2)	(1.8)	(1.7)	(0.5)	(0.8)	(1.6)	(1.3)	(1.2)	(0.4)	(1.1)	(1.4)	(1.5)	(1.7)	-(0.6)
Elast(0.8)	-0.336	-0.256	-0.508	-0.317	-0.472	-0.289	-0.242	-0.388	-0.269	-0.381	-0.175	-0.306	-0.339	-0.293	-0.401	-0.015
	(4.1)	(2.7)	(3.8)	(3.5)	(3.1)	(1.5)	(2.3)	(3.2)	(2.1)	(2.6)	(0.7)	(2.6)	(2.5)	(2.4)	(2.8)	(0.1)
Elast(1)	-0.386	-0.345	-0.508	-0.354	-0.515	-0.368	-0.317	-0.433	-0.280	-0.440	-0.192	-0.362	-0.366	-0.306	-0.422	-0.133
	(7.5)	(5.9)	(6.1)	(5.9)	(5.4)	(2.9)	(4.9)	(5.7)	(3.7)	(4.8)	(1.3)	(5.0)	(4.4)	(3.9)	(4.5)	(1.0)
Elast(1.2)	-0.434	-0.415	-0.528	-0.391	-0.564	-0.434	-0.384	-0.486	-0.303	-0.503	-0.205	-0.418	-0.404	-0.327	-0.452	-0.210
	(7.8)	(6.5)	(6.3)	(6.2)	(5.3)	(3.4)	(5.0)	(5.6)	(3.2)	(4.8)	(1.3)	(4.9)	(4.0)	(3.6)	(4.6)	(1.6)
Elast(1.4)	-0.484	-0.481	-0.560	-0.432	-0.622	-0.497	-0.454	-0.550	-0.337	-0.576	-0.218	-0.481	-0.455	-0.355	-0.491	-0.268
	(8.0)	(6.8)	(6.5)	(6.3)	(5.3)	(3.8)	(5.1)	(5.5)	(2.8)	(4.8)	(1.3)	(4.9)	(3.8)	(3.5)	(4.6)	(2.1)

Table 2

	All households	Size1	Size2	Size3	Size4	Size5	Under25	25 to 34	35 to 44	45 to 54	55 to 64	65 and over
Technical Progress												
Item 1	-0.20%	-0.24%	-0.13%	-1.24%	0.59%	-1.24%	-0.40%	0.27%	-0.41%	-0.99%	-0.17%	-1.22%
	(0.2)	(0.1)	(0.2)	(2.4)	(0.0)	(6.0)	(0.7)	(0.0)	(1.0)	(1.3)	(0.3)	(4.0)
Item 2	2.62%	1.91%	1.66%	1.20%	1.03%	1.72%	1.29%	0.78%	2.26%	1.61%	1.73%	1.92%
	(2.6)	(3.3)	(9.4)	(2.9)	(0.6)	(1.5)	(1.1)	(0.2)	(8.0)	(5.7)	(4.6)	(3.6)
Item 3	-0.02%	-0.11%	-0.33%	-0.34%	-0.19%	-0.66%	-0.30%	0.13%	-0.62%	-0.24%	-0.87%	-0.23%
	(0.0)	(0.1)	(0.9)	(2.7)	(0.8)	(2.1)	(1.1)	(0.0)	(4.5)	(8.8)	(1.4)	(1.5)
Item 4	-0.10%	-0.06%	-0.06%	0.15%	-0.14%	0.12%	0.02%	-0.08%	-0.03%	0.07%	-0.02%	0.05%
	(0.4)	(0.1)	(0.6)	(1.4)	(0.0)	(1.2)	(0.1)	(0.0)	(0.4)	(0.6)	(0.2)	(0.9)
Engel coefficients												
Item 1	0.1472	0.1367	0.1516	0.1495	0.1242	0.1433	0.2474	0.1471	0.1323	0.1385	0.1432	0.1563
	(83.8)	(26.5)	(50.3)	(36.4)	(28.4)	(38.1)	(29.9)	(40.2)	(47.9)	(44.7)	(37.4)	(28.6)
Item 2	0.0358	0.0313	0.0297	0.0317	0.0269	0.0339	0.0414	0.0311	0.0283	0.0301	0.0341	0.0370
	(104.6)	(42.9)	(66.5)	(61.4)	(48.4)	(52.5)	(41.0)	(67.8)	(50.9)	(55.5)	(52.7)	(63.1)
Item 3	0.0429	0.0498	0.0445	0.0459	0.0452	0.0470	0.0381	0.0416	0.0442	0.0462	0.0437	0.0431
	(135.1)	(39.6)	(66.7)	(59.6)	(62.2)	(55.1)	(32.1)	(61.4)	(82.3)	(64.6)	(50.8)	(32.4)
Item 4	0.774	0.782	0.774	0.773	0.804	0.776	0.673	0.780	0.795	0.785	0.779	0.764
Deriv. Engel Coeff.												
Item 1	-0.0926	-0.0774	-0.1706	-0.1391	-0.1144	-0.0801	-0.0486	-0.1369	-0.1160	-0.1332	-0.0571	-0.0644
	(12.8)	(7.8)	(11.2)	(6.3)	(4.2)	(3.7)	(1.9)	(7.3)	(7.3)	(7.9)	(3.5)	(6.1)
Item 2	-0.0395	-0.0317	-0.0461	-0.0522	-0.0563	-0.0640	-0.0171	-0.0493	-0.0552	-0.0430	-0.0434	-0.0239
	(28.0)	(22.3)	(20.2)	(18.6)	(16.3)	(17.0)	(5.4)	(21.0)	(17.2)	(14.5)	(15.7)	(20.8)
Item 3	0.0024	-0.0131	-0.0032	0.0047	0.0048	-0.0007	0.0046	-0.0020	0.0029	0.0015	-0.0062	-0.0060
	(1.8)	(5.3)	(0.9)	(1.1)	(1.1)	(0.1)	(1.2)	(0.6)	(0.9)	(0.4)	(1.7)	(2.3)
Item 4	0.130	0.122	0.220	0.187	0.166	0.145	0.061	0.188	0.168	0.175	0.107	0.094
	(0.0)	(0.8)	(0.0)	(0.0)	(0.8)	(0.0)	(0.0)	(0.5)	(0.0)	(1.6)	(0.0)	(0.0)
Slutsky coefficients												
s12	-0.020	0.001	-0.012	-0.001	0.000	-0.041	-0.022	-0.007	-0.026	-0.012	0.000	-0.039
	(3.0)	(0.1)	(1.8)	(0.1)	(0.1)	(3.7)	(1.4)	(1.0)	(2.8)	(1.1)	(0.0)	(3.7)
s13	0.061	0.050	0.047	0.067	0.041	0.064	0.025	0.065	0.025	0.037	0.040	0.009
	(9.5)	(2.4)	(4.3)	(4.6)	(3.6)	(3.9)	(1.2)	(5.5)	(2.3)	(2.4)	(2.6)	(0.4)
s14	0.098	0.037	0.147	-0.015	0.071	0.130	-0.035	0.073	0.159	0.111	0.154	0.222
	(2.9)	(0.5)	(3.5)	(0.2)	(1.3)	(2.2)	(0.3)	(1.4)	(3.2)	(1.9)	(2.7)	(2.8)
s23	-0.001	0.004	-0.011	-0.002	0.006	-0.010	-0.010	-0.001	-0.017	-0.010	-0.028	0.002
	(0.3)	(0.4)	(2.5)	(0.4)	(1.1)	(1.5)	(1.2)	(0.3)	(4.0)	(1.6)	(4.5)	(0.2)
s24	0.039	0.005	0.037	0.021	0.006	0.085	0.048	0.024	0.067	0.040	0.046	0.058
	(4.4)	(0.3)	(3.5)	(1.4)	(0.6)	(5.5)	(2.0)	(2.1)	(4.8)	(2.6)	(2.9)	(3.2)
s34	0.080	0.069	0.079	0.055	0.268	0.060	0.198	0.118	0.115	0.240	0.075	0.133
	(3.4)	(0.9)	(2.0)	(1.1)	(6.0)	(1.1)	(2.8)	(2.7)	(3.0)	(4.2)	(1.4)	(1.5)
Deriv. Slutsky coeff.												
s'12	-0.007	-0.011	-0.001	0.045	0.000	0.016	-0.031	-0.013	-0.004	0.021	-0.019	-0.094
	(1.0)	(0.9)	(0.1)	(2.0)	(0.0)	(0.6)	(1.0)	(1.3)	(0.3)	(0.8)	(1.2)	(5.8)
s'13	0.082	0.019	0.059	0.159	0.044	0.080	-0.007	0.073	0.068	0.023	0.102	0.028
	(8.6)	(0.8)	(2.8)	(4.8)	(2.8)	(2.2)	(0.2)	(3.6)	(2.5)	(0.6)	(2.7)	(0.7)
s'14	0.037	-0.025	-0.029	-0.083	-0.038	0.032	-0.790	0.250	0.081	0.329	-0.263	0.605
	(0.9)	(0.3)	(0.4)	(0.7)	(0.6)	(0.3)	(3.1)	(3.6)	(0.8)	(2.5)	(2.4)	(5.6)
s'23	-0.003	-0.013	-0.024	0.014	0.011	-0.017	-0.045	-0.026	-0.025	-0.019	-0.045	0.012
	(0.7)	(1.2)	(4.2)	(0.8)	(0.8)	(1.1)	(5.4)	(2.1)	(3.8)	(1.6)	(3.7)	(1.0)
s'24	0.040	0.044	0.049	-0.057	-0.003	0.019	0.094	0.053	0.054	0.008	0.088	0.129
	(5.1)	(2.9)	(4.2)	(1.4)	(0.2)	(0.5)	(3.1)	(4.7)	(3.2)	(0.2)	(3.8)	(5.2)
s'34	0.168	0.070	0.234	-0.099	0.613	0.010	0.312	0.232	0.039	0.466	0.009	-0.103
	(4.5)	(0.7)	(2.3)	(1.1)	(7.0)	(0.1)	(1.9)	(6.1)	(0.4)	(3.5)	(0.1)	(0.7)

Table 3

	All households		Size1		Size2		Size3		Size4		Size5	
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
Engel coefficient	0.0354	0.0358	0.0314	0.0313	0.0297	0.0297	0.0318	0.0317	0.0270	0.0269	0.0349	0.0339
Deriv. Engel Coeff.	-0.0389	-0.0395	-0.0316	-0.0317	-0.0454	-0.0461	-0.0528	-0.0522	-0.0565	-0.0563	-0.0576	-0.0640
Technical Progress	1.39%	2.62%	1.58%	1.91%	1.12%	1.66%	1.48%	1.20%	0.85%	1.03%	1.50%	1.72%
Price elasticity	-0.386	-0.489	-0.368	-0.296	-0.317	-0.374	-0.433	-0.421	-0.280	-0.272	-0.440	-0.815

	AUnder25		A25-34		A35-44		A45-54		A55-64		A65orup	
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
Engel coefficient	0.0414	0.0414	0.0313	0.0311	0.0284	0.0283	0.0302	0.0301	0.0342	0.0341	0.0365	0.0370
Deriv. Engel Coeff.	-0.0177	-0.0171	-0.0487	-0.0493	-0.0533	-0.0552	-0.0426	-0.0430	-0.0427	-0.0434	-0.0241	-0.0239
Technical Progress	0.78%	1.29%	1.10%	0.78%	1.16%	2.26%	1.63%	1.61%	2.23%	1.73%	1.50%	1.92%
Price elasticity	-0.192	-0.357	-0.362	-0.402	-0.366	-0.599	-0.306	-0.450	-0.422	-0.444	-0.133	-0.675

Model 1: Gasoline as a single item
Model 2: gazoline together with other items of private transportation

I.2.2.c Aggregate versus individual data

Econometric estimation with aggregate data are likely to give less precise results than with individual data because the "information" they convey is more limited. This is particularly the case for the Engel curve and in the results presented below the corresponding coefficients are the ones estimation from pooled data (as represented in the graphs above). Differences exist also for technical progress and price elasticity, as shows the table below concerning the specification with gasoline as the single item:

Table 4 : comparison of estimations with aggregate and individual data

	Individual data	Aggregate data		Individual data	Aggregate data		Individual data	Aggregate data
All Households			Size1			Under 25		
Technical Progress	1.39%	0.76%		1.58%	1.94%		0.78%	0.55%
Price elasticity	-0.386	-0.189		-0.368	-0.560		-0.192	-0.024
Engel Coefficient	0.035	0.036		0.031	0.033		0.041	0.044
Deriv. Engel Coeff.	-0.039	-0.038		-0.032	-0.030		-0.018	-0.013
MW			Size2			25 to 34		
Technical Progress	1.40%	1.31%		1.12%	1.03%		1.10%	0.80%
Price elasticity	-0.345	-0.281		-0.317	-0.270		-0.362	-0.255
Engel Coefficient	0.039	0.039		0.030	0.030		0.031	0.031
Deriv. Engel Coeff.	-0.038	-0.036		-0.045	-0.042		-0.049	-0.047
NE			Size3			35 to 44		
Technical Progress	1.79%	1.52%		1.48%	0.92%		1.16%	0.90%
Price elasticity	-0.508	-0.417		-0.433	-0.306		-0.366	-0.348
Engel Coefficient	0.034	0.034		0.032	0.032		0.028	0.029
Deriv. Engel Coeff.	-0.034	-0.032		-0.053	-0.050		-0.053	-0.052
S			Size4			45 to 54		
Technical Progress	1.75%	1.63%		0.85%	0.80%		1.63%	1.37%
Price elasticity	-0.354	-0.288		-0.280	-0.222		-0.306	-0.268
Engel Coefficient	0.038	0.038		0.027	0.028		0.030	0.030
Deriv. Engel Coeff.	-0.041	-0.040		-0.057	-0.052		-0.043	-0.042
W			Size5			55 to 64		
Technical Progress	1.10%	0.67%		1.50%	1.42%		2.23%	1.71%
Price elasticity	-0.515	-0.328		-0.440	-0.408		-0.422	0.038
Engel Coefficient	0.032	0.033		0.035	0.035		0.034	0.035
Deriv. Engel Coeff.	-0.039	-0.039		-0.058	-0.051		-0.043	-0.042
						65 and over		
Technical Progress							1.50%	1.68%
Price elasticity							-0.133	-0.237
Engel Coefficient							0.036	0.037
Deriv. Engel Coeff.							-0.024	-0.024

Aggregate data yield rather smaller values of technical progress and price elasticity of demand for gasoline, but this is not systematic.

Concerning the complete model of demand for private transportation, the comparison has not been performed by category of households, but only for all households taken together.

Table 5

	Individual data	Aggregate data
Technical Progress		
Item 1	-0.08%	0.08%
Item 2	2.02%	1.64%
Item 3	-0.01%	0.24%
Item 4	-0.09%	-0.10%
Direct price elasticity		
Item 1	-1.267	-1.296
Item 2	-0.412	-0.272
Item 3	-4.977	-4.060
Item 4	-0.288	-0.254
Engel coefficient		
Item 1	0.149	0.152
Item 2	0.037	0.038
Item 3	0.042	0.042
Item 4	0.772	0.769
Deriv. Engel coeff.		
Item 1	-0.090	-0.088
Item 2	-0.041	-0.040
Item 3	-0.001	0.002
Item 4	0.131	0.125

For gasoline (item 2) we also obtain a smaller value of the technical progress and of the price elasticity with aggregate data.

I.2.3 The demand for residential energy

As is the case for private transportation, the estimation the demand is subject to a test of convexity that is more stringent that in the case of a single commodity (2 including the "current good" of the economy). If the test passed in the case of All households, this was not systematically verified by category of households, and in particular only for North East at the regional level[13]. Constraining the demand function by assuming (and imposing) additive separability eases the obtaining of convexity. Effectively convexity is then verified for each category of households except for the Southern region and single households.

I.2.3.a By category of households with individual data

Table 6 below presents the results of econometric estimations by category of households. They concern "All classes of income except the lowest", and correspond to the additively separable specification. Only Engel and technical progress coefficients are reported.

[13] This can be explained by the presence among energy items of Fuel, with a small and declining over time weight.

Table 6

	All Households			Region MW			Region NE			Region S			Region W		
	Fuel	Electricity	Gas	Fuel	Electricity	Gas	Fuel	Electricity	Gas	Fuel	Electricity	Gas	Fuel	Electricity	Gas
PT	4.35%	-0.64%	1.14%	5.30%	-0.91%	2.86%	3.72%	0.09%	-0.70%	3.57%	-1.50%	0.85%	-0.45%	0.40%	-0.58%
	(12.8)	(5.1)	(5.6)	(8.6)	(4.7)	(7.3)	(9.0)	(0.5)	(2.8)	(12.3)	(18.9)	(5.0)	(1.1)	(2.7)	(3.6)
Engel(0.6)	0.0017	0.0174	0.0063	0.0015	0.0165	0.0099	0.0061	0.0192	0.0065	-0.0004	0.0217	0.0033	0.0004	0.0139	0.0055
	(19.6)	(57.1)	(38.4)	(8.6)	(41.2)	(32.2)	(27.9)	(54.3)	(20.1)	(4.0)	(57.4)	(22.6)	(6.0)	(43.9)	(45.1)
Engel(0.8)	0.0017	0.0174	0.0063	0.0015	0.0165	0.0099	0.0061	0.0192	0.0065	-0.0004	0.0217	0.0033	0.0004	0.0139	0.0055
	(19.6)	(57.1)	(38.4)	(8.6)	(41.2)	(32.2)	(27.9)	(54.3)	(20.1)	(4.0)	(57.4)	(22.6)	(6.0)	(43.9)	(45.1)
Engel(1)	0.0017	0.0174	0.0063	0.0015	0.0165	0.0099	0.0061	0.0192	0.0065	-0.0004	0.0217	0.0033	0.0004	0.0139	0.0055
	(19.6)	(57.1)	(38.4)	(8.6)	(41.2)	(32.2)	(27.9)	(54.3)	(20.1)	(4.0)	(57.4)	(22.6)	(6.0)	(43.9)	(45.1)
Engel(1.2)	0.0017	0.0174	0.0063	0.0015	0.0165	0.0099	0.0061	0.0192	0.0065	-0.0004	0.0217	0.0033	0.0004	0.0139	0.0055
	(19.6)	(57.1)	(38.4)	(8.6)	(41.2)	(32.2)	(27.9)	(54.3)	(20.1)	(4.0)	(57.4)	(22.6)	(6.0)	(43.9)	(45.1)
Engel(1.4)	0.0017	0.0174	0.0063	0.0015	0.0165	0.0099	0.0061	0.0192	0.0065	-0.0004	0.0217	0.0033	0.0004	0.0139	0.0055
	(19.6)	(57.1)	(38.4)	(8.6)	(41.2)	(32.2)	(27.9)	(54.3)	(20.1)	(4.0)	(57.4)	(22.6)	(6.0)	(43.9)	(45.1)

	Size 1			Size 2			Size 3			Size 4			Size 5		
	Fuel	Electricity	Gas	Fuel	Electricity	Gas	Fuel	Electricity	Gas	Fuel	Electricity	Gas	Fuel	Electricity	Gas
PT	2.95%	-1.66%	-0.83%	3.62%	-0.79%	1.35%	7.02%	-0.67%	1.21%	8.04%	-0.67%	1.10%	5.83%	-1.03%	1.06%
	(5.3)	(5.8)	(1.6)	(13.5)	(7.6)	(5.5)	(6.0)	(5.8)	(5.0)	(3.3)	(5.9)	(3.6)	(4.3)	(9.3)	(5.3)
Engel(0.6)	0.0005	0.0141	0.0060	0.0006	0.0110	0.0048	0.0019	0.0124	0.0050	0.0027	0.0120	0.0053	0.0024	0.0130	0.0053
	(1.9)	(20.0)	(15.8)	(4.3)	(32.0)	(22.6)	(8.7)	(36.4)	(22.7)	(17.8)	(32.4)	(19.6)	(13.7)	(30.0)	(22.7)
Engel(0.8)	0.0005	0.0141	0.0060	0.0006	0.0110	0.0048	0.0019	0.0124	0.0050	0.0027	0.0120	0.0053	0.0024	0.0130	0.0053
	(1.9)	(20.0)	(15.8)	(4.3)	(32.0)	(22.6)	(8.7)	(36.4)	(22.7)	(17.8)	(32.4)	(19.6)	(13.7)	(30.0)	(22.7)
Engel(1)	0.0005	0.0141	0.0060	0.0006	0.0110	0.0048	0.0019	0.0124	0.0050	0.0027	0.0120	0.0053	0.0024	0.0130	0.0053
	(1.9)	(20.0)	(15.8)	(4.3)	(32.0)	(22.6)	(8.7)	(36.4)	(22.7)	(17.8)	(32.4)	(19.6)	(13.7)	(30.0)	(22.7)
Engel(1.2)	0.0005	0.0141	0.0060	0.0006	0.0110	0.0048	0.0019	0.0124	0.0050	0.0027	0.0120	0.0053	0.0024	0.0130	0.0053
	(1.9)	(20.0)	(15.8)	(4.3)	(32.0)	(22.6)	(8.7)	(36.4)	(22.7)	(17.8)	(32.4)	(19.6)	(13.7)	(30.0)	(22.7)
Engel(1.4)	0.0005	0.0141	0.0060	0.0006	0.0110	0.0048	0.0019	0.0124	0.0050	0.0027	0.0120	0.0053	0.0024	0.0130	0.0053
	(1.9)	(20.0)	(15.8)	(4.3)	(32.0)	(22.6)	(8.7)	(36.4)	(22.7)	(17.8)	(32.4)	(19.6)	(13.7)	(30.0)	(22.7)

	AUnder25			A25to34			A35to44			A45to54			A55to64			A65orup		
	Fuel	Electricity	Gas	Fuel	Electricity	Gas	Fuel	Electricity	Gas	Fuel	Electricity	Gas	Fuel	Electricity	Gas	Fuel	Electricity	Gas
PT	5.26%	-1.40%	3.01%	7.44%	-0.97%	0.29%	6.65%	-0.71%	0.96%	2.23%	-0.81%	1.87%	4.71%	-0.48%	2.12%	5.25%	-0.33%	1.24%
	(2.1)	(4.7)	(2.3)	(3.9)	(8.8)	(1.2)	(4.6)	(5.7)	(4.6)	(6.4)	(9.4)	(8.8)	(9.2)	(3.7)	(6.8)	(6.5)	(0.9)	(2.6)
Engel(0.6)	0.0014	0.0231	0.0071	0.0022	0.0118	0.0058	0.0023	0.0129	0.0053	0.0018	0.0142	0.0061	0.0019	0.0159	0.0069	0.0022	0.0203	0.0066
	(9.1)	(37.8)	(22.0)	(18.6)	(35.4)	(30.1)	(17.9)	(34.8)	(33.5)	(12.9)	(43.4)	(32.1)	(9.1)	(42.7)	(28.8)	(7.6)	(44.0)	(15.2)
Engel(0.8)	0.0014	0.0231	0.0071	0.0022	0.0118	0.0058	0.0023	0.0129	0.0053	0.0018	0.0142	0.0061	0.0019	0.0159	0.0069	0.0022	0.0203	0.0066
	(9.1)	(37.8)	(22.0)	(18.6)	(35.4)	(30.1)	(17.9)	(34.8)	(33.5)	(12.9)	(43.4)	(32.1)	(9.1)	(42.7)	(28.8)	(7.6)	(44.0)	(15.2)
Engel(1)	0.0014	0.0231	0.0071	0.0022	0.0118	0.0058	0.0023	0.0129	0.0053	0.0018	0.0142	0.0061	0.0019	0.0159	0.0069	0.0022	0.0203	0.0066
	(9.1)	(37.8)	(22.0)	(18.6)	(35.4)	(30.1)	(17.9)	(34.8)	(33.5)	(12.9)	(43.4)	(32.1)	(9.1)	(42.7)	(28.8)	(7.6)	(44.0)	(15.2)
Engel(1.2)	0.0014	0.0231	0.0071	0.0022	0.0118	0.0058	0.0023	0.0129	0.0053	0.0018	0.0142	0.0061	0.0019	0.0159	0.0069	0.0022	0.0203	0.0066
	(9.1)	(37.8)	(22.0)	(18.6)	(35.4)	(30.1)	(17.9)	(34.8)	(33.5)	(12.9)	(43.4)	(32.1)	(9.1)	(42.7)	(28.8)	(7.6)	(44.0)	(15.2)
Engel(1.4)	0.0014	0.0231	0.0071	0.0022	0.0118	0.0058	0.0023	0.0129	0.0053	0.0018	0.0142	0.0061	0.0019	0.0159	0.0069	0.0022	0.0203	0.0066
	(9.1)	(37.8)	(22.0)	(18.6)	(35.4)	(30.1)	(17.9)	(34.8)	(33.5)	(12.9)	(43.4)	(32.1)	(9.1)	(42.7)	(28.8)	(7.6)	(44.0)	(15.2)

With the additively separable specification we obtain a positive –and sometimes high- technical progress for Fuel oil, a negative one for Electricity (around 1%) and again a positive one for Natural gas (mostly from 1% to 2%) for all categories except two regions (North East and West) and single households.

Engel coefficients are very significant except for the one concerning Fuel with some categories of households (Size 1 and 2, and Middle West).

I.2.3.b With aggregate data

The comparison between individual and aggregate data has been performed only in the case of All households with the additively separable specification. Table 7 below gives the results of this comparison:

Table 7

	Individual data	Aggregate data
Technical Progress		
Item 1	3.61%	3.42%
Item 2	-0.89%	-0.76%
Item 3	0.69%	0.75%
Item 4	0.01%	0.00%
Direct price elasticity		
Item 1	-0.138	-0.100
Item 2	-0.179	-0.146
Item 3	-0.184	-0.145
Item 4	-0.009	-0.006
Engel coefficient		
Item 1	0.002	0.002
Item 2	0.018	0.018
Item 3	0.006	0.006
Item 4	0.974	0.974
Deriv. Engel coeff.		
Item 1	-0.001	-0.001
Item 2	-0.012	-0.012
Item 3	-0.001	-0.002
Item 4	0.015	0.015

With aggregate data, the coefficients of technical progress are very close while price elasticities are slightly smaller. Engel coefficients are identical but this is by construction[14].

II Assessing the welfare cost and equity effects of climate change policy

Implementation of a climate change policy through economic incentives such as a carbon tax or tradable permits affects the whole price system, in the production and in the consumption spheres.

Here only the direct effects for households through changes in the consumer prices of energy will be considered, in the Housing and Transportation sectors. This does not capture the whole effect of a climate change policy but clearly a high share. Effectively, changes in production prices –and

[14] As previously, the Engel coefficients and derivatives are not directly estimated but taken from the pooled data.

changes in taxation- are passed along to the consumer through the change in net income. Then only changes in the prices of other commodities are neglected and they can be considered of a minor importance.

The section is divided into 3 sub-sections. The first one briefly presents a world scenario of climate change policy assessed with the GEMINI-E3 model in the framework of the WG 21 of the Energy Modeling Forum. The second sub-section recalls the formulas yielding the welfare cost of a change in the price system, based on the Harberger's triangle. The third sub-section presents the results of welfare calculations, globally for all households and by category of households.

II.1 A world scenario of climate change policy

The scenario defined for the modeling teams participating to the EMF WG21 is based on the target of stabilizing radiative forcing at 4.5 W/m^2 relative to pre-Industrial times by 2150. This corresponds to an equilibrium temperature of 3.0°C, for a 2.5°C per CO_2 doubling climate sensitivity. Associated to this long term target is a time trajectory of GHG emissions, incorporated in the models (mainly General Equilibrium Models) in order to determine the world carbon price[15].

Two strategies were to be compared, one based on exclusive CO2 abatement and a Multigas strategy, optimizing abatement across all the 6 greenhouse gases. The results below correspond to the multigas strategy, limited to the time horizon of 2050, obtained with the GEMINI-E3 model[16].

	2000	2010	2020	2030	2040	2050
Carbon price ($97 per t of C)	0	10	22	39	70	107
US GHG emissions:						
BaU	1895	2200	2473	2561	2588	2635
Scenario	1895	2080	2238	2203	2043	1906
Rate of abatement		5.5%	9.5%	14.0%	21.1%	27.7%

Associated changes in the prices of energy commodities for the American consumer are:

	Fuel oil and other fuels	Electricity	Natural gas	Gasoline and motor oil
2010	3.18%	1.93%	5.74%	2.79%
2020	7.45%	4.33%	13.49%	6.54%
2030	13.74%	7.31%	24.53%	12.06%
2040	27.32%	13.13%	44.97%	23.98%
2050	43.95%	18.03%	67.97%	38.56%

The differences among energy commodities reflect their CO2 contents, but also their rates of taxation (for instance higher for Gasoline than for Fuel oil). The GEMINI-E3 simulation also exhibits the change in households' real income that results from the redistribution of carbon levies through either a lump sum transfer or a tax abatement on all other commodities. The change is an increase, of a magnitude varying from 0.37% in 2030 to 0.68% in 2050.

II.2 Welfare cost measurement

Welfare cost for an individual consumer is measured by the "surplus", as was originally formulated by Jules Dupuit in the case of a single good, or in its modern expression for several goods by the CVI or EVI. Calculating these quantities needs resorting to the structural specification of the utility function, which can be performed from its local properties by calibration.

[15] See Blanford et alii, 2004
[16] See Bernard, Vielle and Viguier, and the website of GEMINI-E3 (www.gemini-e3.net)

Another –and more direct- way is to use an approximation formula of the CVI up to the second order. The first order term is well-known, it represents (minus) the change in budget at constant consumption:

$$S_1 = -\sum C_i dp_i$$

The second order term is also well-known since the seminal paper or Harberger[17]. It is based on the Slutsky coefficients, and can be written as:

$$S_2 = -\frac{1}{2}\sum_{i,j} s_{ij} dp_i dp_j$$

As the Slutsky matrix is negative semi-definite, the second order term is positive and reduces the effect of the first order term, which is then a majorant of the cost. This can be easily understood: reallocation of the budget to the various commodities allows to do better than just undergo the increased cost of the current basket.

It can also be expressed with only the non-diagonal terms of the Slutsky matrix, as the sum by line (or column) weighted by prices is null:

$$S_2 = \frac{1}{2}\sum_{i<j} s_{ij} p_i p_j \left(\frac{dp_i}{p_i} - \frac{dp_j}{p_j} \right)^2$$

Total surplus, taking into account the change in income, is then[18]:

$$\boxed{S = dr - \sum C_i dp_i + \frac{1}{2}\sum_{i<j} s_{ij} p_i p_j \left(\frac{dp_i}{p_i} - \frac{dp_j}{p_j} \right)^2}$$

This is the formula that will be applied, totally or partially, in the welfare cost measurement of the considered climate change scenario.

II.3 Global welfare cost and equity effects

We will consider energy demand in each function separately, then together with the change in income obtained in the GEMINI-E3 scenario in order to assess a global welfare cost[19]. For reasons of consistency with residential energy, the results presented here come from the econometric estimations related to “All classes of income except the lowest[20]”.

II.3.1 Gasoline and motor oil

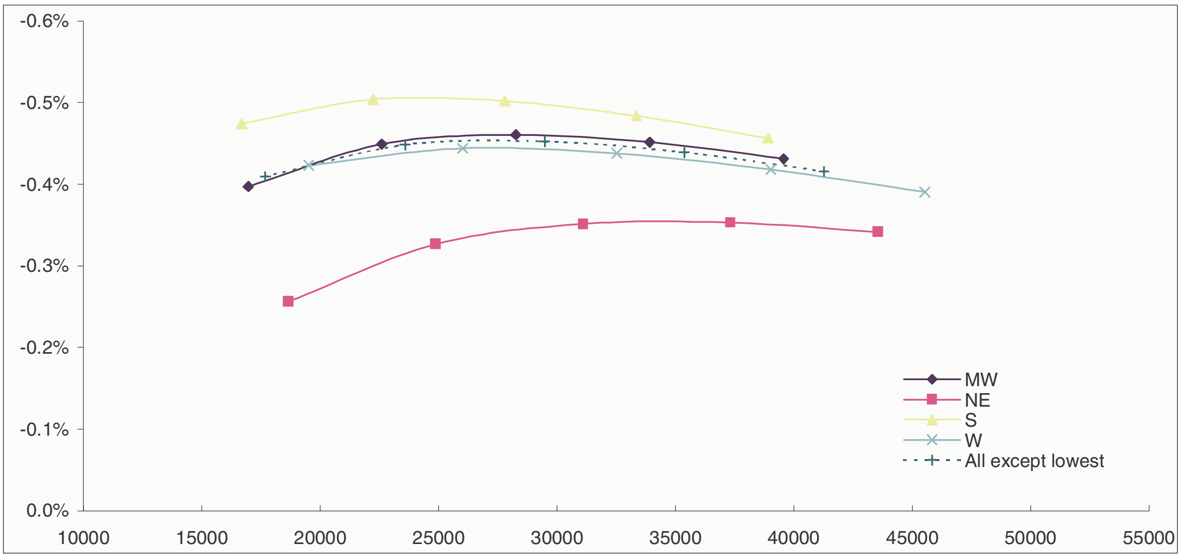
Table 8 below gives the results obtained from the demand model with gasoline as a single commodity (beside the current good of the economy):

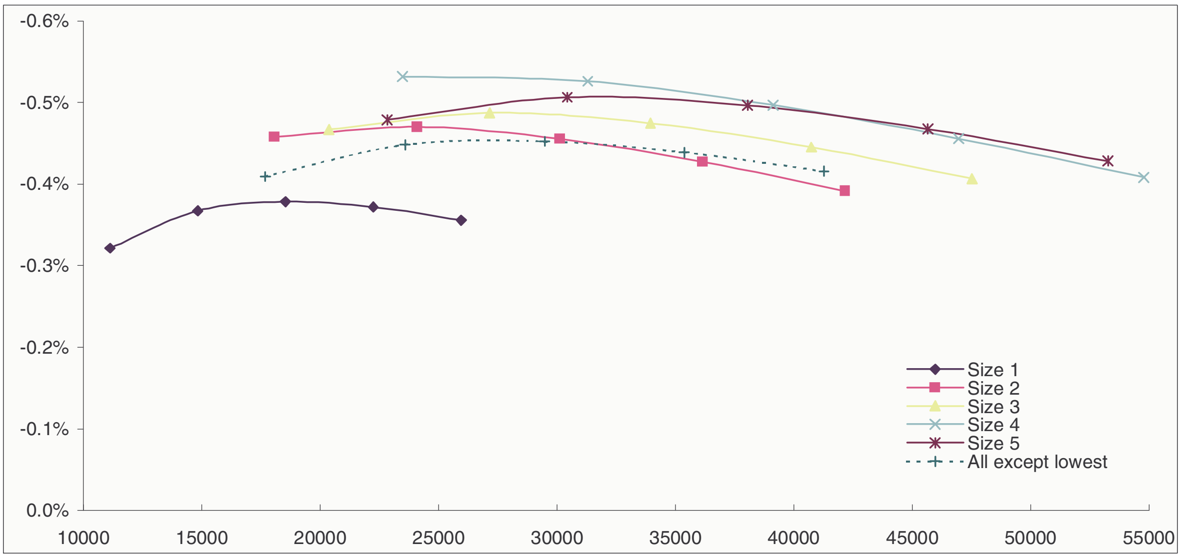
[17] cf. Harberger, 1971. The formula also appears in a “prophetic” paper by Boiteux (1951), which served as a blue-print for his seminal paper on second-best (1956).
Slesnick (1998) surveys in the JEL the “Empirical Approaches to the Measurement of Welfare”, and various approximation formulas.
[18] It is possible to establish a more general formula, taking into account all the second order parameters of the utility function, but that is only relevant for aggregation over consumers.
[19] Under the restriction, as noted above, that changes in prices of other commodities are not taken into account.
[20] The results related to the econometric estimations based on “All classes of income” are nearly identical.

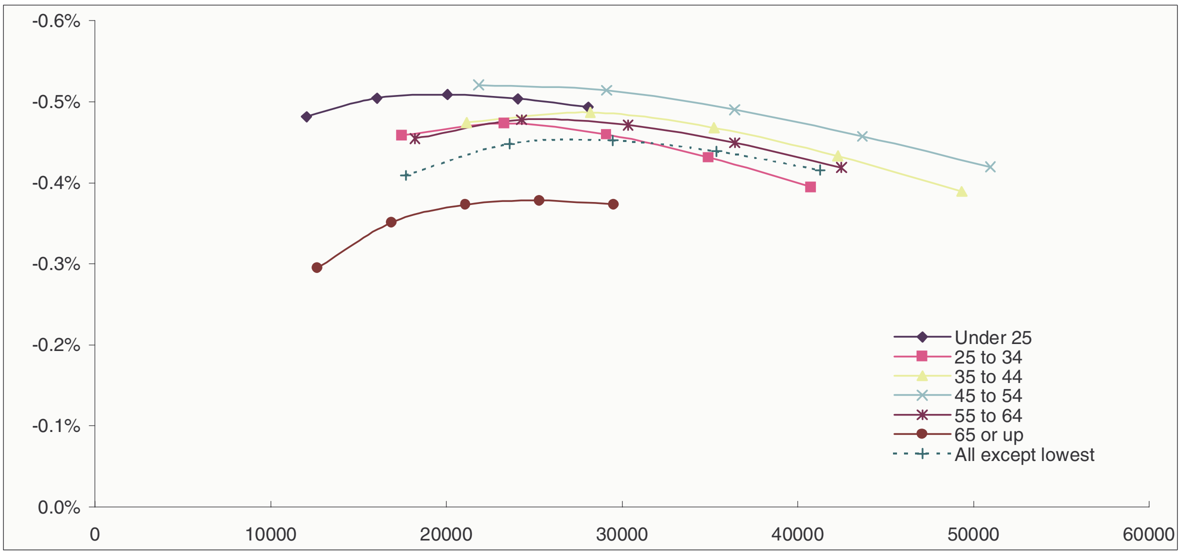
Table 8

	Average income	Relative level of income				
		0.6	0.8	1	1.2	1.4
All categories	29480	-0.42%	-0.45%	-0.45%	-0.44%	-0.41%
Region						
MW	28262	-0.41%	-0.45%	-0.46%	-0.45%	-0.43%
NE	31109	-0.27%	-0.33%	-0.35%	-0.35%	-0.34%
S	27794	-0.48%	-0.50%	-0.50%	-0.48%	-0.46%
W	32525	-0.42%	-0.44%	-0.44%	-0.42%	-0.39%
Size						
Size 1	18538	-0.34%	-0.37%	-0.38%	-0.37%	-0.35%
Size 2	30118	-0.46%	-0.47%	-0.46%	-0.43%	-0.39%
Size 3	33947	-0.46%	-0.48%	-0.47%	-0.45%	-0.41%
Size 4	39128	-0.53%	-0.52%	-0.50%	-0.46%	-0.41%
Size 5	38045	-0.47%	-0.50%	-0.50%	-0.47%	-0.43%
Age						
Under 25	20052	-0.49%	-0.51%	-0.51%	-0.50%	-0.49%
25 to 34	29108	-0.45%	-0.47%	-0.46%	-0.43%	-0.40%
35 to 44	35240	-0.47%	-0.49%	-0.47%	-0.43%	-0.39%
45 to 54	36401	-0.52%	-0.51%	-0.49%	-0.46%	-0.42%
55 to 64	30344	-0.45%	-0.48%	-0.47%	-0.45%	-0.42%
65 or up	21086	-0.30%	-0.35%	-0.37%	-0.38%	-0.37%

which are represented graphically below by categories of households (by region, by size, by generation):







Relatively to the income level, the results are not monotonous: the highest relative cost is borne by middle income households, and this is verified for nearly every category.

According to the categories, it appears that Southerners and families of size 4 and of the 45 to 54 generation bear an higher relative cost than average, while North Easterners, one-person and older families bear a smaller one. Differences may be from approximately simple to double.

It is interesting to distinguish the first and second order effects. The former is related to the budget share of the concerned commodity, the latter to the elasticity (substitution effect). With the considered price changes, the second order effect is marginal compared to the first order effect, as shown on Table 9 below, concerning all categories of households:

Table 9

Income level	0.6	0.8	1	1.2	1.4
First order term	-0.44%	-0.48%	-0.48%	-0.47%	-0.44%
Second order term	0.01%	0.01%	0.01%	0.01%	0.01%

For higher price changes, in particular those obtained for the year 2050, the second order term becomes relatively more important, though the first order term remains dominant.

With the complete demand function for private transportation in 3 commodities (plus the current good of the economy), though were obtained in the econometric estimations some differences in the price elasticities, the results in terms of welfare cost are not significantly different. This is to be related to the small weight of the second order term concerning price changes at the 2030 horizon.

At the 2050 horizon, with price changes of energy that are approximately in a factor three compared to 2030, differences are more visible though still very limited as shows the Table below:

Table 8

	Average income	Relative level of income				
		0.6	0.8	1	1.2	1.4
All categories	29480	-0.42%	-0.45%	-0.45%	-0.44%	-0.41%
Region						
MW	28262	-0.41%	-0.45%	-0.46%	-0.45%	-0.43%
NE	31109	-0.27%	-0.33%	-0.35%	-0.35%	-0.34%
S	27794	-0.48%	-0.50%	-0.50%	-0.48%	-0.46%
W	32525	-0.42%	-0.44%	-0.44%	-0.42%	-0.39%
Size						
Size 1	18538	-0.34%	-0.37%	-0.38%	-0.37%	-0.35%
Size 2	30118	-0.46%	-0.47%	-0.46%	-0.43%	-0.39%
Size 3	33947	-0.46%	-0.48%	-0.47%	-0.45%	-0.41%
Size 4	39128	-0.53%	-0.52%	-0.50%	-0.46%	-0.41%
Size 5	38045	-0.47%	-0.50%	-0.50%	-0.47%	-0.43%
Age						
Under 25	20052	-0.49%	-0.51%	-0.51%	-0.50%	-0.49%
25 to 34	29108	-0.45%	-0.47%	-0.46%	-0.43%	-0.40%
35 to 44	35240	-0.47%	-0.49%	-0.47%	-0.43%	-0.39%
45 to 54	36401	-0.52%	-0.51%	-0.49%	-0.46%	-0.42%
55 to 64	30344	-0.45%	-0.48%	-0.47%	-0.45%	-0.42%
65 or up	21086	-0.30%	-0.35%	-0.37%	-0.38%	-0.37%

II.3.2 Residential energy

For residential energy, it is convenient to start with the results concerning all categories of households. They are given in Table 11 below.

Table 11

Income level	0.6	0.8	1	1.2	1.4
Welfare cost	-0.77%	-0.64%	-0.57%	-0.51%	-0.46%
of which:					
First order term	-0.77%	-0.65%	-0.57%	-0.52%	-0.48%
Second order term	0.001%	0.002%	0.005%	0.014%	0.026%

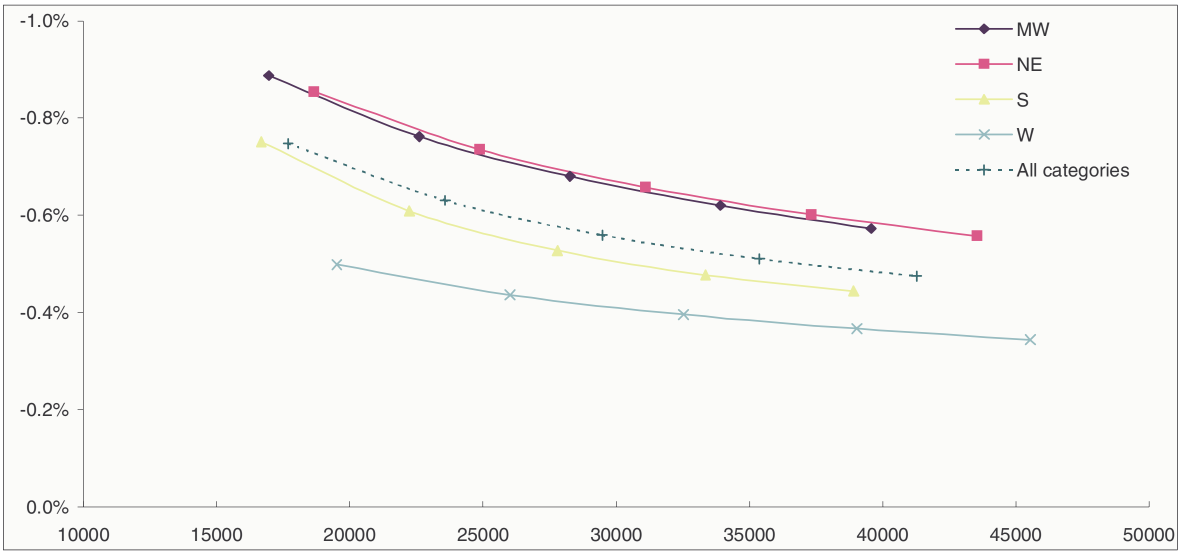
The second order term is negligible, except only maybe higher than average levels of income (even for the level 40% above the average, it represents just over 5% of the first order term). Thus, neglecting this term does not bias the result of comparisons perceptibly.

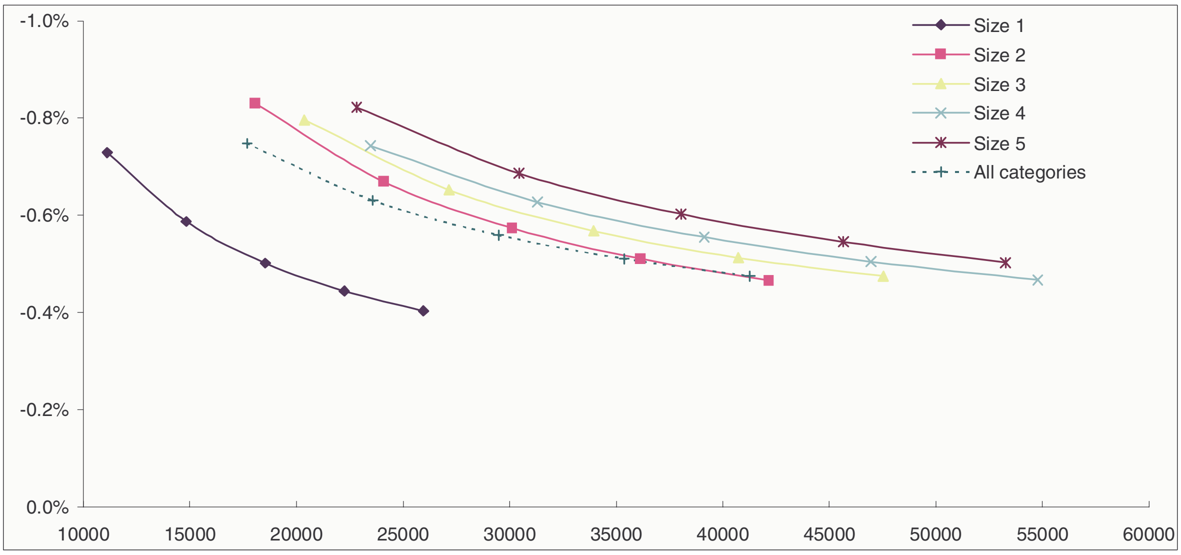
It is then legitimate to resort to additively separable specifications that set constraints on the Slutsky coefficients and may bias then. The corresponding results are given in Table 12 below, and in the associated graphs.

At the difference of the previous case the results follow a monotonic behavior, the higher the level of income the smaller the relative cost borne by the households. Clearly the implementation of a climate change policy, without compensations tailored according the level of income, would be regressive (at the only exception of families of the Under 25 generation).

According to categories of households, the most penalized are the North Easterners (the Middle Westerners are in a close tie), large families and those belonging to the 55 to 64 generation. The least penalized are the Westerners, small and young families.

The range between extremes is fairly large, from 0.2% to 1%. It would be even larger for bigger price increases, for instance those obtained in the GEMINI-E3 scenario for 2050.


MW
NE
S
W
All categories
-1.0%
-0.8%
-0.6%
-0.4%
-0.2%
0.0%
10000
15000
20000
25000
30000
35000
40000
45000
50000


Size 1
Size 2
Size 3
Size 4
Size 5
All categories
-1.0%
-0.8%
-0.6%
-0.4%
-0.2%
0.0%
10000
15000
20000
25000
30000
35000
40000
45000
50000
55000
60000

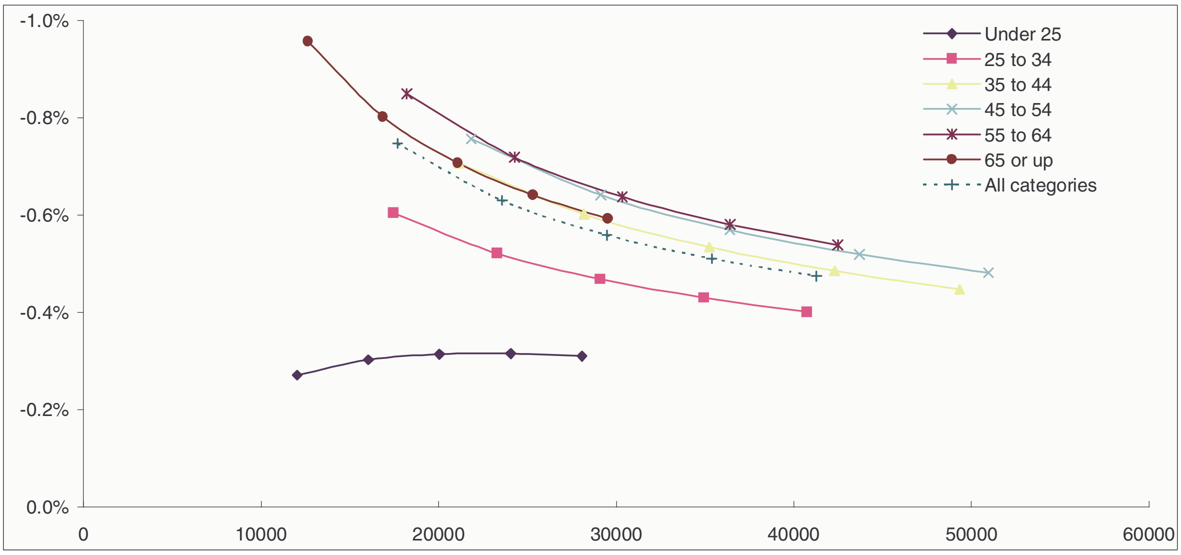

Under 25
25 to 34
35 to 44
45 to 54
55 to 64
65 or up
All categories
-1.0%
-0.8%
-0.6%
-0.4%
-0.2%
0.0%
0
10000
20000
30000
40000
50000
60000

Table 10

	Demand model with gasoline alone					Complete demand model for private transportation				
Relative level of income	0.6	0.8	1	1.2	1.4	0.6	0.8	1	1.2	1.4
All categories	-0.75%	-0.63%	-0.56%	-0.51%	-0.47%	-0.75%	-0.63%	-0.56%	-0.51%	-0.47%
Size										
Size 1	-1.06%	-1.14%	-1.15%	-1.11%	-1.05%	-1.03%	-1.19%	-1.24%	-1.22%	-1.17%
Size 2	-1.44%	-1.46%	-1.40%	-1.30%	-1.18%	-1.51%	-1.54%	-1.49%	-1.39%	-1.28%
Size 3	-1.40%	-1.47%	-1.43%	-1.33%	-1.20%	-1.54%	-1.60%	-1.56%	-1.46%	-1.34%
Size 4	-1.62%	-1.62%	-1.53%	-1.40%	-1.24%	-1.75%	-1.72%	-1.62%	-1.48%	-1.32%
Size 5	-1.43%	-1.52%	-1.49%	-1.40%	-1.26%	-1.60%	-1.67%	-1.63%	-1.53%	-1.41%
Age										
Under 25	-1.54%	-1.59%	-1.59%	-1.56%	-1.53%	-1.56%	-1.63%	-1.65%	-1.63%	-1.60%
25 to 34	-1.38%	-1.44%	-1.40%	-1.31%	-1.19%	-1.50%	-1.55%	-1.50%	-1.41%	-1.30%
35 to 44	-1.45%	-1.48%	-1.42%	-1.31%	-1.17%	-1.57%	-1.60%	-1.53%	-1.41%	-1.27%
45 to 54	-1.59%	-1.58%	-1.51%	-1.41%	-1.29%	-1.74%	-1.69%	-1.60%	-1.49%	-1.37%
55 to 64	-1.37%	-1.45%	-1.42%	-1.36%	-1.26%	-1.52%	-1.58%	-1.55%	-1.48%	-1.38%
65 or up	-0.99%	-1.13%	-1.17%	-1.17%	-1.15%	-0.93%	-1.13%	-1.20%	-1.22%	-1.21%

The complete demand model for private transportation gives rather higher welfare costs, but this is not systematic. Differences remain nevertheless small.

II.4 Overall assessment

Summing the results relative to both end-use energies, and taking into account the change in income obtained in the GEMINI-E3 scenario yields an overall assessment. The calculation is performed here concerning the year 2030, all categories of households taken together, under two alternative assumptions:

a) an identical relative change in income across households:

Table 13: identical relative change in income

Level of income	0.6	0.8	1	1.2	1.4
CVI (Ren)	-0.75%	-0.63%	-0.56%	-0.51%	-0.47%
CVI (Mfuel)	-0.42%	-0.45%	-0.45%	-0.44%	-0.41%
Real income	0.37%	0.37%	0.37%	0.37%	0.37%
Total surplus	-0.79%	-0.71%	-0.64%	-0.58%	-0.52%

b) a constant lump sum transfer:

Table 14: constant lump sum transfer

Level of income	0.6	0.8	1	1.2	1.4
CVI (Ren)	-0.75%	-0.63%	-0.56%	-0.51%	-0.47%
CVI (Mfuel)	-0.42%	-0.45%	-0.45%	-0.44%	-0.41%
Real income	0.61%	0.46%	0.37%	0.31%	0.26%
Total surplus	-0.55%	-0.62%	-0.64%	-0.64%	-0.63%

Without a compensating policy, i.e. in the present case with a redistribution of carbon levies through a tax abatement on non-energy commodities, the climate change policy has anti-redistributive effects, bringing an higher welfare cost to the lower-income than to the higher-income families. With a redistribution through a uniform lump-sum transfer the anti-redistributive effects are exactly wiped-off, which is an interesting and very satisfying result.

Nonetheless this result holds only on the average, i.e. all categories of households taken together. By category of households, some big differences would remain even with redistribution through a uniform lump sum transfer, mainly owing to differences in residential energy consumption. Beyond regional differences explained by climatic conditions, it appears that some categories of households, mostly the larger and the older ones, would be much more penalized than average by the implementation of a climate change policy. And this would be even more the case with more drastic climate change policies, such as the ones that are contemplated for the distant future, 2050 and beyond. Working out policies aimed at correcting anti-redistributive effects appears a priority in the political agenda.

III Main lessons and future developments

Two main lessons can be drawn from the above analysis. The first one is about the answer to the issue that has been raised, i.e. the prospect of inequities resulting from a climate change policy based on big price increases for energy commodities imposed upon households. In particular a very important result of the research is to be highlighted: while a redistribution of carbon levies through a uniform lump sum transfer may wipe-off on average the anti-redistributive effects of a climate change policy and the associated energy price increases, some important discrepancies among categories of households should remain, penalizing in particular the larger and the older families. Working out policies aimed at correcting these discrepancies appears a priority in the political agenda.

The second one is about methodology and available statistical information. It has been shown that the Consumer Expenditures Survey is an invaluable source of information on the households' decisions, and correlatively their "preferences" according to the language of welfare economics. Highly significant estimations of parameters of interest have been obtained, concerning the Engel curves (this could be easily expected with data covering a large range of income), but also concerning much more elusive coefficients such as direct and cross price-elasticities. In particular, a price-elasticity in the range from 0.3 to 0.5 for nearly all categories of households is a very strong result. For residential energy, which includes three different commodities, the econometric estimation is more difficult, and it has been performed in the present work only for the total set of households.

A very interesting and innovative result concerns what has been labeled "technical progress", which reflects changes in demand not related to changes in prices or income but just the "passing of time". It has been shown that technical progress can be estimated with a fairly high precision, and that the lack of consideration of time in demand models may bias significantly the estimation of the other parameters of interest, mainly price-elasticities (Engel coefficients being nearly not affected).

The specifications implemented in the analysis are, as was said at the beginning, "reduced forms" of a more general specification taking into account all commodities. Though it represents a long term target, it is not possible to contemplate an estimation of the whole demand function, with 53 end-use commodities. It is unavoidable to make separability assumptions, which means to nest them in some hierarchical way.

A first path, in relation to the present issue, was to consider private transportation as a whole, with the three commodities that are Vehicle purchase and insurance, Gasoline and motor oil and Other vehicle charges. Results presented here show that though the parameters of interest may (in particular the price elasticity of the item energy) may be fairly different, the results are not significantly changed as for the welfare costs and the assessment of equity effects of a climate change policy.

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Appendix: dimensions of the database

Classes of income: nine brackets, starting from Under 5 000$ of income before taxes to 70 000$ and over, but less for some years and/or some categories of households
Categories of households:
- *by region*: four regions, Middle west, North East, South, West
- *by size*: five, from 1 to 5 and over
- *by age of the reference person*: six, from Under 25 to 65 and over