department of economics
"S. Cognetti de Martiis"

Via Po, 53 – 10124 Torino (Italy)
Tel. (+39) 011 6702704 - Fax (+39) 011 6702762
URL: http//www.de.unito.it

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SCRAPPING OLD CARS FOR REDUCING AIR POLLUTION: AN ENVIRONMENTAL EVALUATION OF THE ITALIAN 1997-1998 INCENTIVE POLICY

Giovanna Garrone

Dipartimento di Economia "S. Cognetti de Martiis"

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Scrapping old cars for reducing air pollution: an environmental evaluation of the Italian 1997-1998 incentive policy

Giovanna Garrone
(University of Torino)

Introduction

Road transport is responsible for a large and increasing share of environmental externalities in general[1], and more specifically of atmospheric emissions, both in terms of greenhouse gases a of traditional pollutants. Increased awareness of air pollution-related health risks, and of a very skewed distribution of emissions, a large share of which is generated by a modest numbers of high emitting vehicles, call for policies targeting specifically pollution from the existing fleet, rather than ensuring the production of cleaner models.

Among market-based policy instruments able to accelerate the renewal of the car stock, scrappage subsidies are seen as a relatively cost-effective tool for pollution reduction. Since the early 90s many scrapping incentive programmes have been implemented in different forms in Europe and North America.

Especially in the cash-for-replacement type that was privileged in European countries, these policies can require substantial spending on the part of the implementing authority, and can serve a range of policy purposes, environmental and not, as is discussed thoroughly for the Italian case. Assessing the performance of such instruments as emission reduction policies becomes thus an interesting question.

Section 1 briefly discusses economic incentives to accelerate vehicle retirement as emission reduction measures environmental policy and their expected impacts in terms of sales, prices and profits, and on environmental quality. Crucial variables for the design and evaluation of such measures are identified.

Sections 2 and 3 are devoted to an in-depth study of the cash for replacement scheme implemented in Italy in 1997 and 1998. Section 2 provides an overview of the motivations and details of the scheme, and a discussion of the positive assessments that the programme received by both the regulatory authorities and the automobile industry.

In Section 3 a detailed empirical analysis aims, within the limitations of the available data, at a deeper discussion and a more realistic assessment of the emission reduction achieved through the policy. The limitations of the available data suggest an assessment strategy aiming at achieving an *upper bound* estimate. The data used come mainly from two sources:

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[1] Interesting estimates on external costs of transport are provided by EEA (2003). For a discussion of transport externalities see Maddison et al (1996).

- Official figures published by ACI (*Automobile Club Italia*), on car fleet, new registrations, cancellations and scrapping "ACI".
- 1995-1999 series of the age distribution of the car fleet (separate series for petrol/diesel cars) produced by Fiat Auto[2]. "FA".

1 Scrapping incentives as environmental policy measures

Some of the externalities from road transport are specifically associated with the age of cars, notably car emissions of traditional air pollutants. Emissions rates from older vehicles are high due to both a *vintage* effect (as increasingly strict emission standards were imposed over time on the production of new cars) and an *age* effect (caused by deterioration of vehicle emission control equipment).

Traditional "command and control" types of regulation such as emission and technological standards only target pollution from *new* vehicles. The skewed distribution of air pollution caused by dirtier vehicles calls instead for policies aimed at accelerating the renewal of the fleet. Taxes based on the level of total emissions would be the ideal instrument but are virtually impracticable. Both registration fees differentiated by age or by emission rate and scrapping subsidies act by changing relative prices of older (more polluting) cars with respect to newer (cleaner) ones, but neither provides any incentive to reduce the number of kilometres travelled. The relative advantages of scrapping incentives are:

- to avoid the equity concerns[3] raised by differential taxes (which have regressive impacts)
- to regulate not only the scrapping *rate* but also, at the same time, the scrapping *process*, entailing additional environmental gains in terms of reduced disamenity and increased materials recovery and recycling.

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[2] Kindly provided by Fiat Elasis, Traffic Management and Control Research Laboratory. Numbers for petrol cars are given in thousands, for diesel in units. The two sources cannot be compared directly as the universes covered are not identical:
1) ACI covers cars with all kinds of engine while FA only includes petrol (excluding hybrid) and diesel.
2) ACI figures cover all vehicles for which the *road tax* is paid (all vehicles registered in the P.R.A.), while FA series was constructed by linking cars on which the road tax is paid with the cars for which insurance is paid. The latter should thus reflect the actually circulating fleet more accurately. Further discrepancy is attributable, according to Fiorentino (1995), to vehicles that are registered but are held by car dealers, and vehicles that have been scrapped but not yet cancelled. More generally there seems to be significant delays in the cancellation from the PRA, that cause some inconsistency between data from different sources.
The bulk of the analysis is based on the FA data, but it will be occasionally complemented by information drawn from ACI. Unless otherwise explicitly stated, all charts and tables presented are my own elaboration on ACI or FA data.

[3] Cf Walls and Hanson (1999).

A fundamental distinction is to be drawn between “pure” scrapping incentives (*cash-for-scrapping or CFS)* and cash-for-replacement (CFR) ones, in which a bonus is offered for scrapping an old (high-emitting) vehicle provided that it is replaced – usually with a new one. The two types of schemes have quite different economic impacts. While CFS programmes tend to cause mainly an anticipation of demand, possibly followed by a subsequent decline in sales, CFR ones induce participants not simply to bring forward their natural purchase decision, but to switch to the choice of a new model (from the presumably spontaneous choice of a second-hand one). The fleet composition will therefore be re-adjusted towards a higher share of small-sized (and arguably less polluting) models. As an indirect effect, price dynamics might reinforce the increase in sales.

The environmental consequences of scrapping policies can be framed in terms of a LCA (life cycle approach): the environmental impact of car *use* represents a variable external cost, while the environmental impact of *construction and dismantling* is a fixed external cost. The share of the former grows, while that the latter decreases, with the length of the vehicles life cycle. By shortening cars lifetime the variable component of external costs is reduced but the fixed one is increased. Once both are brought into the picture, repeated or permanent incentives to scrappage could turn out to be on the whole detrimental to the environment (A result in this sense is found for the Netherlands by Van Wee et al, 2000).

Adopting a narrower focus limited to in use emissions, the impact of a scrapping programme in terms of emission reductions depends on (i) the difference between the emission rates of scrapped and replacement vehicles, (ii) the remaining lifetime, (iii) vehicle kilometres travelled per year, and (iv) the scale of the programme.

While it is unquestionable that strong differentials in emission rates ensure that scrappage incentives do achieve some reduction in traditional pollutants, impact in terms of CO_2 emissions are more ambiguous and debated.

On the whole, the cost-effectiveness of scrappage incentive policies is higher for CFS schemes than for CFR. Moreover, as noted by Hahn (1995), it decreases with the size of the bonus and if the scheme is repeated over time.

A potential long-term perverse effect of these policies, suggested by ECMT (1999), is to slow down the diffusion of a cleaner technology if this happens to be introduced after the end of the programme.

The literature allows to identify a few "black boxes" as crucial for the assessment of a CFR incentive scheme. Some of the key questions concern effectiveness in the selection of participating vehicles: the *deadweight* problem, the *distortion* from natural behaviour and the related risk of partially missing the target in terms of *exclusion* of worse–off households. Others regard more directly the identification of actually achieved pollution reduction, and involve the issue of *remaining lifetime of selected vehicles*, of *actual usage* of both the retired the replacement cars.

2 The 1997-1998 Italian cash-for-replacement scheme: motivations, details, participation

A large scale cash-for-replacement incentive programme was carried out in Italy between January 1997 and July 1998, much along the lines of those implemented in earlier years in France and Spain. The programme subsidised the purchase of a new vehicle by car owners who would scrap an old one (the eligibility threshold being a car age of 10 years).

2.1 Too many birds with one stone?

The incentive programme was justified by the regulatory authorities mainly as an environmental and safety policy that could be pursued by stimulating the renewal of the car fleet. In 1994, the passenger car fleet amounted to 27 million. Of these, 6% were newly registered, 67% were between 1 and 9 years old, the remaining 27% was older than 10 years. The average age was 6,4 and the average life 14,4.[4] Both increased in the following years: the stagnation of the car market had begun in recession year 1993 with a 29% drop in new car sales with respect to 1992 (from 2,389,395 to 1,693,323) and lasted until 1996, as is shown Fig. 2. 1 below. The long-lasting impact on the age structure of the fleet is portrayed in Fig. 3. 5.

EEA (1999) reports that the average age of the Italian passenger car fleet was higher in 1996 than in 1987, with a lower share of cars under 5 years and a larger share of cars over 10. In fact, at the beginning of 1997, pre-1987 cars (eligible for the incentive) added up to almost 30% of the total circulating fleet – and it is reasonable to believe that they accounted for a much larger share of polluting emissions.[5] The rationale for the policy was then the usual one – to reduce the emissions per car, by retiring from circulation the higher emitters. (Improvements in safety were also mentioned among its objectives.)

But there certainly were other, more or less explicit, purposes motivating the incentive policy.

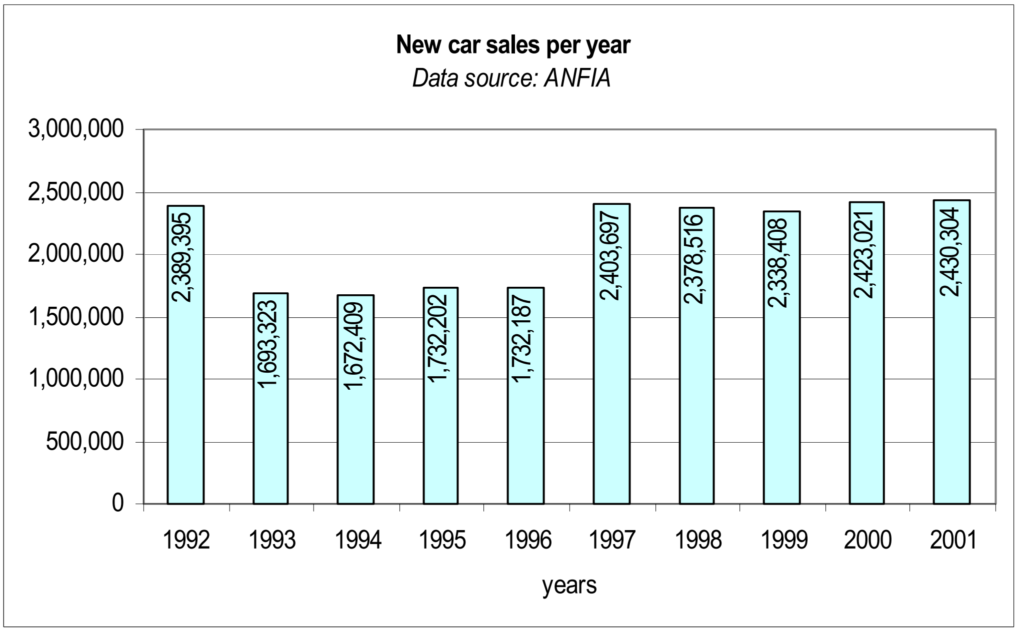
[4] Fiorentino (1995). The figure refers to cars for which insurance was paid.
[5] For USA, Alberini et al. (1999) report that pre-1980 cars, that are 18% of the national fleet and account for 8% of miles driven, produce 40% of the total HC emissions and 25% of NOx. See also Glazer et al (1995).

It was openly intended as a substantial (albeit arguably short-lived, because of the anticipation effect and the risk of increased competition between manufacturers) support to the car industry – a crucial sector in the Italian economy[6], with a significant lobbying power that has often heavily influenced government economic policies (such as governmental incentive programmes to investment in Southern Italy). The car market in 1996 still showed no signs of recovery. The effect of the recession had been reinforced also by the very restrictive fiscal policy (aimed at reducing the public deficit and at financing the national pensions system), which decreased households disposable income and thus discouraged purchase of durable goods.

The incentive programme represented also an employment measure, motivated by the concerns about the employment dimension of the car industry crisis, in terms of layoffs but especially of workers made idle. It has been argued that the money saved on wage supplementation funds (*Cassa Integrazione Salari*) should be included among the benefits in a public finance assessment of the policy.

From a macroeconomic point of view, the policy was expected to stimulate, through the quite high "multiplying factor" of the car industry, the overall growth of GDP. A special concern was placed on this in 1997, as a certain rate of GDP growth was needed in order to attain a Debt/GDP ratio compatible with the Maastricht Treaty requirements.

Fig. 2. 1 New car sales, 1992-2001



[6] ANFIA (2000) claims that when both direct and indirect employment are taken into account, including collateral service and sales activities, the car sector counts one and a half million workers (7% of total employment), and that it accounts for 4.5% of total industrial value added.

2.2 *Details of the policy*

The government offered a sum that ranged from Lit 1,000,00 (€ 516) to Lit 2,000,00 (€ 1,033) depending on the size of the engine, the fuel consumption and the different time periods in which the policy applied. The incentives were first introduced for a 9 months period from the 7th of January to the 30th of September 1997, and later extended, with some modifications, to the October 1997 – July 1998 period (details in Table 2. 1).[7]

To be eligible, a vehicle either had to have been registered before 01/01/1987 or 10 years had to elapse from the date of first registration while the programme was in place. A further restriction applied: the vehicle had to have belonged to the same owner for at least six month before the beginning of the programme (June 1996 for the initial period, March 1997 for the extension), in order to prevent eligible cars from being sold with the sole purpose of letting the new owner take advantage of the incentive.[8]

In addition to the cash-for-replacement subsidy, the possibility was offered to those owners of eligible cars who would *not* replace them with a new one of scrapping them all the same without incurring all the related costs (administrative fees and the like).

Table 2. 1 Amount of incentive

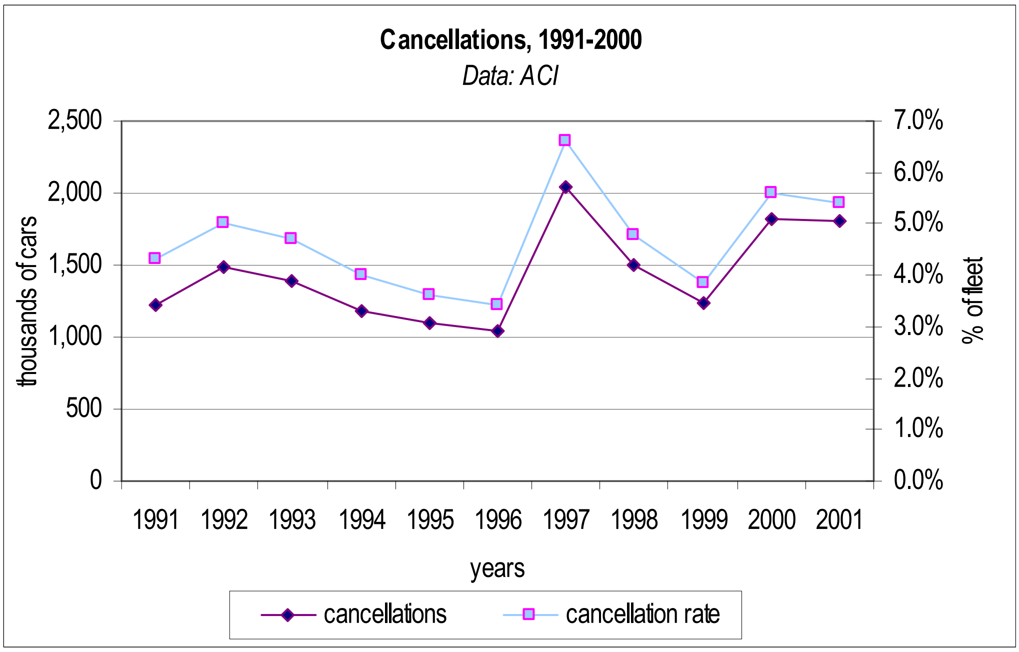
Period	Jan 97 – Sep 97		Oct 97 – Jan 98	Feb 98 – July 98		Electric engine	Scrapping without replacement
New vehicle's engine size *new* vehicle	up to 1300 cc.	over 1300 cc.	--	--	--		
New vehicle's consumption for 100 km	--	--	--	7-9 litres	Up to 7 litres		Exemption from scrapping fees
Lit	1,500,000	2,000,000	1,500,000	1,000,000	1,250,000	3,500,000	--
€	774.69	1,032.91	774.69	516.46	645.57	1,807.60	--
Total discount for purchaser = at least: €	1,549.38	2,065.82	1,549.38	1,032.92	1,291.14	--	--

[7] Placing a purchase order before the end of July was enough to be entitled to the incentive, so that in fact it applied to purchases actually realised in September.
[8] The relatively high costs associated with a change in car ownership in Italy should discourage such transactions anyway to some extent.

2.3 Participation in the scheme

ACI official figures for cancelled and scrapped cars[9] (Table 2. 2 and Fig. 2. 2) provide a first glance at the scale of the participation, which was undoubtedly wide. The number of cancelled cars rose remarkably in 1997 (nearly doubling the 1996 levels), in 1998 it remained well above the previous years level, then decreased in 1999 to increase again in 2000 and 2001 – when leaded petrol was phased out. Many new vehicles were bought taking advantage of the incentives, and even more old vehicles were retired – not only those that got replaced with new ones, but also the considerable amount (30% of total cancellations according to ACI figures) that were scrapped fee-exempt. It would probably not be correct to assume that all of the owners of the latter vehicles chose not to replace them. It is more plausible that some, unable to afford buying a new model, demanded a second hand one.

Fig. 2. 2 Cancellations of cars from P.R.A.



[9] ACI, for some years (since the beginning of the incentive policy) publishes figures for both "scrapped" and "cancelled" cars. The ratio between the two figures is illustrated in Table 2. 2. In FA data, "outflows" are derived from fleet size and new registrations, as described below, and thus conceptually closer to "cancellations", or "exits". Nevertheless for convenience they will be referred to as "scrapping" in a broader sense.

Table 2. 2 Cancellation of cars by cause

	1997	%	1998	%	Sum of policy years	%	1999	%
Tot cancelled Of which:	2,037,586		1,557,719		3,595,305		1,228,276	
Scrapped	1,996,907	98.00%	1,467,891	94.23%	3,464,798	96.37%	982,030	79.95%
Of which:								
Incentive	1,150,999	*57.64%*	693,229	*47.23%*	1,844,228	*53.23%*		
"no fees"	550,200	*27.55%*	492,026	*33.52%*	1,042,226	*30.08%*		
tot 10+	1,701,199	*85.19%*	1,185,255	*80.75%*	2,886,454	*83.31%*		
non eligible		*14.81%*		*19.25%*		*16.69%*		
Exported	39,339	1.93%	47,657	3.06%	86,996	2.42%	66,718	5.43%
Other	1,340	0.07%	42,171	2.71%	43,511	1.21%	166,793	13.58%

Source: ACI

The share of scrapping over the total of cancelled cars offers the chance for a brief digression. Such ratio, unfortunately not available for pre-policy years, appears in fact to be quite higher in 1997-1998 than in 1999. This suggests that the scheme gives some car owners an incentive to choose scrapping against alternative ways of getting rid of old cars. The other reasons for the cancellation of a vehicle from the P.R.A. are divided in "export" and the somewhat mysterious residual category "other", which grows from less than 3% during policy years to 13.6% in 1999. It comprises reasons such as "entry in other registers" (quite a rare occurrence, "other registers" referring to military and diplomatic vehicles) and "circulation restricted to private areas".

ACI (2002), reporting data for years 1998-2001, makes it possible to have a closer look into the latter. The cancellation of vehicles for circulation in private areas in fact jumps from 3% in 1998 to 15% and 14% in subsequent years (reaching over 40% in some Southern regions, notably Basilicata and Calabria). Since a sudden dramatic increase of the number and size of private areas within which to circulate – or the demand for motor vehicles to circulate within them – appears implausible, it is legitimate to suspect these figures mask many cars that are actually retired from circulation and ought to be officially demolished but end up being illegally disposed of. In fact, in mid-1998 the Legislative Degree 22/97 on waste disposal had come into effect, prescribing (art.46) the "ecological" (i.e. not imposing risks to human health and the environment) disposal of end-of-life vehicles, and anticipating to a large extent the contents of Directive 2000/53/EC on end-of-life vehicles (ELV Directive). Retiring vehicles on private areas appears then as a way of dodging the difficulties imposed by the long distances from, and high fees charged by, the authorised treatment centres.[10]

The cost of clean dismantling and disposal, if borne by last owner, can increase the number of abandoned vehicles and, as is likely in the Italian case, the illegal dismantling and resale of parts. The European legislator appears aware of such risk when prescribing (article 5 of the ELV Directive) that the delivery of end-of-life vehicles to authorised treatment facilities be free if the vehicle has no or negative value (from July 2002 for vehicles put on the market from this date and from January 2007 for those put on the market before July 2002.)

2.4 First sight economic assessments of the policy

Parallel to the boom in scrappage, at the other end the car market saw a spectacular recovery: new sales grew by 39%[11] in 1997 with respect to 1996 (reaching an all-time peak of 2 403 697 units sold), and in the first 7 months of 1998 (duration of the policy) there was an extra 6% growth with respect to the same months in 1997. In the absence of the incentive policy, manufacturers claim no such growth was forecasted. As for the employment side, Fiat Auto (which accounts for 35.5% of the domestic car market, and 68.9% of domestic production) claims that such recovery allowed the recruitment of 2000 new workers[12]. At the macroeconomic level, the total growth of the GDP in 1997 (which contributed crucially in meeting the parameters required by the Maastricht Treaty) was 1.5%. The Bank of Italy estimated that 0.4% was ascribable to the car sector.[13]

From the public finance point of view, the balance between total expenditure on subsidies and increased revenues (with respect to 1996 levels) from VAT and other taxes was hugely positive: around Lit 1,214 billion (€ 623 million) for 1997, and Lit 816 billion (€ 421 million) for 1998.

At first sight the replacement incentive policy could thus look like a win-win solution that could leave everyone happy.[14] But serious objections arise on the issues of deadweight, of assessing mid-term effects and the impact on public finances, and about the actual real environmental outcome.

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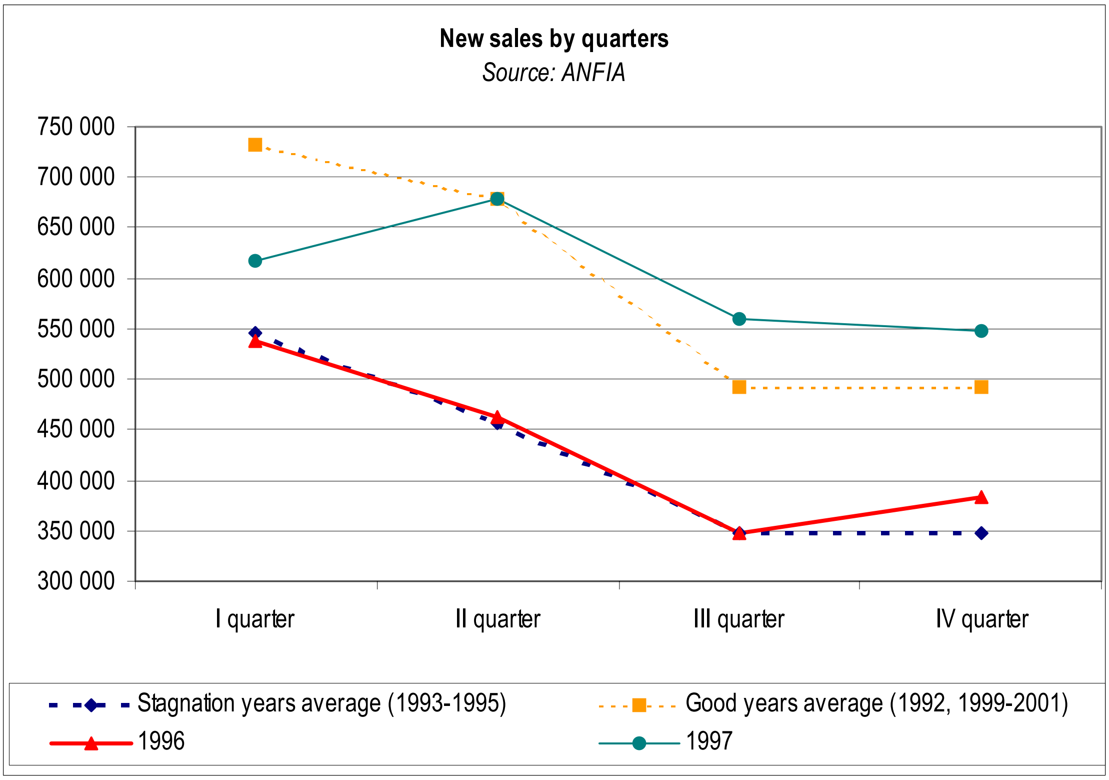
[10] ACI (2002), p.22.
[11] Car purchases by households, increased by 31%, represented half of the total increase in private consumption (Banca d'Italia 1998).
[12] Dr. Severino Damini, of Fiat Auto D.A.P.I. (*Direzione Ambiente e Politiche Industriali*, Environment and Industrial Policies), personal communication, July 2002.
[13] This takes into account firms purchases, imports and exports, while the whole impact on allied industries is not quantified (Banca d'Italia 1998).
[14] And indeed enthusiasm was widespread, *in primis* among manufacturers. Staff from Fiat Auto D.A.P.I. Management, eager to support the view that this policy had no losers, provided most of the figures here quoted and what I term the

Not all of the increase in sales can be attributed to the incentive policy. In years 1993-96, when disposable household income had remained low, the fleet had aged significantly. It is thus reasonable to assume that both components of vehicle demand – incremental and replacement – had been at least partly postponed and would soon have rebounded anyway. To this point, Banca d'Italia (1998) reports that signs of recovery could be seen towards the end of 1996, in terms of a considerable increase in orders placed in the last months of the year. This trend is only barely perceptible in the series of first registrations series (Fig. 2. 3) because registrations tend to follow orders with a delay of 2 to 4 months. Such delay is consistent with the relatively low level of sales reported for the first quarter of 1997 in the same Fig. 2. 3. In fact, with respect to the typical quarter profile of sales, which is very similar between the two averages (dotted lines) referring respectively to stagnation and to good years, in 1997 the level for the first quarter is relatively low, while for 1996 the fourth one is slightly higher than average.

This appears to provide a first clear hint that some kind of autonomous dynamics was at work and might have added to the genuine effects of the policy.

Fig. 2. 3 Quarter profile of new sales



"naïve" estimate of environmental impact shown in Table 2. 3, insisting particularly on the (dubious) claim that prior to the implementation of the programme there were no expectations of recovery.

Estimates of the longer term impact on the car market are highly uncertain. For the French case, Adda and Cooper (2000) use a dynamic discrete choice model of car ownership to analyse both the immediate effects of the scrapping scheme on output and public finances and the subsequent effects that take place over time as the age distribution of cars evolves. Their conclusion is that an initial burst of activity is followed by a subsequent considerable fall in sales (and tax revenues).
In Italy, however, the price trend helped sustaining the sales of new cars in 1999 well above the pre-policy level, while in 2000 and 2001 it was the phasing out of leaded petrol that contributes to explaining the high levels of fleet renewal. ECTM (1999) reports in fact that the introduction of the incentives was immediately followed in January 1997 by a dramatic fall of car prices (3.5% in *nominal* terms) which was not compensated by later increases. The Italian car price index fell below the European one and the general consumer price index. In the months that followed the end of the incentive programme producers kept prices quite low.

When it comes to public finance, the optimistic view that extra tax revenues (VAT, excise and registration taxes) from new vehicles sales could outweigh the cost of covering the bonuses granted is far too simplistic. Both of the problems already discussed, deadweight and anticipated demand, are of course relevant in this context. It is certainly not correct to count among the benefits of the programme the taxes paid on replacements that would have taken place anyway. And if sales are likely to decline in the mid-term, so are tax revenues. Just as for firms' profits, part of the increase represents only a shift in time.

Moreover, a budget constraint argument applies. Increased purchases of cars reduce households' income available for other expenditures, and especially for other durables. ECMT (1999) reports evidence for 1997 of a decline in expenditure for furniture, household maintenance and construction – all activities that also generate VAT tax base.

2.5 Environmental impact – a "naïve" scenario and its major flaws

In order to illustrate the beneficial impact of the policy on air quality, Fiat Auto constructed an estimate of emissions savings on the basis of the total number of replacements that benefited from the bonus in the January 1997 - July 1998 period, using differences in average emission rates and assuming for all vehicles – "new", replacement cars as well as "old", replaced ones – an average mileage of 10 000 km/year. The pollutants included in this computation, summarised in Table 2. 3, are those for which emission limits are set by EU directives (ECE and EURO standards).[15]

[15] Fiat Auto D.A.P.I. provided parameters and the structure of the computation, to which marginal modifications were made in order to adjust it to ACI official figures for total replacement with incentives. While the EURO II parameters

A number of assumptions are implied in the above computation:

- *All replacements benefiting from the incentive are counted as induced by the policy*. No account is taken of the deadweight – those that would have happened even in the absence of the incentive. On the other hand, only scrapped *and* replaced cars are included – but not those that get scrapped fee exempt.
- *All cars are assumed to drive 10 000 kilometres a year*. No acknowledgement is made of the relationship between vehicle age and typical mileage, nor of the possibility that cars that get scrapped are driven less or more than average.

Table 2. 3 Yearly emissions savings– "Naive" scenario

	Old cars			New cars	Difference	emissions savings per car (10,000 kms)	Total emission savings on 1,844,228 replacements
Pollutant	1983 directive (ECE 15/04)? g/km	deterioration factor for 10+ cars	g/km	EURO II g/km*	g/km	kg/year	tons/year
CO	12	1,85	22.2	2,2	20.0	200	368,846
HC	3	1,3	3.9	0,3	3.7	37	68,236
Nox	2	1,3	2.6	0,2	2.4	24	44,261
CO_2	…	…	194	164	30.0	300	553,268

Source: Fiat Auto D.A.P.I.

* = petrol cars, engine displacement <1400 cc.

- *The same mileage is imputed to replaced and replacement cars*. This implies ruling out any 'pure' age effect – i.e., the possibility that newer, safer, and possibly more comfortable cars are used more intensely or on a different range of trips type.
- *All scrapped cars are assumed to be replaced with small ones*. Although there are theoretical reasons to expect a significant distortion of sales towards smaller models, as well as empirical evidence clearly supporting it, this appears extreme and might lead to overestimate emission reductions. (Assumptions on types of retired cars, on the other hand, are less clear.)

refer quite clearly to small-engine petrol models, the assumptions on size and fuel distribution underlying those provided for ECE 15/04 are less obvious.

- *Average emission rates are imputed to scrapped vehicles*. No account is taken of the potential adverse selection in terms of maintenance status of the vehicle and deterioration of emission rates (nor of actual mileage).
- *No explicit assumption is made on the remaining lifetime*, as this computation aims at identifying the emission savings over one year – thus bypassing the issue of the correct time horizon over which to assess improvements in air quality. In fact all issues of self-selection (remaining lifetime, mileage, maintenance) are neglected.
- Finally*, the focus is restricted to air pollution due to vehicle usage.* Environmental impact of car manufacturing, maintenance and dismantling are ignored, as much as environmental externalities from usage other than polluting emissions.

All such assumptions appear unsatisfactory. The assessment presented in the next section aims at addressing most of these shortcomings.

3 Policy analysis for emission reduction assessment

3.1 Structure of impact assessment

The diagram in Fig. 3. 4 illustrates the structure of this section, and the steps of the impact assessment procedure leading to an estimate of the emission savings attributable to the incentive policy.

A few *caveats* immediately apply. On the one hand, the available data is far from ideal. In fact the main ingredient of the computation – the FA age distribution series – suffers from two fundamental limitations: it is very short (1995-1999), and only two pre-policy years cannot be considered fully 'representative' (see discussion in subsection 2.4). On the other hand, we lack of appropriate information needed for a reasonable treatment of *all* relevant aspects (notably those related to selection problems). Therefore, the analysis presented here aims not so much at attaining a reliable and perfectly accurate estimate of the tons of pollutants saved, but rather to provide a methodological contribution as far as at least *some* of the crucial issues are concerned.

Ideally in a similar framework one would want to produce both an upper and a lower bound for the object of estimation. Unfortunately the limitations in our data (particularly the short span of the FA series) preclude doing so in a sensible way. It is in fact the very first step of the calculation (i.e. using 1995-96 scrapping rates as the basis for constructing a "no policy" baseline) that bears an inevitable bias towards an overestimation of environmental gains. The strategy followed is thus to keep erring on the same side in all subsequent steps, i.e. to make choices that are consistent with ensuring that all additional biases 'have the same sign'. This in order to ensure that the final result of the estimation can be safely regarded as an upper bound for emission reductions.

3.2 Evolution of car fleet and expected effects of incentive scheme

Table 3. 4 lists the components of "outflows from" and "inflows to" the fleet during policy years, and the expected effects on each. It helps identifying what one can expect to observe in the available data with respect to a no policy scenario.

Table 3. 4 Expected effects of programme on fleet outflows and inflows

		Effects of policy	
	Outflows	**Direct**	**Indirect** (through prices and 2nd hand market)
(a)	Replaced aged >= 10 (eligible for incentive)	+	+
(b)	Replaced aged < 10 (non eligible for incentive)	No	+
(c)	Non replaced aged >= 10 (eligible for fee-exemption)	+	No
(d)	Non replaced aged < 10 (non eligible for fee-exemption)	No	No
	Inflows:		
(e)	Bought in replacement with incentive	+	+
(f)	Bought in replacement without incentive	No	+
(g)	New demand	No	+

With necessarily (a)=(e) and (b)=(f)

- *Total size*. Direct effects encourage outflows ("scrapping" in the broad sense) more strongly than inflows, and should thus induce a decrease in the overall size of the fleet. When the potential role of indirect effects is taken into account the overall impact on the fleet size is more uncertain. However, it appears reasonable to assume that indirect effects are weaker than direct ones, and therefore expect the total car stock to shrink.

- *Scrappage activity*. By definition, the policy will induce a visible increase both in absolute *numbers* of scrapped cars and in scrapping *rates*.

- *Rejuvenation*. This, again, is trivial: the average age of the car stock is expected to decline for both the increased entry of new vehicles and the accelerated retirement of older ones.

- *Age-specific effects.* More specifically, it is the eligible age cohorts – and only the eligible ones – that will be *directly* affected by the policy (which does not however rule out a role for indirect phenomena through price dynamics).

Fig. 3. 5 a,b,c portray the evolution over time of the age distribution for petrol, diesel and total cars respectively. The long-lasting influence of sales dynamics (with alternating booms and stagnation periods) on the age structure of the fleet age is clear, as are the marked differences in time trends of sales for petrol and diesel cars.

Fig. 3. 4 Structure of impact assessment

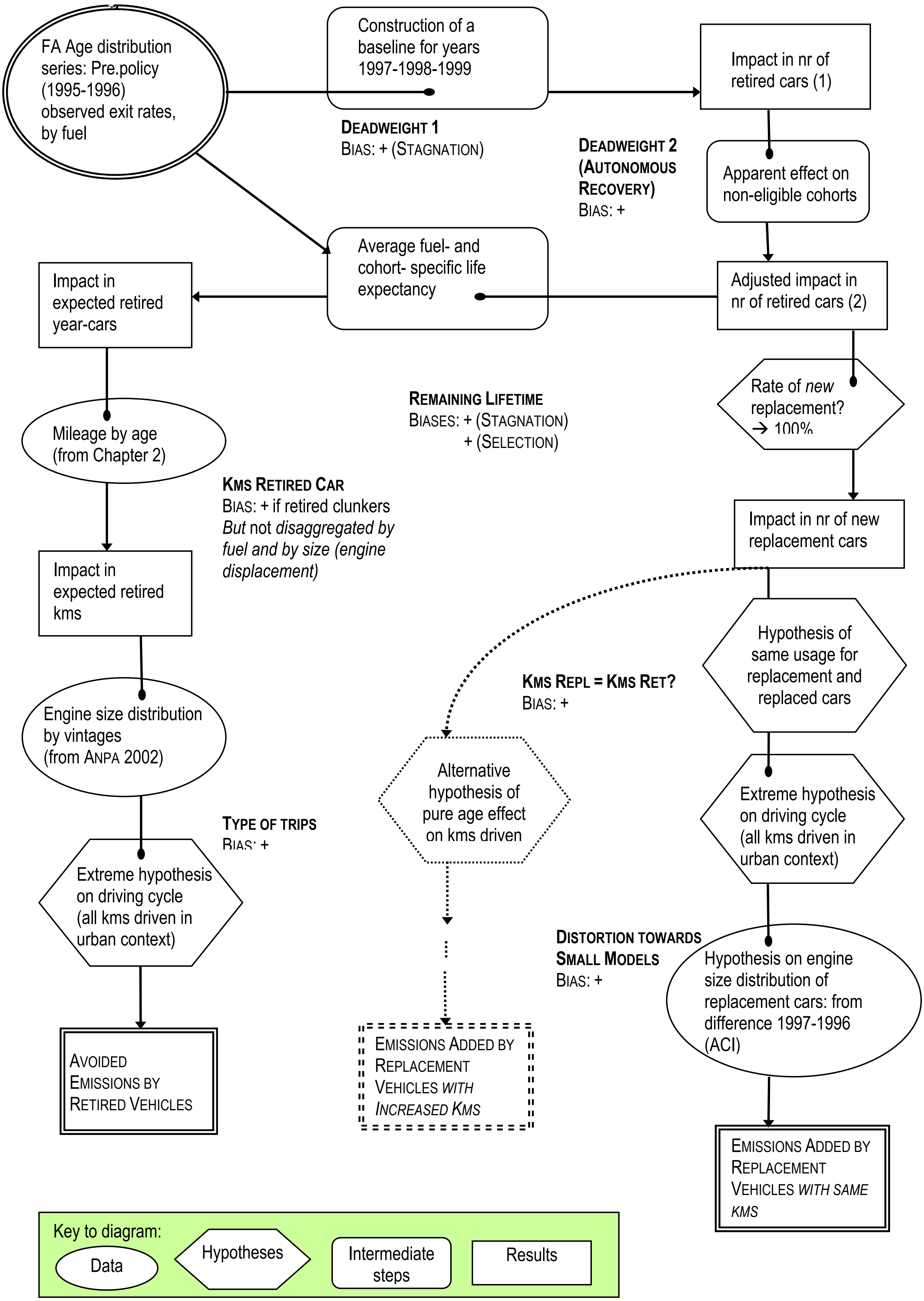
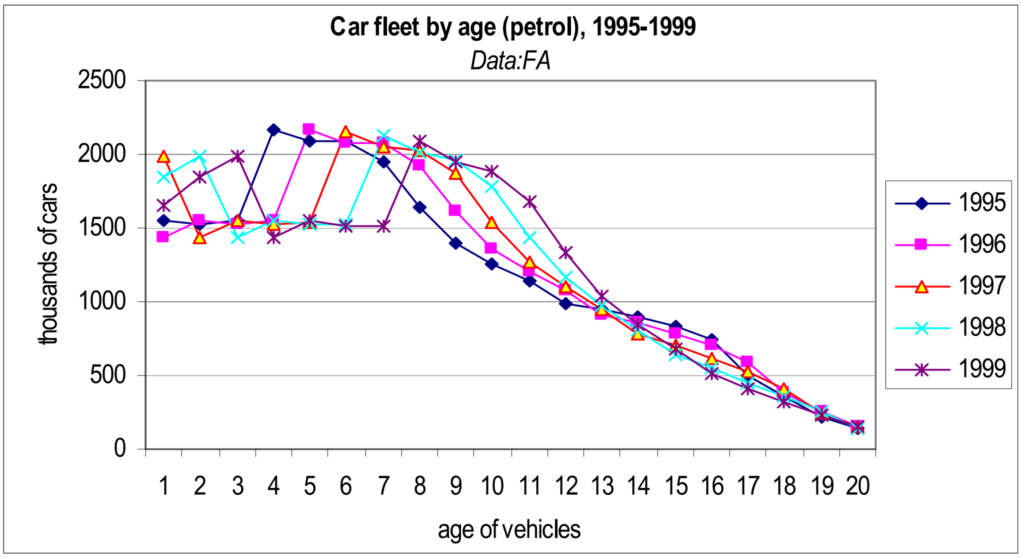
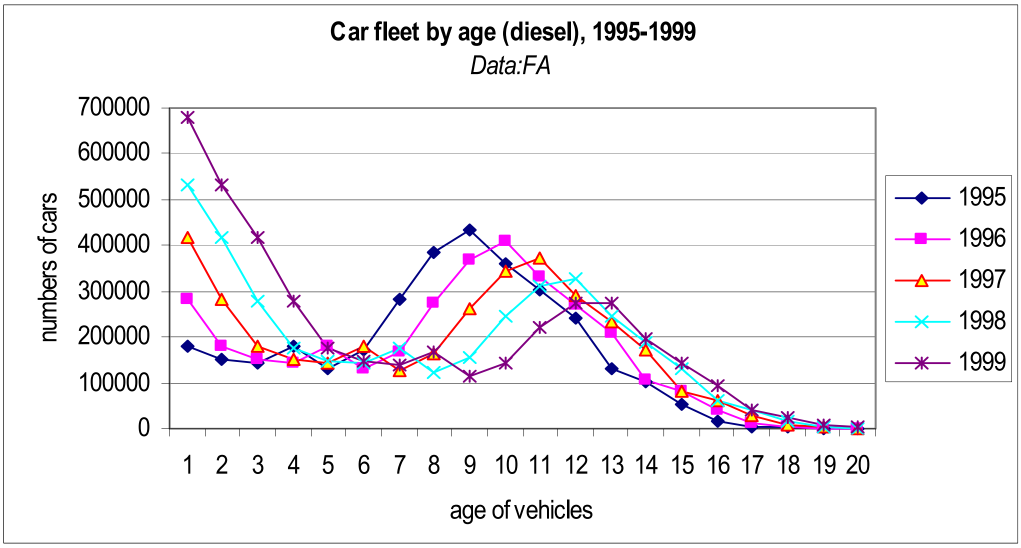
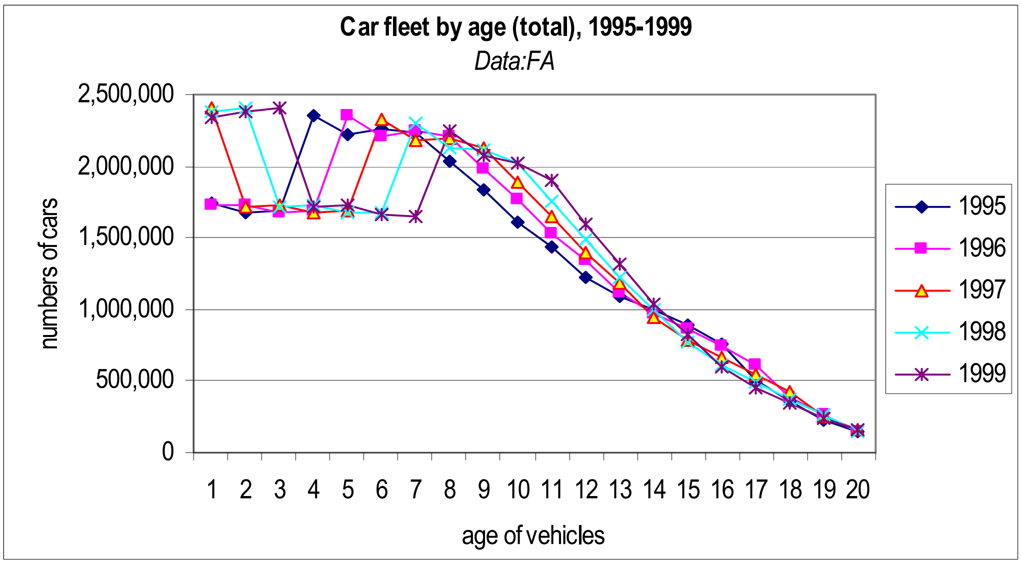


Fig. 3. 5 a,b,c *Age structure of the car stock*







The aggregate scrapping activity as reflected in the FA series is summarised in Table 3. 5, where the scrapping rates are derived as follows. Simplifying Table 3. 4, in each period the evolution of the total car fleet is driven by 4 elements:

(1) + Incremental demand
(2) + Replacement demand
(3) – Scrappage with replacement
(4) – Scrappage without replacement

with (2) obviously = (3)

The *net variation* in total fleet, $F_t - F_{t-1}$, is given by: (1)+(2)–(3)–(4) = (1)–(4).
The total demand coincides with the *new registrations* = (1)+(2)
From a time series of aggregate fleet and new registrations, the number of scrapped cars, (2)+(4), can thus be derived as the difference between new registrations and net variation:

$$\textit{Total scrapped} = [(1)+(2)] - [(1)-(4)] = (2)+(4)$$

The scrapping rate is computed as the ratio between *total scrapped* in year *t* and the fleet in *t-1:*

$$\textit{Scrapping Rate} = (\textit{new registrations in } t - \textit{net variation in } t) / F_{t-1}.$$

The overall exit rates clearly increase both for petrol and diesel engine types in 1997 and 1998 and drop again in 1999, but keeping above 1996 levels.

Table 3. 5 Scrapping activity 1996-1999

Years	***Petrol***		***Diesel***		***Total (sum)***	
	Scrapping rate	*tot scrapped*	*scrapping rate*	*tot scrapped*	*scrapping rate*	*tot scrapped*
1995	5		5.2		--	--
1996	5.1	1,234,000	6.5	214,126	5.3	1,448,127
1997	7.3	1,781,000	8	265,940	7.4	2,046,941
1998	7.2	1,770,000	8.7	304,403	7.4	2,074,404
1999	6.4	1,582,000	8.7	323,653	6.7	1,905,655

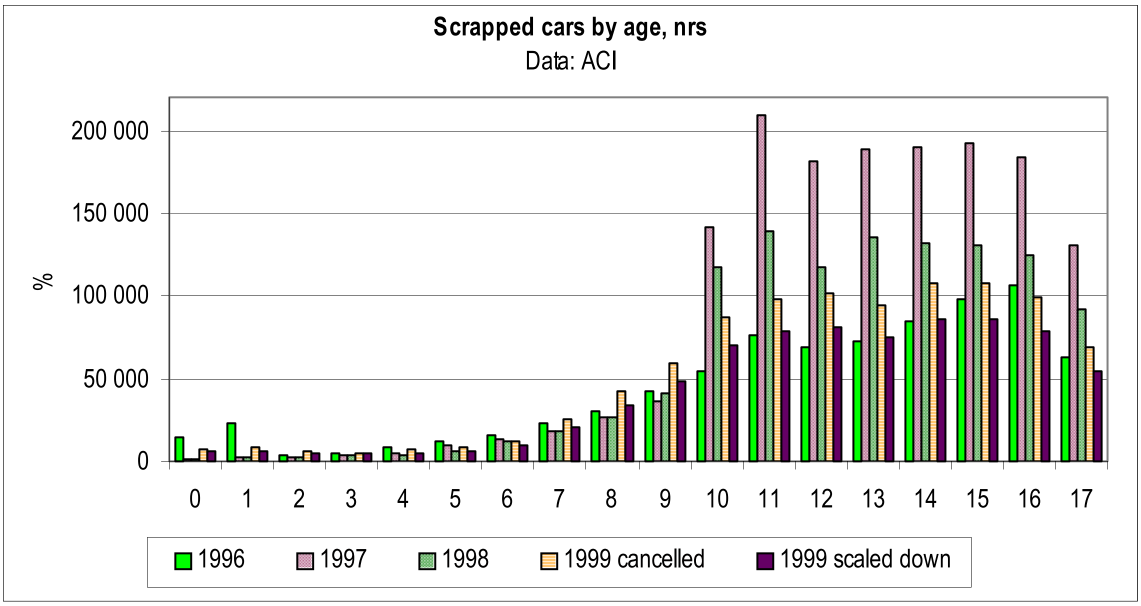
Data: FA

The higher scrapping rate for diesel cars in all years, and especially in 1999, is only to some extent explained by the age composition of the diesel car stock (Fig. 3. 5 b). The hump of older cars, built between 1983 and 1989, are likely to get closer to their natural end-of-life ages. But on the other hand, differences in cohort- specific exit rates might play a role (as will be shown in the next subsection).

3.3 Scrapping activity by age cohorts

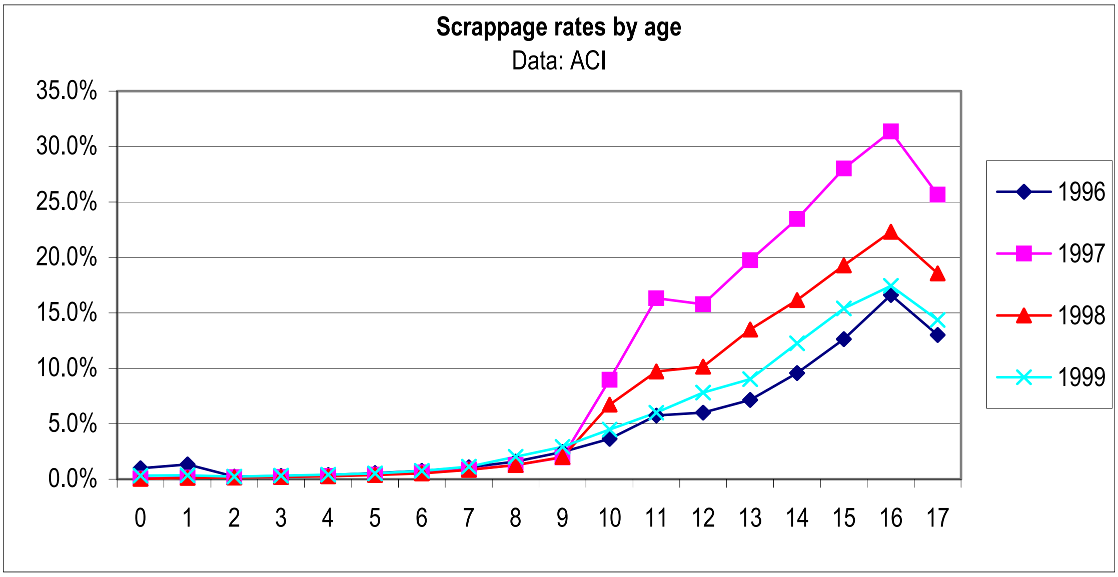
Here we turn to the analysis of the policy impacts by cohorts of vehicles, using both official figures and the FA time series from which age-specific survival rates are extracted.
The two charts that follow (absolute numbers in Fig. 3. 6, age-specific rates in Fig. 3. 7) illustrate scrappage by age as reflected in ACI data. There is evidently a strong increase in scrappage of eligible vehicles in the two policy years with respect to 1996, while the absolute numbers for non eligible vehicles look virtually unchanged.[16]

Fig. 3. 6 Increased scrappage in ACI figures



[16] Figures for 1999 are available only for all cancelled cars. In Fig. 3. 6 these have been scaled down using the scrapped/cancelled ratio reported in Table 2. 2: the resulting age profile has a very similar shape to pre-policy levels. For the sake of readability only ages 1 to 17 have been included: as scrapping of car aged 18 or more represent almost 25% of total including them would "flatten" the charts.

Fig. 3. 7 Scrapping rates in ACI figures



ECTM (1999), on the basis of ACI figures, reports an increase in the proportion of scrapped cars across all eligible cohorts, but also a higher success for the relatively younger ones. The ratio between the 1997 and 1996 scrapping rates was 2.3 (equivalent to a 130% increase in scrapping rates) for car aged 10 to 13, while only 1.7 (70%) for those over 15. Such indication of a stronger impact on vehicles aged 10-13 could be read in support of the concern that worse-off owners unable to afford buying a new model might be left out of cash-for replacement schemes, i.e. evidence of the *missed target* problem.

Such ratios are replicated separately by engine types on FA data and shown below in Fig. 3. 9c and Fig. 3. 10c: even though the value of the ratios is much lower than those reported by ECTM (1999), especially for diesel cars, the age profile of the ratios is nonetheless similarly decreasing.

The above results can be compared and enriched with those based on FA data, which can be disaggregated by fuel type. Fig. 3. 8 a,b,c show the numbers of scrapped vehicles for petrol, diesel and all cars respectively. Diesel cars appear to be scrapped at much earlier age than petrol cars. This is probably because they wear out more quickly than petrol cars due a much heavier usage. Moreover, while the age distribution of scrapped petrol cars moves to the left between 1996 and 1999 (the median age decreases from to 15 to 14), consistently with the fact that when scrapping is accelerated older cars are affected first, the opposite is true for diesel: the median age goes from 11 to 14, reflecting the progressive ageing of diesel vehicles.

The same behaviour can be analysed in terms of year- and age- specific survival rates (hazard rates). Defining:

$f(a,t)$ the number of cars in year *t* fleet aged *a,*

survival and hazard rates are computed as follows:

$$sr(a) = \frac{f(a,t)}{f(a-1,t-1)}$$ survival rate

$$hr(a) = 1 - \frac{f(a,t)}{f(a-1,t-1)}$$ hazard rate = age-specific scrapping rate

Fig. 3. 9 a,b,c and Fig. 3. 10 a,b,c represent each, for petrol and diesel cars respectively:

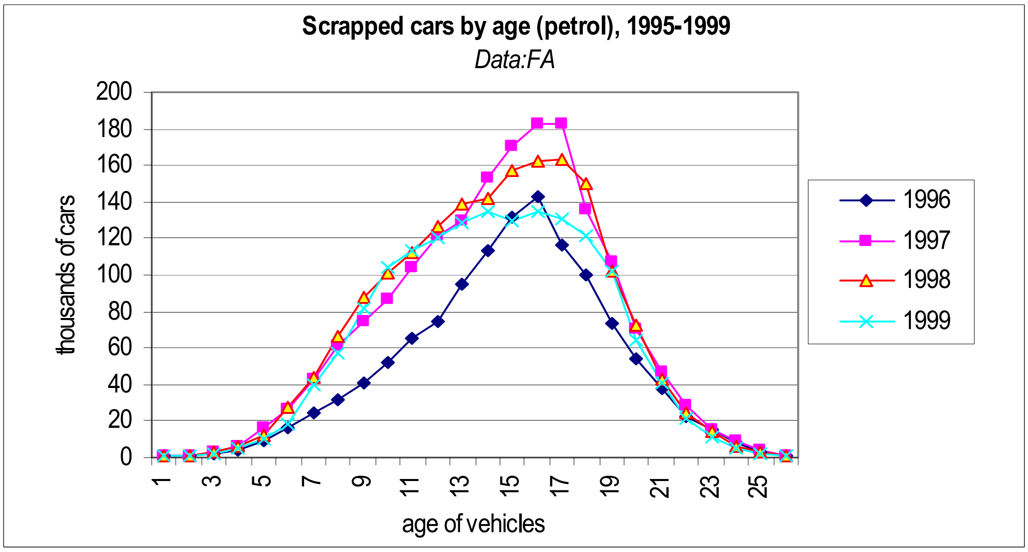
- the age-specific survival rates for all years
- the difference between policy years and 1996 rates
- the ratio between policy years and 1996 rates.

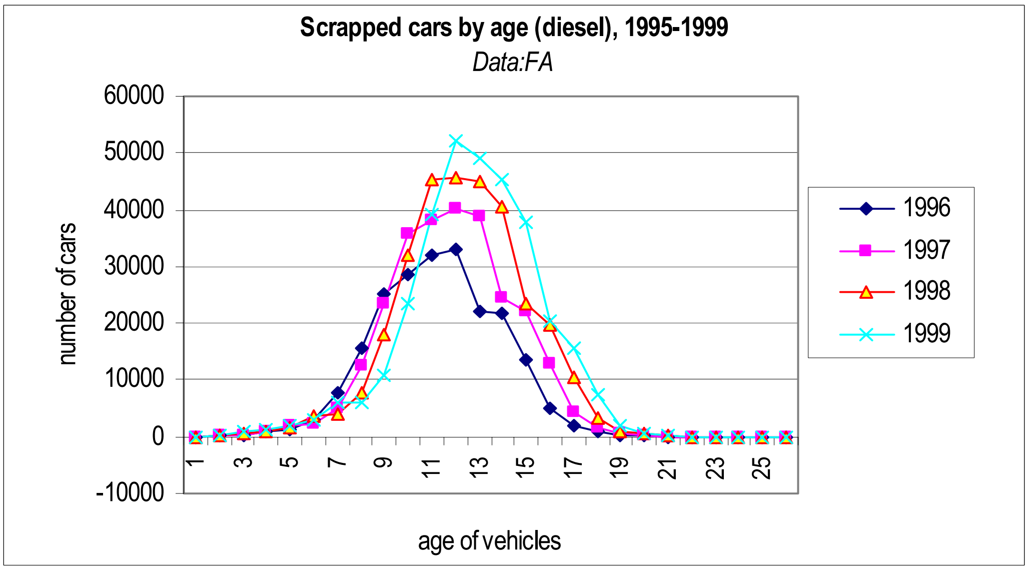
Although the reduction in survival rates (corresponding to an increase in the hazard = scrapping rate) grows monotonically with age and is stronger for eligible cars, it concerns cars aged 7 or more as well, for both petrol and diesel cars. This apparent effect on non-eligible cohorts could be read as indication of some autonomous trend ascribable to the ageing of the car stock, to economic recovery, or to price dynamics.

In general, the impact appears to be stronger for petrol cars than for diesel, both in terms of differences (b) and of ratios (c) in Fig. 3.8.

While *absolute differences* are stronger for older cohorts, the *ratio* between policy years and 1996 scrapping rates decreases with age, reflecting the fact that the "natural" scrapping rate (against which the observation for the policy years is compared) is higher for older vehicles.

Fig. 3. 8 a,b,c Age distribution of scrapped cars





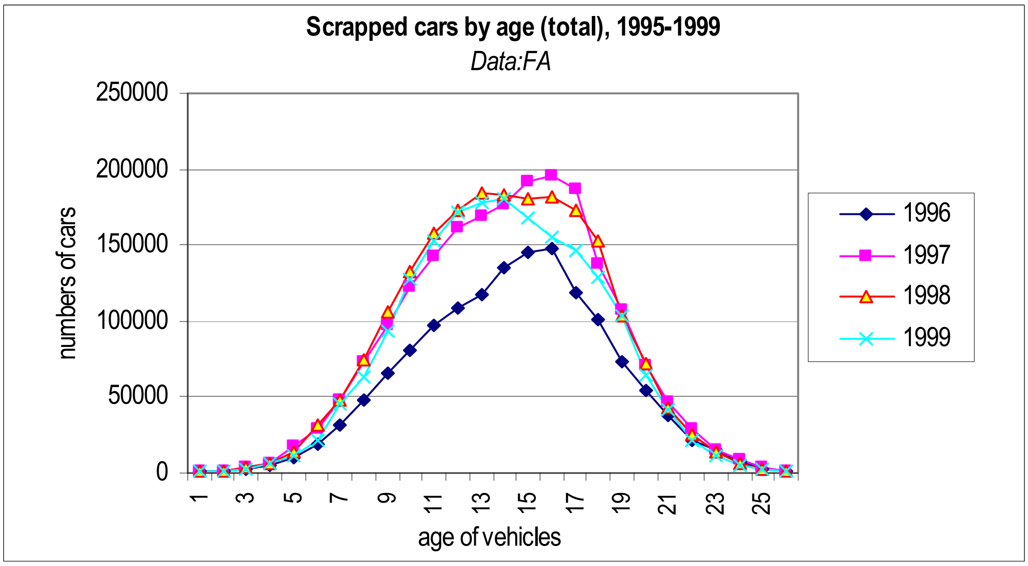
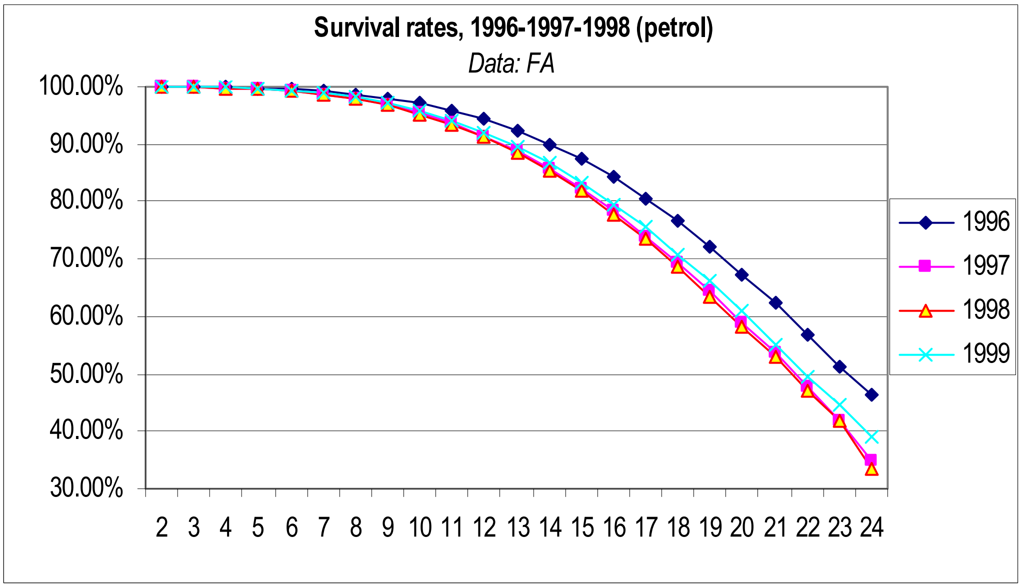
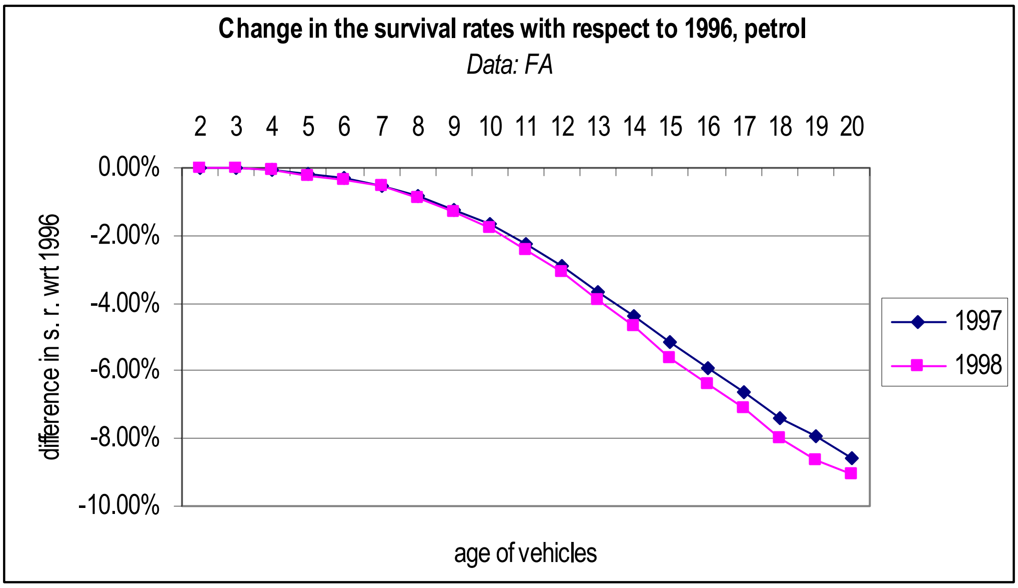


Fig. 3. 9 a, b, c   Policy impacts on survival/hazard rates, Petrol cars





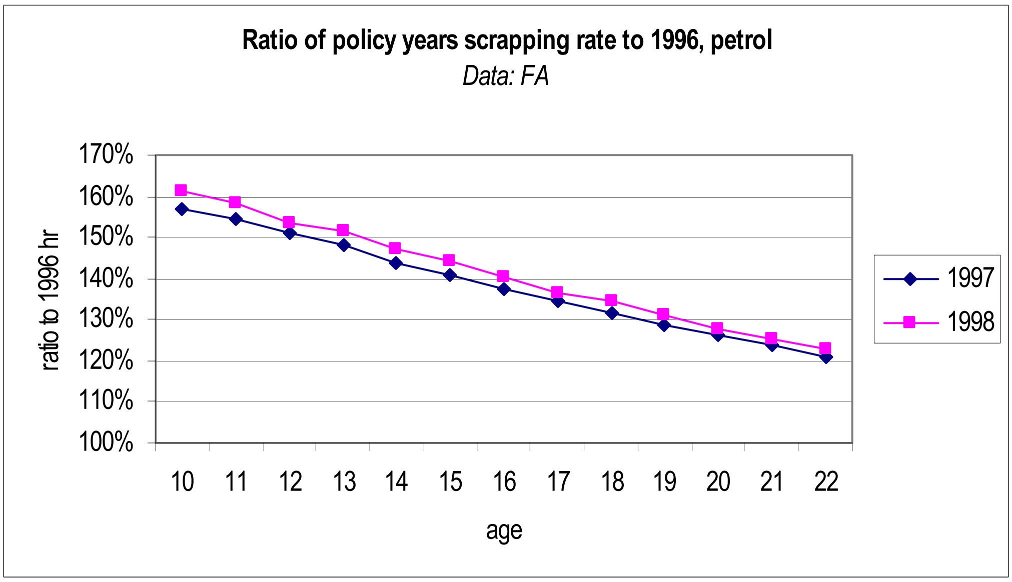
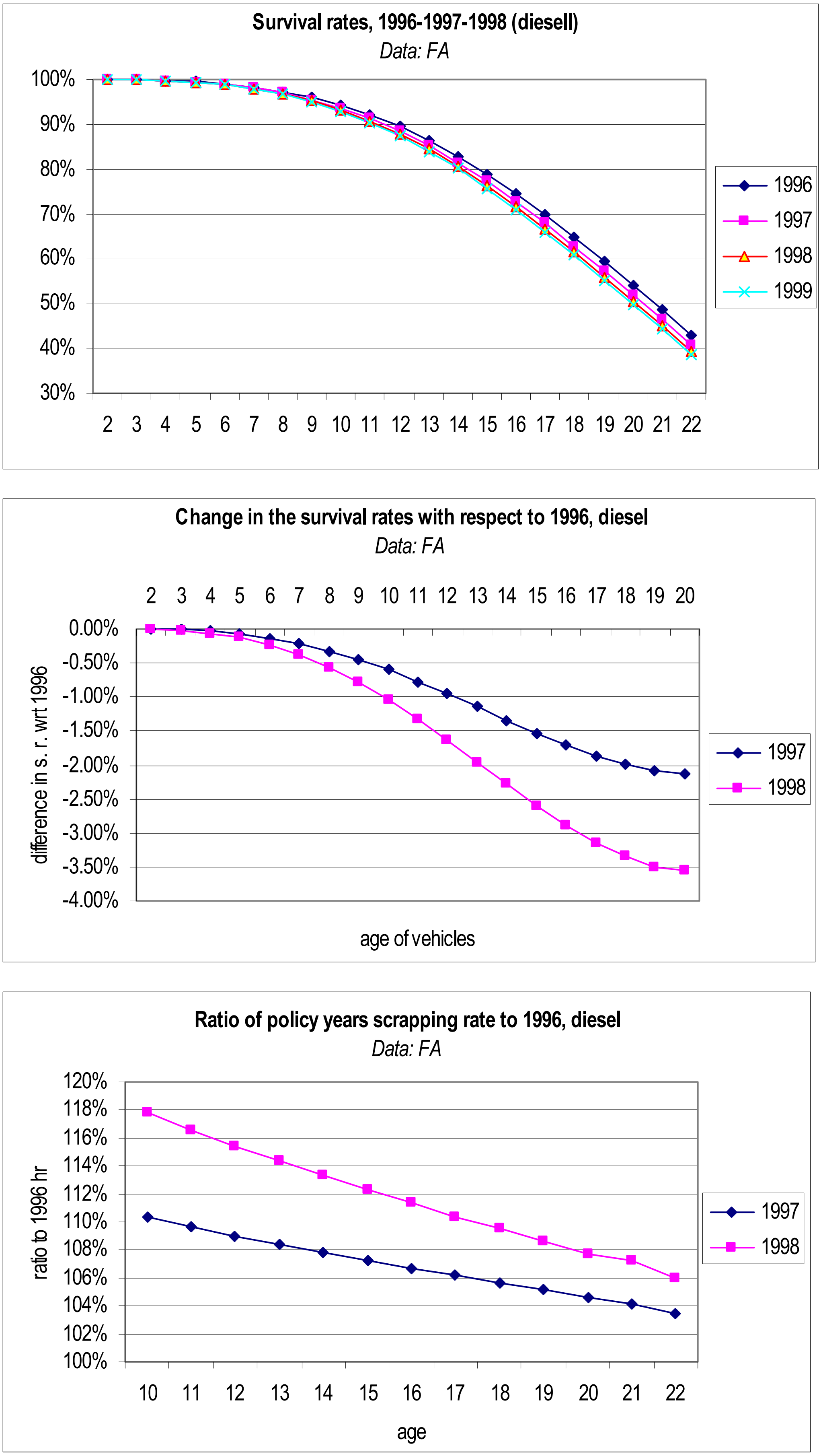


Fig. 3. 10 a, b, c Policy impacts on survival/hazard rates, Diesel cars



3.4 Construction of a baseline

Survival rates allow constructing a "no policy" baseline against which one can assess the impact of the incentive programme. Under the simple, and simplistic, assumption that the observed pre-policy years 1995-1996 rates are representative of a 'normal' behaviour of car owners, a baseline distribution of fleet by age for 1997 is obtained by applying age-specific survival rates computed for period 1995-1996 as:

$$sr_{1996}(a) = \frac{f(a,1996)}{f(a-1,1995)}$$

to each corresponding cohort of 1996 distribution, so that the baseline value for 1997 is given by:

$$\hat{f}_{1997}(a) = sr_{1996}(a) * f_{1996}(a-1)$$

This is done separately for petrol and diesel fleets. The total number of new registrations are set at the average between 1995 and 1996 levels, but applying the relative share of petrol/diesel cars observed in 1997 new sales.[17]

The difference between the real distribution and the baseline could then could be interpreted as the measure of the impact of the policy. Unfortunately such baseline is likely to be far too generous with our scrapping scheme. While ideally the construction of a baseline would require a "neutral" benchmark, in the lack of a longer series (that would allow some flexibility in determining what could be regarded as representative) hypotheses regarding as a longer time series is not available, taking year 1996 as a benchmark is an inescapable choice. But as discussed in 2.4, far from being representative of normal car owners' behaviour 1996 is a year of stagnation, with unusually *low* fleet renewal activity.

Table 3. 7 shows the results of the real-baseline comparison for the total fleet over the 1997-1999 years. Baseline for 1998 and 1999 have been carried on according to:

$$\hat{f}_{1998}(a) = sr_{1996}(a) * \hat{f}_{1997}(a-1)$$

$$\hat{f}_{1999}(a) = sr_{1996}(a) * \hat{f}_{1998}(a-1)$$

[17] The alternative idea of imputing a figure derived from the ratio between first registration and cancellations was abandoned. Such ratio is not stable in time, nor should it be: scrapping and buying decisions are not so strictly related outside of cash-for-replacement incentive programmes, and depend on demographic and urbanisation trends.

Fig. 3. 11 and Table 3. 6 provide a summary of the results in terms of the first post-policy year (1999).

Fig. 3. 11 Impact on 1999 age distribution

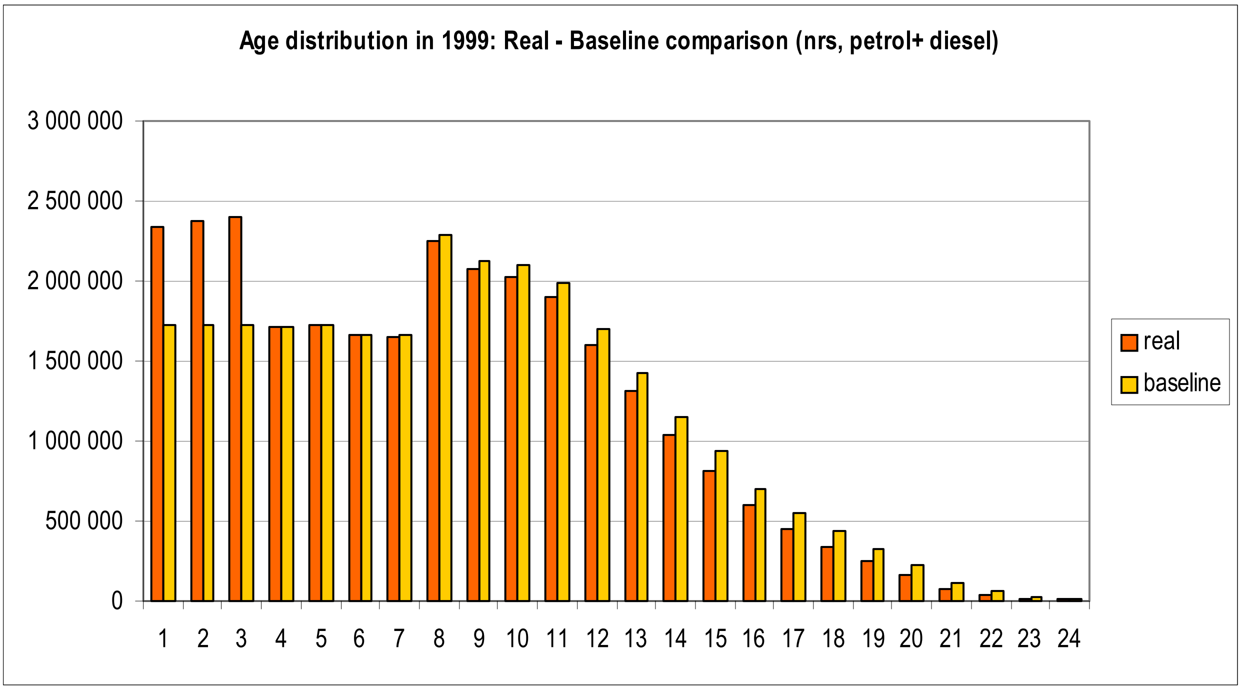


Table 3. 6 Impact on 1999 age distribution

Age groups	Real		Baseline		Real-Baseline
	Nrs	col %		col%	% diff
1-5	10 556 373	36.6%	8 632 339	30.7%	22.3%
6-10	9 656 311	33.5%	9 807 797	34.9%	-1.5%
11-15	*6 673 604*	23.1%	*7 202 967*	25.6%	-7.3%
16+	1 948 102	6.8%	2 455 487	8.7%	-20.7%
Total	*28 834 390*		*28 098 590*		*2.6%*

In Table 3. 7, the darker shading indicates the expected direct impacts – trivially:

a) The reduction in eligible cohorts: 11-20 and 21-26. The sum of the reduction for the two can be read as the upper bound of the policy impact.
b) The increase in new registrations.

Table 3. 7 Evolution of the car stock: difference real-baseline (Sum of Petrol + Diesel)

Age	Real age distribution			Baseline age distribution			Difference as % of baseline		
	1997	1998	1999	1997	1998	1999	1997	1998	1999
1	2 402 899	2 377 799	2 337 898	1 730 000	1 730 000	1 730 000	38.9%	37.4%	35.1%
2	1 721 471	2 401 851	2 376 734	1 721 549	1 729 056	1 729 105	0.0%	38.9%	37.5%
3	1 733 359	1 720 250	2 400 503	1 733 363	1 720 444	1 727 947	0.0%	0.0%	38.9%
4	1 676 849	1 729 896	1 717 484	1 677 923	1 730 997	1 718 022	-0.1%	-0.1%	0.0%
5	1 683 320	1 669 932	1 723 754	1 686 579	1 674 385	1 727 278	-0.2%	-0.3%	-0.2%
6	2 330 691	1 669 609	1 658 074	2 337 602	1 678 561	1 666 389	-0.3%	-0.5%	-0.5%
7	2 181 719	2 299 009	1 648 571	2 193 053	2 318 057	1 664 401	-0.5%	-0.8%	-1.0%
8	2 193 026	2 133 585	2 253 081	2 211 069	2 164 206	2 286 951	-0.8%	-1.4%	-1.5%
9	2 129 370	2 119 127	2 070 434	2 154 177	2 164 638	2 119 535	-1.2%	-2.1%	-2.3%
10	1 885 243	2 023 334	2 026 151	1 914 266	2 083 582	2 096 848	-1.5%	-2.9%	-3.4%
Tot 1-10	*19 937 947*	*20 144 392*	*20 212 684*	*19 359 582*	*18 993 926*	*18 466 476*	*3.0%*	*6.1%*	*9.5%*
%	70.96%	70.92%	70.09%	69.28%	67.66%	65.63%			
11	1 646 858	1 752 234	1 895 816	1 680 658	1 821 779	1 987 822	-2.0%	-3.8%	-4.6%
12	1 392 873	1 489 443	1 600 001	1 431 135	1 566 341	1 702 126	-2.7%	-4.9%	-6.0%
13	1 182 575	1 220 355	1 317 167	1 224 982	1 304 300	1 426 776	-3.5%	-6.4%	-7.7%
14	950 174	998 572	1 042 287	992 564	1 086 213	1 156 193	-4.3%	-8.1%	-9.9%
15	790 120	767 605	818 333	836 182	852 490	932 582	-5.5%	-10.0%	-12.3%
16	671 397	609 552	599 786	719 166	695 807	704 465	-6.6%	-12.4%	-14.9%
17	547 077	489 597	454 313	594 599	573 238	554 146	-8.0%	-14.6%	-18.0%
18	419 525	373 633	343 051	463 890	452 512	434 399	-9.6%	-17.4%	-21.0%
19	247 217	266 215	245 198	277 464	334 045	324 524	-10.9%	-20.3%	-24.4%
20	153 759	144 120	162 099	176 058	186 734	224 566	-12.7%	-22.8%	-27.8%
Tot 11-20	*8 001 575*	*8 111 326*	*8 478 051*	*8 396 699*	*8 873 459*	*9 447 598*	*-4.7%*	*-8.6%*	*-10.3%*
%	28.48%	28.56%	29.40%	30.05%	31.61%	33.58%			
21	81 185	81 341	79 496	94 569	109 927	116 536	-14.2%	-26.0%	-31.8%
22	43 036	38 073	40 132	51 174	53 705	62 405	-15.9%	-29.1%	-35.7%
23	21 006	18 012	17 024	25 562	26 151	27 438	-17.8%	-31.1%	-38.0%
24	8 000	7 001	7 003	10 679	11 865	12 135	-25.1%	-41.0%	-42.3%
25	4 000	2 000	2 000	5 000	4 107	4 563	-20.0%	-51.3%	-56.2%
26	1 000	1 000	0	1 250	1 250	1 027	-20.0%	-20.0%	-100.0%
Tot 21-26	*158 227*	*147 427*	*145 655*	*188 233*	*207 004*	*224 104*	*-15.9%*	*-28.8%*	*-35.0%*
%	0.56%	0.52%	0.51%	0.67%	0.74%	0.80%			
Total	*28 097 749*	*28 403 145*	*28 836 390*	*27 944 514*	*28 074 389*	*28 138 179*	*0.5%*	*1.2%*	*2.5%*

The striped shading is used instead to highlight other relevant but unexpected observations:

c) The growth in total size of the fleet: the bottom row of the table provides a lower bound estimate for incremental demand.
d) The apparent impact on in non-eligible cohorts (2-10).

Results sub c) and d) point to some considerable autonomous driving force at play other than the policy. Dwelling on the apparent impact on non-eligible cohorts, this reveals an autonomous rebound of the car market that could be due to a general economic recovery and/or to a price dynamics (not entirely exogenous). If the autonomous economic recovery story (supported by evidence mentioned in 2.4) is credited, the impact of the incentive policy is simultaneous to a rebound of both incremental and replacement demands that had been postponed during recession years. In terms of the replacement demand, which is most relevant here, what we have in mind is the marginal decision of the owner of an old (close to end-of-life) vehicle, between replacing it (preferred choice in a good year) or repairing it to make it do for another period (preferred choice in a bad year). It is thus reasonable to assume that the impact of such autonomous recovery on different cohorts would be increasing with age. The real-baseline difference for non-eligible cars can thus be taken as a lower bound for the impact it has on eligible ones.

Fig. 3. 12 Conservative adjustment for autonomous recovery

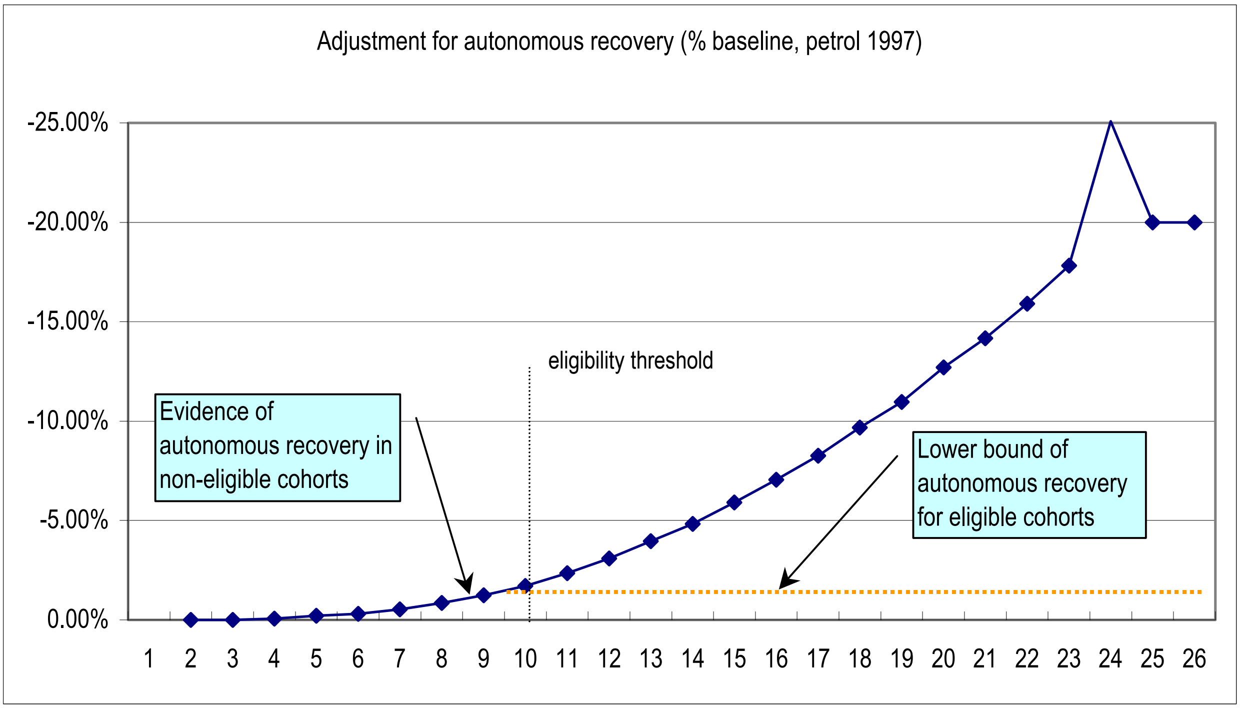


Fig. 3. 12 illustrates the logic of the adjustment applied to what has been identified in Table 3. 7 as the upper bound for the policy impact.

Table 3. 8 to 3.11 report the result of such adjustment carried out separately for petrol and diesel cars and for the two policy years. The mean of the percentage difference for ages 9 and 10 was imputed as a measure of autonomous recovery.

Notice that here the baseline for year 1998 is not the same as in Table 3. 7, but is obtained carrying on the *real* 1997 distribution with baseline survival rates:

$$\tilde{\hat{f}}_{1998}(a) = sr_{1996}(a) * f_{1997}(a-1)$$

Table 3. 8 Policy impact and autonomous dynamics – Petrol cars, 1997

	Real	Baseline	diff	% diff	Adjustment		
	(a)	(b)	(c)	(d)	(e)	(f)	(g)
1	1 986 000	1 429 972	556 028	38.88%			
2	1 441 000	1 441 074	-74	-0.01%			
3	1 555 000	1 554 984	16	0.00%			
4	1 527 000	1 528 023	-1 023	-0.07%			
5	1 540 000	1 543 153	-3 153	-0.20%			
6	2 152 000	2 158 669	-6 669	-0.31%			
7	2 055 000	2 066 054	-11 054	-0.54%			
8	2 030 000	2 047 499	-17 499	-0.85%			
9	1 866 000	1 889 560	-23 560	-1.25%			
10	1 541 000	1 567 805	-26 805	-1.71%			
1-10	*17 693 000*	*17 226 792*	*466 208*	*2.71%*			
					Percentage adjustment: **-1.48%**	(c)*(e) Policy impact (overestimate)	(c)-(f) Autonomous recovery (underestimate)
11	1 275 000	1 305 656	-30 656	-2.35%	-0.9%	-11 355	-19 301
12	1 101 000	1 136 113	-35 113	-3.09%	-1.6%	-18 318	-16 795
13	951 000	990 293	-39 293	-3.97%	-2.5%	-24 653	-14 639
14	779 000	818 576	-39 576	-4.83%	-3.4%	-27 475	-12 101
15	707 000	751 419	-44 419	-5.91%	-4.4%	-33 311	-11 108
16	612 000	658 378	-46 378	-7.04%	-5.6%	-36 646	-9 733
17	520 000	566 782	-46 782	-8.25%	-6.8%	-38 403	-8 379
18	412 000	456 127	-44 127	-9.67%	-8.2%	-37 384	-6 743
19	245 000	275 167	-30 167	-10.96%	-9.5%	-26 099	-4 068
20	153 000	175 268	-22 268	-12.71%	-11.2%	-19 677	-2 591
11-20	*6 755 000*	*7 133 778*	*-378 778*	*-5.31%*		*-273 322*	*-105 456*
21	81 000	94 375	-13 375	-14.17%	-12.7%	-11 980	-1 395
22	43 000	51 136	-8 136	-15.91%	-14.4%	-7 380	-756
23	21 000	25 556	-4 556	-17.83%	-16.3%	-4 178	-378
24	8 000	10 679	-2 679	-25.08%	-23.6%	-2 521	-158
25	4 000	5 000	-1 000	-20.00%	-18.5%	-926	-074
26	1 000	1 250	-250	-20.00%	-18.5%	-232	-18
21-26	158 000	187 995	-29 995	-15.96%		*-27.216*	*-2.779*
Total	24 606 000	24 548 565	57 435	0.23%			

Table 3. 9 Policy impact and autonomous dynamics – Petrol cars, 1998

	Real	Baseline	diff	% diff	Adjustment		
	(a)	(b)	(c)	(d)	(e)	(f)	(g)
1	1 845 000	1 342 517	502 483	*37.43%*			
2	1 985 000	1 984 724	276	*0.01%*			
3	1 440 000	1 440 059	-59	0.00%			
4	1 552 000	1 552 991	-991	-0.06%			
5	1 521 000	1 524 188	-3 188	-0.21%			
6	1 528 000	1 533 372	-5 372	-0.35%			
7	2 124 000	2 135 517	-11 517	-0.54%			
8	2 011 000	2 029 721	-18 721	-0.92%			
9	1 964 000	1 990 559	-26 559	-1.33%			
10	1 778 000	1 811 470	-33 470	-1.85%			
1-10	*17 748 000*	*17 345 117*	*402 883*	*2.32%*			
					Percentage adjustment: **-1.59%**	(c)*(e) Policy impact (overestimate)	(c)-(f) Autonomous recovery (underestimate)
11	1 440 000	1 477 251	-37 251	-2.52%	-0.9%	-13 749	-23 502
12	1 163 000	1 202 111	-39 111	-3.25%	-1.7%	-19 986	-19 125
13	974 000	1 017 082	-43 082	-4.24%	-2.6%	-26 901	-16 181
14	812 000	856 398	-44 398	-5.18%	-3.6%	-30 773	-13 625
15	637 000	680 646	-43 646	-6.41%	-4.8%	-32 817	-10 829
16	550 000	595 235	-45 235	-7.60%	-6.0%	-35 765	-9 470
17	450 000	493 415	-43 415	-8.80%	-7.2%	-35 565	-7 850
18	357 000	398 632	-41 632	-10.44%	-8.9%	-35 290	-6 342
19	262 000	297 556	-35 556	-11.95%	-10.4%	-30 822	-4 734
20	143 000	165 156	-22 156	-13.42%	-11.8%	-19 529	-2 628
11-20	6 788 000	7 183 481	-395 481	*-5.51%*		*-281 196*	*-114 285*
21	81 000	95 625	-14 625	-15.29%	-13.7%	-13 104	-1 521
22	38 000	46 023	-8 023	-17.43%	-15.8%	-7 291	-732
23	18 000	21 978	-3 978	-18.10%	-16.5%	-3 628	-350
24	7 000	9 750	-2 750	-28.21%	-26.6%	-2 595	-155
25	2 000	3 077	-1 077	-35.00%	-33.4%	-1 028	-49
26	1 000	1 000	0	0.00%	1.6%	16	-16
21-26	147 000	177 452	-32 452	-18.29%			
Total	24 683 000	24 706 051	-23 051	-0.09%		*-27 629*	*-4 823*

Table 3. 10 Policy impact and autonomous dynamics – Diesel cars, 1997

	Real	Baseline	diff	% diff	Adjustment		
	(a)	(b)	(c)	(d)	(e)	(f)	(g)
1	416 899	*300 028*	*116 871*	38.95%			
2	280 471	280 475	-4	0.00%			
3	178 359	178 379	-20	-0.01%			
4	149 849	149 899	-50	-0.03%			
5	143 320	143 427	-107	-0.07%			
6	178 691	178 934	-243	-0.14%			
7	126719	127 000	-281	-0.22%			
8	163 026	163 569	-543	-0.33%			
9	263 370	264 618	-1 248	-0.47%			
10	344 243	346 461	-2 218	-0.64%			
1-10	*2 244 947*	*2 132 790*	*112 157*	5.26%			
					Percentage adjustment: **-0.56%**	(c)*(e) Policy impact (overestimate)	(c)-(f) Autonomous recovery (underestimate)
11	371 858	375 002	-3 144	-0.84%	-0.3%	-1060	-2084
12	291 873	295 022	-3 149	-1.07%	-0.5%	-1510	-1640
13	231 575	234 690	-3 115	-1.33%	-0.8%	-1810	-1304
14	171 174	173 988	-2 814	-1.62%	-1.1%	-1847	-967
15	83 120	84 763	-1 643	-1.94%	-1.4%	-1172	-471
16	59 397	60 788	-1 391	-2.29%	-1.7%	-1053	-338
17	27 077	27 817	-740	-2.66%	-2.1%	-586	-155
18	7 525	7 763	-238	-3.06%	-2.5%	-195	-43
19	2 217	2 298	-81	-3.51%	-3.0%	-68	-13
20	759	790	-31	-3.93%	-3.4%	-27	-4
11-20	*1 246 575*	*1 262 921*	*-16 346*	*-1.29%*		*-9327*	*-7019*
21	185	194	-8	-4.39%	-3.8%	-7	-1
22	36	38	-2	-4.55%	-4.0%	-2	0
23	6	7	-1	-11.11%	-10.6%	-1	0
21-26	*227*	*238*	*-11*	-4.61%		*-10*	*-1*
Total	*3 491 749*	*3 395 949*	*95 800*	2.82%			

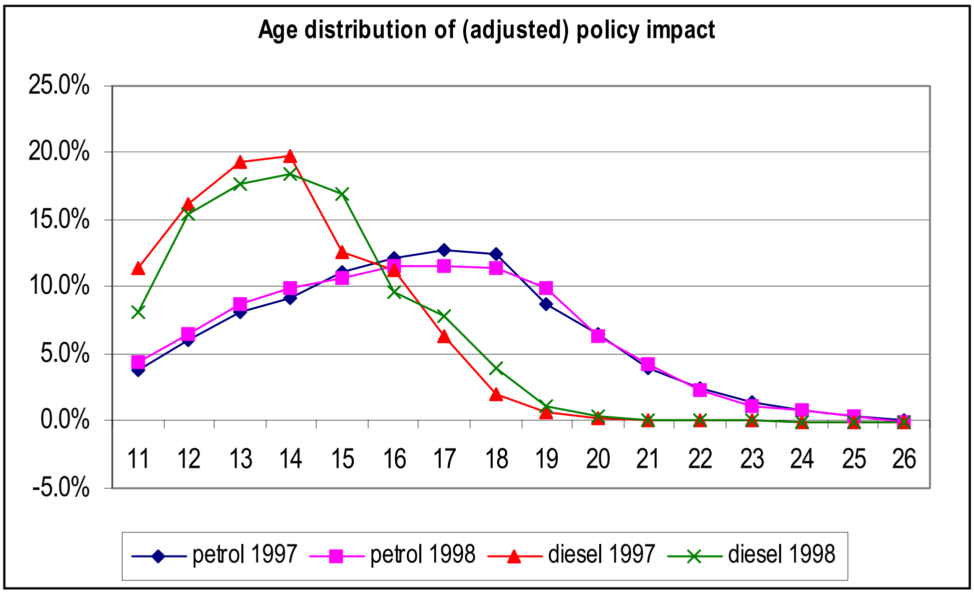
Table 3. 11 Policy impact and autonomous dynamics – Diesel cars, 1998

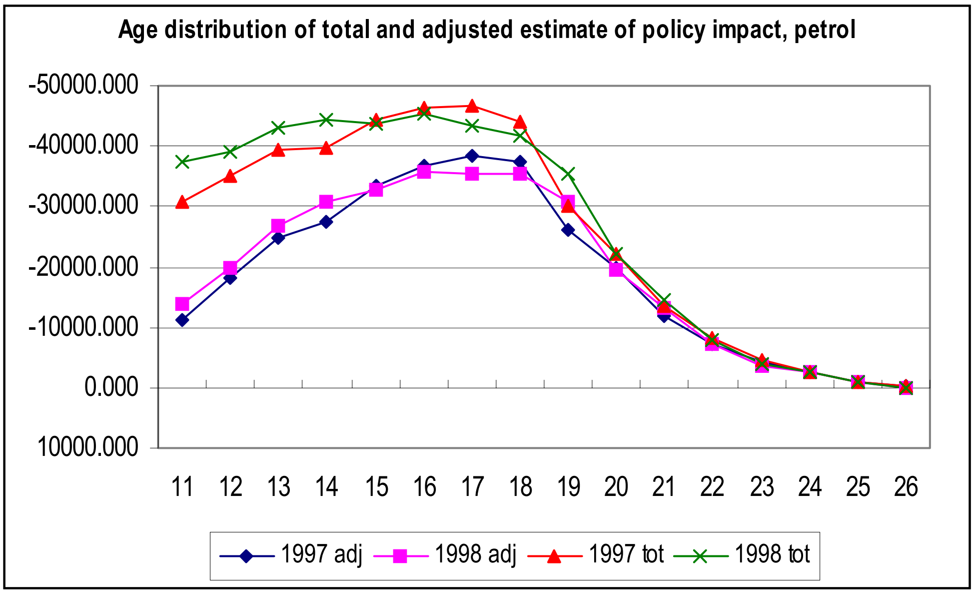
	Real	Baseline	diff	% diff	Adjustment		
	(a)	(b)	(c)	(d)	(e)	(f)	(g)
1	532 799	*387 483*	*145 316*	*37.50%*			
2	416 851	416 864	*-13*	*0.00%*			
3	280 250	280 307	-57	-0.02%			
4	177 896	178 002	-106	-0.06%			
5	148 932	149 126	-194	-0.13%			
6	141 609	141 944	-335	-0.24%			
7	175 009	175 683	-674	-0.38%			
8	122 585	123 294	-709	-0.58%			
9	155 127	156 399	-1 272	-0.81%			
10	245 334	248 065	-2 731	-1.10%			
1-10	*2 396 392*	*2 257 168*	*139 224*	*6.17%*			
					Percentage adjustment: **-0.96%**	(c)*(e) Policy impact (overestimate)	(c)-(f) Autonomous recovery (underestimate)
11	312 234	316 791	-4 557	-1.44%	-0.5%	-1524	-3032
12	326 443	332 515	-6 072	-1.83%	-0.9%	-2889	-3183
13	246 355	252 062	-5 707	-2.26%	-1.3%	-3294	-2413
14	186 572	191 851	-5 279	-2.75%	-1.8%	-3443	-1836
15	130 605	135 045	-4 440	-3.29%	-2.3%	-3147	-1293
16	59 552	61 951	-2 399	-3.87%	-2.9%	-1806	-593
17	39 597	41 460	-1 863	-4.49%	-3.5%	-1466	-397
18	16 633	17 538	-905	-5.16%	-4.2%	-737	-168
19	4 215	4 478	-263	-5.88%	-4.9%	-220	-43
20	1 120	1 199	-79	-6.58%	-5.6%	-67	-11
11-20		*1 354 890*	*-31 564*	*-2.33%*		*-18595*	*-12969*
21	341	369	-28	-7.59%	-6.6%	-24	-4
22	73	79	-6	-7.93%	-7.0%	-6	-1
23	12	14	-2	-11.11%	-10.2%	-1	0
21-26	427	*461.802*	*-34.802*	-7.54%		*-31*	*-3*
Total	3 720 145	*3612519*	*107626*	2.98%			

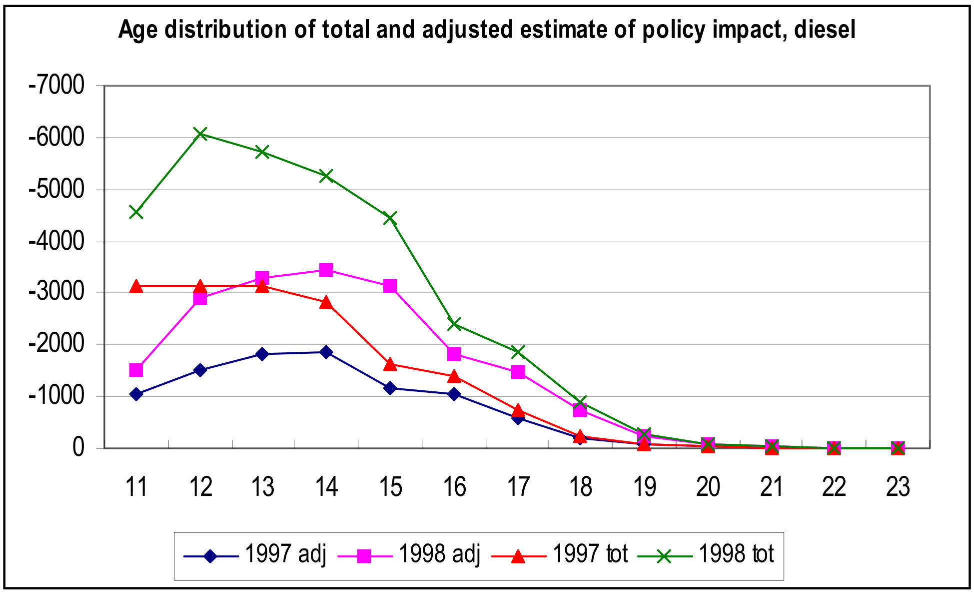
The adjustment proposed, however, introduces a distortion. In fact, in spite of claiming that the *relative* strength of the autonomous dynamics is expected to increase with age, in the lack of grounds for more clever assumptions, and in order to keep the adjustment conservative, the same (percentage) amount is subtracted from the percentage real-baseline difference for all cohorts. As a consequence, the adjustment will end up being heavier for cohorts for which such percentage difference (column (d) in the tables above) is lower – i.e. the younger ones.

Still, under the assumption that this procedure is truly a conservative one – i.e., that the threshold identified is indeed a lower bound of autonomous recovery – this does not affect the direction of the general bias towards an overestimate of emissions reductions. The distortion is felt instead in the age distribution of the scrapped cars identified as the true impact of the incentive, due not to an excessive trimming of the younger cohorts but to an overly conservative one on the older cohorts (see Fig. 3. 13 a,b,c below).

Fig. 3. 13 a,b,c   Autonomous recovery adjustment: modification on age distribution of impact







3.5 *"Adjusted" survival rates*

In theory, once the autonomous dynamics has been gauged, and some measure for it obtained, it can be used to 'work backwards' and adjust the baseline scrapping rates towards a better estimate of their 'natural' value, i.e. ideally a value that truly incorporates everything but the policy impact.

Defining $d(a,1997)$ the autonomous dynamics, which by construction will have a negative sign for most cohorts, the adjusted survival rate can be computed as:

$$adjsr_{1996}(a)\frac{\hat{f}(a19979+d(a,1997)}{f(a-1,1996)}$$

This in turn can be useful, for instance, in providing a more correct basis for computing the expected remaining lifetime, and thus the expected remaining kilometres (see next sections, respectively 3.6 and 3.7.)

This correction was attempted here but the relative size of the adjustment is so small that it does not affect significantly the rates, nor the average remaining lifetime (see below Fig. 3. 14 a,b). In addition, the caveat expressed in the previous subsection applies: the true adjustment to be made should probably be stronger on older cohorts. Some difference is traceable however in the average remaining lifetime of cars retired as a result of the policy (Table 3. 12).

3.6 *Expected remaining lifetime*

Survival and hazard rates allow us to compute the age-specific average lifetime of the fleet, and the expected remaining lifetime of vehicles. The latter however, far from being a good estimate of the remaining lifetime that scrapped vehicles would have enjoyed in the absence of the replacement incentive, is only to be intended, again, as an *upper bound* for such estimate – for at least two reasons. The first is the already discussed issue of 1996 not being a good benchmark year. The second is that imputing a cohort average remaining lifetime to the subset of scrapped vehicles equates to ignoring the *selection* issue: vehicles that get scrapped are expected to be in *worse* than average conditions, and thus have a *shorter* than average expected lifetime. (Otherwise their value on the second hand market could be higher than the replacement bonus, which would of course discourage scrapping).

In fact, most assessment of scrapping schemes use an estimate for remaining lifetime that never exceeds three years. Hahn (1995) surveys estimates from a number different studies that lie all between 1 and 3 years.

The probability of reaching age *n* starting from age *m* is computed as the product of all survival rates between *m* and *n*:

$$pr(m,n) = \prod_{a=m}^{n} sr(a)$$

The probability of being scrapped at age *n* starting from age *m* is the product of all survival rates between *m* and *n-1* and the hazard rate corresponding to age *n*:

$$ps(m,n) = hr(n) * \prod_{a=m}^{n-1} sr(a)$$

The expected lifetime for a vehicle aged *m* then is:

$$EL(m) = \sum_{a=m}^{N} ps(m,a) * a$$

And the expected remaining lifetime for a vehicle aged *m*:

$$ERL(m) = \sum_{a=m}^{N} ps(m,a) * a - m$$

The average lifetime of the fleet at year *t* can be computed as:

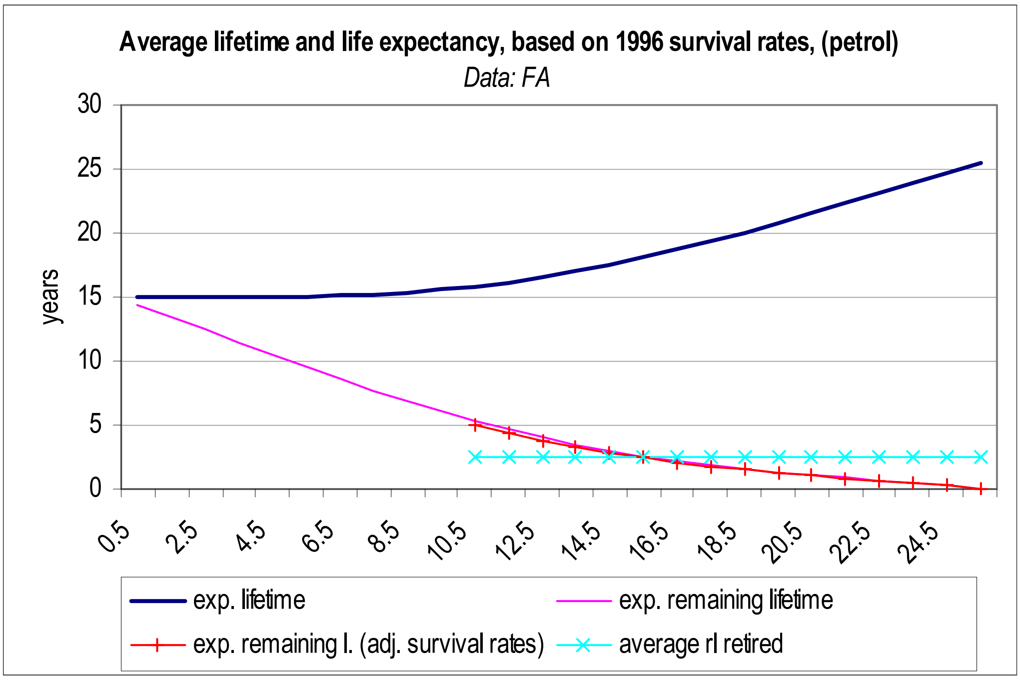
$$EL_t = \sum_{m=1}^{N} EL(m) * \frac{f(m)_t}{F_t}$$

Similarly, in the awareness of the implicit double bias explained above, an upper bound can be computed for the natural average remaining lifetime of scrapped cars:

$$ARLS_t = \sum_{a=1}^{N} ERL(a) * \frac{s(a)_t}{S_t}$$

Fig. 3. 14 a,b show the average expected lifetime and remaining lifetime for each cohort of vehicles. While the latter obviously decreases with the age of vehicles, until reaching zero for the oldest observed cohort, the former regularly increases with age, as it constitutes the expected lifetime *conditional on* having survived to a certain age.

Fig. 3. 14 a,b   Average vehicles lifetime



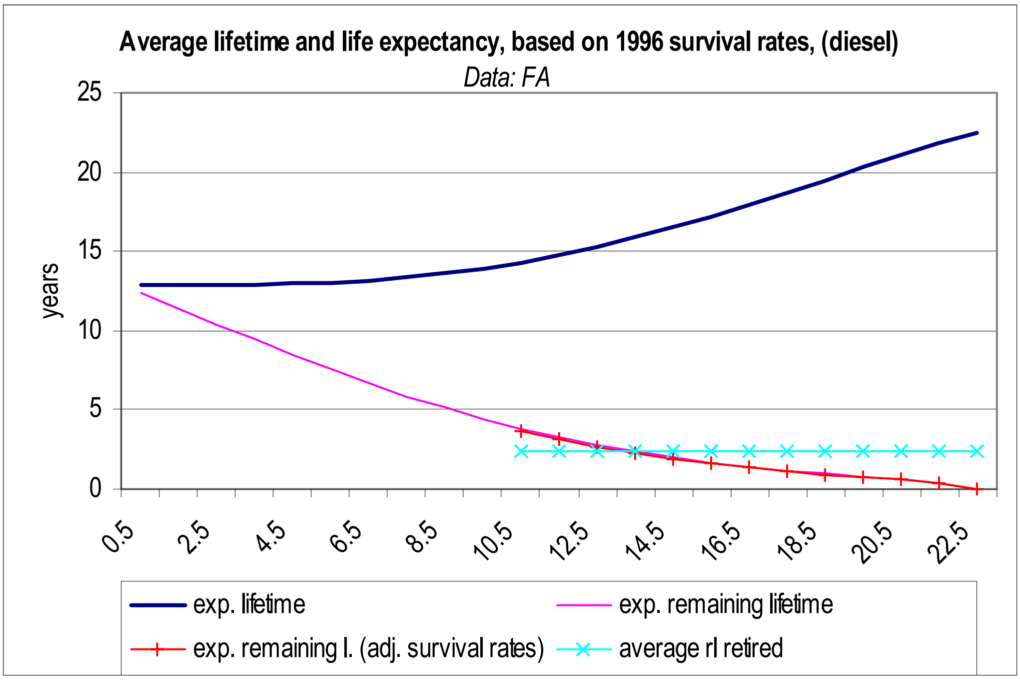


Table 3. 12 Average remaining lifetime for cars retired as result of policy

	petrol		diesel	
	1997	1998	1997	1998
Impact (1): real-baseline	2.84	2.91	2.73	2.61
Impact (2): real-baseline+autonomous recovery adjustment	2.58	2.63	2.53	2.42
Impact (2) with adj. Rates	2.46	2.51	2.47	2.36

3.7 Mileage

Having computed an expected remaining lifetime for each vehicle type (fuel and age), the next step is to impute an expected amount of kilometres driven which can be interpreted as the saving in terms of 'dirty' kilometres driven.

The expected retired kilometres for a vehicle aged *m* are in fact computed as:

$$ERK(m) = \sum_{n=m}^{N} pr(m,n) * Ekm(m)$$

where $pr(m,n)$ is the probability of reaching age *n* conditional on having reached age *m*, and $Ekm(m)$ is the estimate for fuel-specific average yearly mileage obtained from French household survey data[18].

Table 3. 13 Average mileage imputed, by fuel (estimates form French household data)

age	Petrol cars		Diesel cars	
	Expected kms (Ekm)	Expected retired kms (ERK)	Expected kms (Ekm)	Expected retired kms (ERK)
11	10 436	53 066	18 135	83 665
12	9 929	45 945	17 913	73 295
13	9 440	39 618	17 719	64 148
14	8 966	34 053	17 509	56 070
15	8 504	29 177	17 244	48 915
16	8 052	24 951	16 882	42 541
17	7 608	21 300	16 383	36 818
18	7 170	18 149	15 704	31 619
19	6 734	15 447	14 805	26 821
20	6 299	13 134	13 645	22 303
21	5 863	11 113	12 183	17 899
22	5 422	9 390	10 377	13 412
23	4 974	7 890	8 186	8 186
24	4 518	6 383		
25	4 050	4 928		
26	3 568	3 568		

[18] *INSEE Enquête de Conjoncture auprès des Ménages,* years 1980-92, semipanel component of the survey: households interviewed in two subsequent waves and detailed information on car ownership and usage is gathered.

Of course, this step will again suffer by a double bias towards a generous assessment of the environmental result of the policy, because of the bias in the baseline survival rates and because selection effects regarding remaining lifetime are neglected. It can be argued that a third bias is introduced by imputing to each vehicle age an age-specific *average* of kilometres driven, whereas once more, the consideration of selection issues might suggest that if vehicles that get retired are likely to be in worse-than-average conditions, they are also likely to be driven less often or on shorter trips.

3.8 Hypotheses on engine size

In order to estimate the emission savings, some hypotheses on the engine size distribution are necessary, as engine size is an important determinant of emission rates, and in fact emission standards are set by engine displacement brackets. The size groups on which European regulations are based are 1 400 cc and 2 000 cc for petrol engines and 2 000cc for diesel ones.

The expected retired kilometres computed in the previous subsection are imputed to engine size groups on the basis of the 1997 distributions reported by ANPA (2002) for each vintage defined in terms of emission standards regulations (reported in Table 3.14 below).

Table 3. 14 Vintage- specific engine size distribution for 1997

petrol						**diesel**			
	years	<1400	1400 - 2000	>2000	tot		<2000	>2000	tot
Pre ECE	1972	1 120 285	112 758	22 202	1 255 245	Pre-euro	1 795 285	643 083	2 438 368
		89.2%	9.0%	1.8%		(up to 1990)	73.6%	26.4%	
ECE 15/00 and 15/01	1973-78	1 026 945	108 992	15 309	1 151 246				
		89.2%	9.5%	1.3%					
ECE 15/02	1979-81	1 606 694	215 997	20 373	1 843 064				
		87.2%	11.7%	1.1%					
ECE 15/03	1982-84	2 087 255	308 454	17 080	2 412 789				
		86.5%	12.8%	0.7%					
ECE 15/04	1985-89	8 992 457	2 688 204	45 346	11 726 007				
		76.7%	22.9%	0.4%					

Source Anpa (2002)

As regards the necessity of making a hypothesis on the engine size distribution of new cars, ACI official figures for the composition of the car stock by engine displacement come useful.

Fig. 3. 15 shows the evolution of the engine size composition (in percentage terms) over 15 years covering the policy period. On the one hand, it confirms the general tendency of the car stock to evolve over time towards more powerful (higher displacement) engines. Fleet renewal normally does not imply substitution with similar models but tends to entail upgrading.
On the other hand, such trend is clearly interrupted in the two policy years (highlighted by a striped pattern in the histogram), providing further evidence of the *distortion* of the 'natural' owners behaviour induced by the policy (and in this sense, proving its success). Car owners benefiting from the incentive bonus in the absence of the programme would have been more likely to buy a second-hand car. Constrained by the policy replacement requirement to buy a new model, they will choose smaller (cheaper) ones. Furthermore, if the amount of the incentive is fixed, a bias in first registrations in favour of smaller cars is stems from the fact that the price of smaller cars is lowered by a larger percentage.

An even clearer indication in this sense comes from Fig. 3. 16, based on figures reported by ECMT (1999) comparing the engine displacement distribution for new registrations between 1996 and 1997.

Fig. 3. 15 Evolution of engine size distribution1985-1999

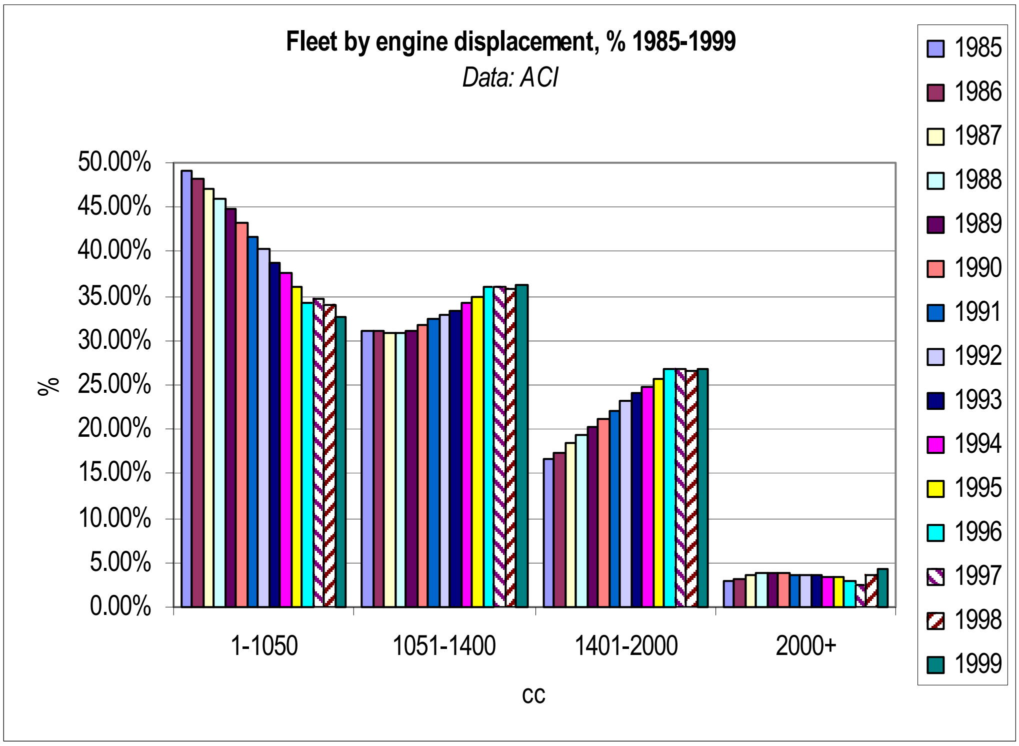
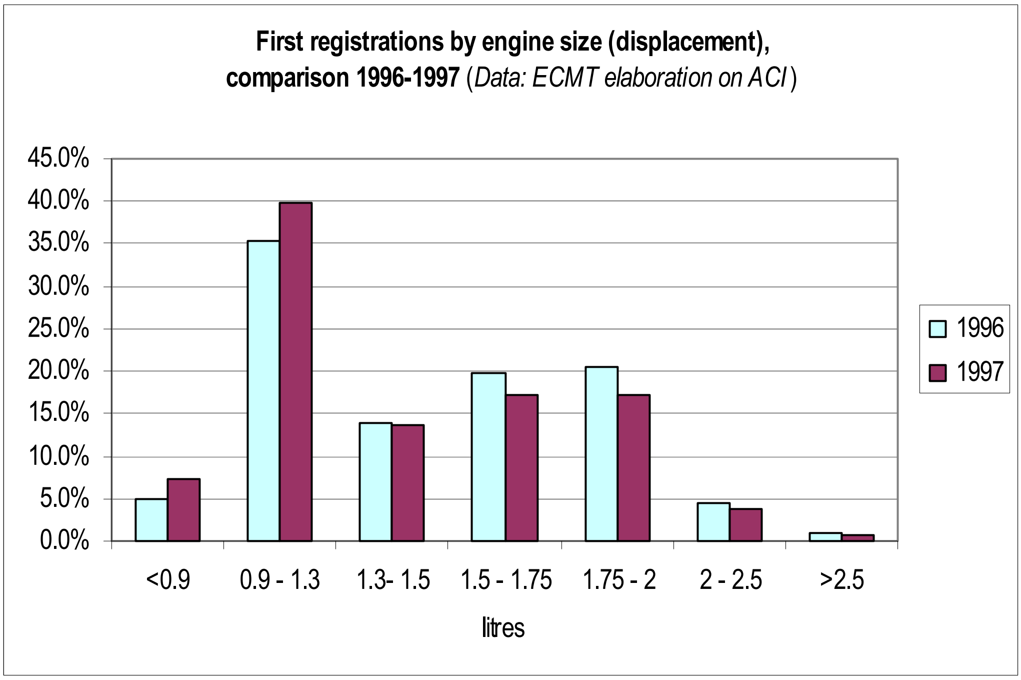
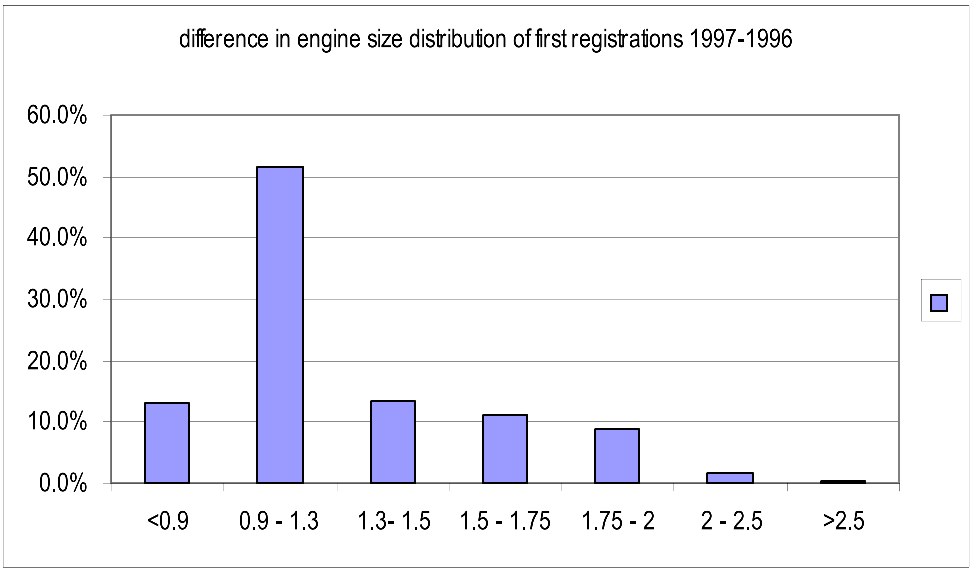


Fig. 3. 16 Engine displacement distribution for new cars



A hypothesis on the engine size distribution of new sales is extracted from Fig. 3. 16. The distribution for petrol cars is imputed on the basis of the *difference* between 1997 and 1996 new registrations (Fig. 3. 17). The 1.3-1.5 class is split equally between the <1400 cc and 1400-2000 cc groups. For diesel cars, typically bigger and more powerful than petrol ones, the proportion between under 2 000 cc and over 2 000 cc is readjusted on the basis of the relative stock distribution. It can safely be assumed that such procedure implies a bias towards smaller sizes, which are also cleaner in terms of most pollutants, and is thus compatible with the general strategy.

Fig. 3. 17 Change in engine size composition of sales between 1997 and 1996



3.9 *Final steps for assessing emissions reduction*

A few more assumptions are needed as final steps towards assessing emission savings.

- *Rate of replacement of scrapped cars with new models*. This might appear trivial, as the policy in question is an incentive to *replacement*, but as shown in Table 2. 2 (p.9), during the policy years the cars that were scrapped fee-exempt but not replaced amounted to 30% of the total scrapping. These must account for some share of the retirements identified here as policy-induced. However, the choice is made to assume that all retired cars are replaced by new models. The issue is whether this is consistent with the overestimation strategy. There are three possibilities for an eligible car that is scrapped but not replaced with a new one:

  a) Not replaced at all: In this case its scrappage can hardly be considered a result of the policy, and its remaining kilometres-lifetime is likely to be very low: by attributing a clean replacement and imputing average mileage and average emission rates to both replaced and replacement vehicles the environmental gain is certainly overestimated.

  b) Replaced by a second hand car imported from abroad: this case is problematic as the replacement vehicle is dirtier than assumed. However, this occurrence is unlikely to be frequent.

  c) Replaced by a second hand car from the domestic market, in which case the behaviour of the seller of the replacement vehicle becomes is in turn relevant: if s/he chooses not to replace we're back sub a); if s/he replaces with a new car the final outcome from an aggregate point of view is analogous to a new replacement by the owner of the eligible car; if s/he chooses replacement on the second hand market we are back, recursively, to c).

- *Mileage for new cars relative to replaced ones*. The availability of a new car might induce an increase in usage with respect to the replaced vehicle, that is an increase autonomous from the variation in mobility needs that might have motivated the replacement decision. This could be due to any of a range of different characteristics related to comfort, safety, engine power, fuel efficiency. A strong observed relationship between kilometres driven and vehicle age can be read as evidence of the existence of such effect. However, quantifying its strength is difficult. The conservative (and arguably unrealistic) choice is then to assume that new cars replace old ones in the literal sense that they take their place, being driven for the same number of kilometres on the same kind of trips.

- *Type of trips*. Car emission rates are heavily affected by the driving style, the speed, and the number of cold starts (particularly as far as vehicles equipped with catalytic converters are concerned). In order to estimate emissions, some assumption is needed on the distribution of kms driven between urban, highway, rural trips. A realistic estimate would then require a complex model of the relationships between car age, engine size and type, and the distribution of trip types. This is certainly beyond the scope of the present exercise. Rather than making arbitrary assumptions aimed at realism, we choose to make a simple and unrealistic one which ensures once more the control over the direction of the bias: that all trips of all cars are take place at the same speed, corresponding to a an urban context. This is where emission rates are higher[19] for both retired and new cars but also the difference between the two is maximised.

The ER are taken from the Vehicle Emission Factor Database developed by UKs National Atmospheric Emissions Inventory (NAEI)[20]. This database provides the complete set of speed-emission factor coefficients for NOx, PM10, CO, HC, benzene, 1,3-butadiene, CO_2 and fuel consumption. Coefficients are provided for functions relating emission factor in grammes per kilometre to average speed, for all the different types and sizes of vehicles in all the categories of European emission standards. While vintage effects are thus taken in to account with great precision, no adjustment is provided here for the age effect on the deterioration of emission rates.

The speed chosen is 30 kms/h.

Final results of the estimation for CO, HC NOx and CO_2 are reported in Table 3. 15.

[19] This is also where emissions cause the worst damage because of the wide population exposed.
[20] Available at http://www.naei.org.uk.

Table 3. 15 Policy impact in terms of emission savings

Pollutant	CO tons	HC tons	NOx tons	CO_2 Tons
Petrol cars				
Avoided emissions	295 694	34 035	23 612	3 245 970
Added emissions	23 861	1 426	3 308	2 515 094
Net savings	**271 833**	**32 609**	**20 304**	**730 876**
Net savings as % of avoided	*92%*	*96%*	*86%*	*23%*
Diesel cars				
Avoided emissions	1 403	327	1 146	317 512
Added emissions	591	133	989	267 647
Net savings	**813**	**193**	**157**	**49 865**
Net savings as % of avoided	*58%*	*59%*	*14%*	*16%*
Sum				
Avoided emissions	297 097	34 362	24 758	3 563 482
Added emissions	24 452	1 559	4 297	2 782 741
Net savings	**272 645**	**32 803**	**20 461**	**780 741**
Net savings as % of avoided	*91.8%*	*95.5%*	*82.6%*	*21.9%*
% of net savings from Petrol	*99.7%*	*99.4%*	*99.2%*	*93.6%*

The average speed chosen is likely to lead to a serious overestimate of total emissions and consequently to an overgenerous evaluation of the air quality impact of the policy. Moreover, it is also likely to affect the relative environmental gains in terms of different pollutants as speed does not influence emissions rate of all compounds in the same way.

3.10 Concluding remarks

With all these caveats in mind, Table 3. 15 provides a few interesting indications.

First of all, in relative terms (looking at the percentage of avoided emissions), the policy appears to have been more successful in reducing emission s from petrol cars than from diesel ones, at least for traditional pollutants.

In fact, looking at the bottom row percentages, most (virtually all) of the total emission reduction is attained by replacing petrol cars, again as far as traditional pollutants are concerned (the share of petrol cars on the total of retired is 95.6%).

A particularly interesting indication emerges from the relative size of emission reductions. While they reflect a considerable success in reducing traditional pollutants (especially CO and HC), results for CO_2 appear far more dubious, as the estimated reduction is 22% of the avoided emissions.

In fact this suggests that under different assumptions or different frameworks of analysis the impact in terms of CO_2 could easily turn out to be negative, and not only because the computation overestimates avoided emissions. Three additional orders of considerations arise in this sense:

1. Some of the assumptions made along the way in this section are likely to underestimate CO_2 from replacement cars. This is certainly true of the hypothesis made for the size-distribution of new cars, conservatively biased towards smaller engines (which are in general, although not under all condition, more fuel-efficient). The (questionable) assumption of identical usage between old and new vehicles also plays obviously a crucial role in this result. The oversimplifying assumption on the type of trips is more ambiguous in this sense, as the relationship between speed and fuel consumption is U –shaped: emissions rate are higher at lower and higher speeds, that is both in the urban traffic and on highways). Modifying such hypothesis is likely to increase the estimate of added CO_2 emissions.

2. New cars are more often than older ones equipped with on-board energy-consuming devices such as air conditioning.

3. As mentioned in Section 1, a more comprehensive environmental evaluation should adopt a Life Cycle Analysis (LCA) approach and look at the environmental impact (in this case, specifically the energy requirement) generated by all phases of a product's life. The relatively small amount of avoided CO_2 emissions that turn out as net emissions savings (22%) should be compared to reliable estimates (in terms of lifetime percentages) on energy requirements in vehicle construction and dismantling. The latter is likely to outsize the former in absolute levels.

Finally, these results are not of course directly comparable to the "naïve assessment" presented in subsection 2.5, both because they do not take into account age deterioration effects and because they are computed over an age-specific remaining lifetime rather than on a yearly basis.

Even so, if the naïve estimate is repeated leaving aside the age effect (in order to make it comparable in this respect), on the basis of standard emission rates that old cars had at the beginning of their lifetime, the results (reported in Table 2. 1) appear far more optimistic than those produced in this section. In particular, figures for reductions in HC and NOx over one year are greater than those estimated here over the whole potential remaining lifetime.

Table 3. 16 Results for Naïve estimate without vintage effect

Pollutant	Old cars g/km	New cars EURO II g/km*	difference	Net emission savings
CO	12	2,2	9.8	180 735
HC	3	0,3	2.7	49 794
Nox	2	0,2	1.8	33 196
CO2	194	164	30	553 268

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