Accelerating car scrappage: a review of research into the environmental impacts

Abstract
This paper reviews the literature on policies that aim to accelerate car scrappage and on related models. We conclude that substantial model efforts have been made to capture the direct reaction of households with older cars to the scrappage schemes, but that indirect effects on the second hand car market, effects on car use and emissions from car use and on lifecycle emissions have received far less attention. Emission effects are modest and occur only in the short term. The cost-effectiveness of scrapping schemes is often quite poor. The most favourable cost-effectiveness scores occur in large densely populated areas, and only (or mainly) if cars with old (or no) emissions control technologies are scrapped. A full overview of the pros and cons of scrapping schemes, including all the dominant effects and their determinants in an advanced way, is lacking. Nevertheless we think the general conclusions with respect to the effects and cost-effectiveness as presented above are quite robust.

1. Introduction

Several countries, including the US, South Korea, Japan, Germany and the Netherlands, recently introduced temporary policies to scrap older cars, mainly to reduce the negative impacts of the economic crisis but also to improve the environment. There were comparable policies in the 1990s in several European countries, including France, Spain, Italy, Hungary, Norway, Denmark, and Greece, as well as several US states and Canada. Environmental benefits, mainly in the area of air quality, were the dominant motivation for the schemes, other reasons being to boost car sales (e.g. Britain and France in the 1990s), or to improve safety (e.g. Italy, Ireland, Argentina – see Dill, 2001).

Several publications have focused on the impacts of such policies, especially on the environment and vehicle transactions. Two reports discuss scrappage at the level of the EU (Fontana, 1999, Nemry et al., 2009). This paper reviews the literature on (1) theoretical assumptions on the estimations of environmental effects, (2) models/methods to estimate these effects, and (3) empirical results on environmental effects. The aim is to both review the effects of the schemes as well as the methodologies used.

2. Theoretical framework

As the basis of the review we use the theoretical framework presented in this section including an overview of the effects of accelerated scrappage (section 2.1), the determinants of participation in scrapping schemes and impacts on car ownership and car use (section 2.2) and a discussion on evaluation frameworks (section 2.3).

2.1 Which effects result from accelerated scrappage?

Table 1 summarizes the effects that could be included in the evaluation of scrappage schemes

(Table 1 about here)

A first category of effects are the environmental effects. Most important are the emissions in the use stage (emissions resulting from car use, mainly exhaust emissions like CO_2, NO_x, PM, CO, HC, but also emissions due to the evaporation of fuel, mainly HC). In particular the differences in the per kilometre emissions between scrapped vehicles and replacement vehicles matter. Replacement vehicles are generally new(er) vehicles having lower emissions levels, firstly because of the use of more advanced technologies, and secondly because a car's emissions increase the older it gets or the more kilometres it has driven (Baltas and Xepapadeas, 1999; Dill, 2001). Newer cars do not necessarily have lower CO_2 emissions because technological improvements may be compensated by a shift to larger, heavier, more powerful cars with more safety and luxury (for example air conditioning) options (Van den Brink and Van Wee, 2000).

A second type of environmental effects includes the non-use related life-cycle emissions, the most relevant being the emissions from the production of vehicles (manufacturers and suppliers), followed by the transport of parts and complete cars and replacement parts. And finally, as addressed above, the 'gains' due to recycling the scrapped vehicles and scrapping ifself should be included in the equation. One could argue that these would occur anyway, just at a later moment in time. At the level of the individual car this is true, but scrapping schemes reduce the average life span of a car increasing scrapping and related emissions.

A third and fourth type of environmental effect relates to the concentrations of pollutants, preferably location specific (based on the number of people exposed and the exposure time) and to exposure. For concentrations the link between the locations where people stay and the duration of the actual stay matters.

A fifth type of impact are health impacts. For these impacts exposure is translated into health impacts. Therefore, characteristics (e.g. age, health characteristics) of the people exposed matter. Other relevant environmental impacts are noise exposure related effects (sleep disturbance, noise annoyance, cardio-vascular health effects) – replacement vehicles could have noise emission characteristics that differ from the scrapped vehicles.

Travel behaviour changes, the second category of effects, influence the environmental effects. Firstly, car use levels (vehicle miles travelled) could change due to accelerated scrappage e.g. because replacement cars have lower per kilometre costs, for example because they are more fuel efficient, comfortable or reliable. The annual number of kilometres decreases with the age of the car (Hsu and Sperling,1994). As an illustration Table 2 presents this relation for the USA.

(Table 2 about here)

The relationship as found in Table 2 does not necessarily mean one-directional causality; other intervening factors could be relevant as well. People who drive more might own and use newer cars, e.g. because of comfort, or safety, because of the (assumed) higher levels of reliability of newer cars, or because they have a company car. Income is also positively related to car use - on average high income people drive more - and income is very likely negatively related to age of the car. The relationships between the age of cars, annual kilometres driven, and other factors becomes even more complicated when a distinction is made between first, second, and third (+) cars. Second (+) cars have lower annual mileages than first cars and households can substitute between cars. To the best of our knowledge the (dynamics in the) relationships between the age of cars, annual miles driven per car, and other characteristics (e.g. individual and household income, company car availability, household structure) has not been disentangled, and, in terms of understanding the effects of scrapping schemes it would be preferable if the micro (household) approach and the macro (fleet) approach were combined.

Secondly, accelerated scrapping may increase the use of other modes (public transport, slow modes). None of the studies we found addressed this issue. Because of the (probably) limited impacts on the use of other modes, we ignored this issue.

A third category is that of non-environmental effects. A first effect is that some scrapping schemes have explicitly aimed to boost the economy or at least to stimulate car sales. So, the effect on car sales and maybe even the economy is of relevance. A second effect is often claimed to occur by car enthusiast clubs: scrapping schemes would destroy cultural heritage (e.g. Dill, 2001). It is not certain if this is really true – it is likely that the cars scrapped earlier are not the best of the older cars (Chen and Niemeier, 2005). And the market absorption capacity of old timers is to some extent limited by the number of old car enthusiasts and the number of cars these enthusiasts prefer to own. As a response to the reactions of old car enthusiasts, the state of Illinois prohibits the retirement of vehicles in their scheme that are 25 years or older (Dill, 2001). A next potential impact could occur via the car market because accelerated scrapping reduces the supply of older cars. As a result their prices will increase. In addition the price of cars that are still too young to receive the subsidy could increase, not only because they could be replacement vehicles, but also because (potential) buyers might anticipate a subsidy for scrapping in the future. Dill (2001) states that the required purchase of a new vehicle may limit participation to middle- or upper-income households. Kavalec and Setiawan (1997) emphasize the effect of scrapping schemes on the prices of the lowest cost vehicles, resulting in adverse effects on low income households. In addition they argue that a multi-year program may create an incentive to keep a targeted vehicle longer since the vehicle's resale value does not decrease but remains at the amount of the bounty as long as the vehicle is in running condition.

Further, safety could improve because both active and passive safety are positively related to the year of manufacture of a car (generally newer cars are safer). Congestion levels could decrease, firstly due to shorter distances between vehicles given a certain speed, e.g. because new(er) cars have better brakes (e.g. ABS) allowing for shorter distances between cars on motorways. Secondly, accident related congestion might decrease because newer cars more often have Advanced Driver Assistance Systems (ADAS) that could decrease accident levels. In addition, preliminary scrapping could reduce congestion by reducing the number of breakdowns - see Hahn (1995).

In addition the effects included in Table 1 we think that theoretically interactions between cars in the active car fleet could occur. For example, people within a multi-car household could redistribute their Vehicle Miles Travelled (VMT) over their cars, depending on their characteristics, and even companies that owe or lease cars could do so. And the trade fleet (used cars, in some cases also new cars, at dealers and other places that are for sale but currently not used) should be included to fully understand the impacts of scrapping schemes. We have not found a single paper discussing this issue, let alone including it in the analysis. We do not include this aspect in the review because we think the effects are limited.

There are some papers that discuss the potential perverse effects of scrapping schemes. For example a scheme may attract sellers from neighbouring states. Secondly, people could use the opportunity to get cash for dead cars that have not been scrapped yet. Thirdly, people may import used cars to replace scrapped cars. Typical measures to avoid such behaviour include a minimum time requirement that the vehicle should be registered in a state or country, a valid (safety or maintenance) inspection, the stipulation that the vehicle be driven to the scrap yard under its own power, or technical requirements (see Dill, 2001; Hahn, 1995; Hsu and Sperling, 1994).

2.2 Determinants of participation in scrapping schemes and impacts on car ownership and car use

Estimation of the impacts of scrapping schemes should start from the impacts of scrappage schemes on consumers in terms of car ownership (including car type choice) and car use.

Replacement vehicles can firstly be defined at the micro (individual or household) level: the vehicles people buy (or use – if the vehicle is not privately owned) to replace their scrapped vehicles. This is the definition used in most papers. Another definition focuses on the macro level: those that at the fleet level will be the replacement vehicles. There will be no difference if people whose vehicles are scrapped buy a new car. But – depending on the specific design of a scrapping scheme – many of them might buy a used car (if subsidized by the scheme) whose seller might subsequently buy a new(er) car. If this is not a new car even more cars could be involved in the chain of transactions. In our review we elaborate on this discussion using the label ‘replacement dynamics’.

A major category of the determinants of participation in a scrappage scheme relates to the scrappage policy. The higher the subsidy, the higher the participation rate. Secondly, limitations with respect to the characteristics of cars matter, the (minimum) age of a car to be eligible being the most common characteristic. Thirdly, it is important whether there are conditions with respect to future car ownership. Some schemes only subsidise accelerated scrappage if a new car is bought (e.g. France in the 1990s), other schemes also subsidise conditional on buying a used car (e.g. the recent scheme in Germany), or have no restrictions (usual for the USA and Canadian schemes in the 1990s).

A second category of determinants relate to prices of second hand and new cars, and repair and maintenance costs. These are relevant because consumers will not only compare the value of their current (potentially to be scrapped) car, and their potential repair and maintenance costs, with scrapping subsidies, but also with the costs for the replacement cars.

Thirdly, preliminary scrapping implies transaction costs for consumers. These costs are generally ignored in models of consumer behaviour. Schiraldi (2006) found that in 75% of all transactions in Italy these costs exceeded the price of the cars considered.

Fourthly, macro-economic determinants such as GDP (changes) and fuel prices matter. In periods of high economic growth people might be more easily persuaded to replace their old car. High fuel prices could be an incentive to replace an old car with a new(er) more fuel efficient one.

For the evaluation of the pros and cons of scrapping schemes some additional factors are of relevance. Firstly it is theoretically possible that the driving behaviour in replacement vehicles differs from that of scrapped vehicles: new(er) cars on average are more comfortable, and powerful, and might have better road-holding. None of the papers we found address this issue. We left it out of the evaluation because we think the relevance of this factor is relatively limited compared to the other determinants.

Secondly, effects change over time. For instance if a car is scrapped and replaced with a new car one year earlier than was otherwise planned, the effect on emissions (and concentrations as well as related health effects) only differ for one year, assuming that the new replacement vehicle was equivalent with or without the accelerated scrapping. If the replacement vehicle would have had lower emissions if it was bought a year later (e.g. because of new emissions regulations), accelerated scrapping would mean that after the first year emission levels would be higher (until the year of the next replacement). Therefore it is highly relevant that scrapping schemes are evaluated dynamically, including a period long enough to capture most relevant effects.

A third additional factor is that the characteristics of both the vehicles and the households involved in preliminary scrapping might differ. It is likely that several kinds of self-selection occur. Firstly it is likely that vehicles offered for scrapping are in a poorer than average condition compared to equally old vehicles (Alberini *et al.*, 1995; Chen and Niemeier, 2005). Secondly, for scrapping without replacement it is likely that vehicles with very low annual vehicle miles are offered more than average for preliminary scrapping. Dill (2001) found that scrapped vehicles in the USA had a lower than average annual mileage for their vintage. Thirdly, consumers/households who have recently changed travel behaviour or plan to do so in the near future might be more inclined to participate in a scrapping scheme. One can think of persons retiring who expect to greatly reduce their car use, and prefer a new(er) car that better fits their needs, or persons accepting a new job with a large change in commuting distance. We refer to this category of determinants using the term self-selection.

Finally, scrapping schemes have budget consequences for households and governments. Households that buy a new(er) car will probably spend more on car ownership and car use, which might have implications for the consumption of other goods. Governments that spend money on scrapping schemes do not spend that money on other policies. Scrapping schemes can therefore have environmental impacts through subsequent changes in household consumption, or alternative budget allocations by governments. Again, none of the studies we found addressed this issue. Because of the (probably) limited impacts of budget issues we ignored these issues.

Understanding the impact *of a scrapping scheme* on overall scrapping is important. It is almost impossible to distinguish between subsidising the scrapping of vehicles that would have been scrapped at the same moment anyway, versus *accelerated* scrapping - there probably are a lot of free riders. So it is not relevant how many of the scrapped cars received a subsidy, but how many of these are scrapped *early*, and when they would have been scrapped without the subsidy.

2.3 Evaluation frameworks

Once the effects of interest of scrapping schemes have been selected, one could simply report the effects, e.g. emission effects, which in itself is useful. To come to conclusions on how to evaluate the effects an evaluation framework is needed. A simple framework could be a cost-effectiveness analysis (CEA) for the policy costs per tonne (or kg) reduction in emissions or concentrations. Calculation seems straightforward, but in practice it is not. A first reason is that the implications for government budgets not only result from the costs of the scrapping schemes, but are also influenced by the taxes on (additional) new car sales. Theoretically it is even possible that the additional VAT incomes for the government due to additional new car sales outbalance the costs of a scrapping scheme (Adda and Cooper, 2000). In addition, yearly tax revenues can change due to a scrapping scheme because car ownership levels might change and because yearly taxes on replacement vehicles might differ. Thirdly, the revenues for the government due to levies on fuels might change, because the fuel economy of replacement vehicles might differ from the replaced cars, because the fuel mix (share of petrol, diesel, LPG, hybrids, in the future Electric Vehicles - EVs) might change, or because VMT might change (most likely: increase) because people might increase their car use if they own a newer car.

A second complicating factor with a CEA is that the costs presented are not consistent with those in a Cost-Benefit Analysis (CBA) as cost definitions differ. Costs in a CEA are generally costs *for the government*, whereas a (social) CBA includes all the costs *for society*. In CBA it is important to realize that the consumers that participate in a scheme benefit: the bounty they receive is at least equal to the price for which they are willing to sell their car, and in most cases higher: there is a consumer’s surplus.

Another reason why a CBA (or a Multi Criteria Analysis – MCA) is preferred over a CEA is that the emissions of multiple substances might decrease, and it is even possible that emissions of some substances decrease (pollutants) whereas those of others (CO_2) increase. A simple cost-effective analysis, focussing on only one substance would therefore be too limited. It is important to realize that costs precede benefits, especially in terms of emissions reductions. Discount rates are commonly used in CBA to correct for this time discrepancy.

Based on section 2 we derived a list of items we included in the review – see Table 3.

(Table 3 about here)

3. An overview of studies

We selected academic studies via the search engine SCOPUS and Scholar google. Table 4 summarises both the papers on the effects of vehicle scrappage schemes, as well as those on modelling vehicle scrappage behaviour.

(Table 4 about here)

Most of the papers in Table 4 assess (ex ante or ex post) the effects on emissions, cost-effectiveness, and in a few cases the economic impacts, and use quite simple models or assumptions with respect to vehicle replacements.

4. A review of methods

This section reviews the models that have been used to provide the effects of accelerated scrappage schemes. These models are usually micro-models, explaining the behaviour of households in the presence of scrappage programs. In order to predict the effect of a scrappage scheme on area-wide vehicle emissions the following components are needed in the model system:

1) A model (or some simple rules) of how car–owners will react to the scheme in terms of the options ‘do nothing’, ‘scrap and replace’ and ‘scrap without replacement’. The choice between the latter two options is also dependent on the type of scrappage scheme: is there the requirement to replace it with a new (or newer) car or not? Also the reference situation (no scrappage scheme) should be simulated to obtain the number of cars that would be scrapped at some point in time anyway. Opponents of car scrapping schemes sometimes argue that many of the cars for which a subsidy is received would have been scrapped anyway. In the more recent micro-level literature there are basically two ways to model the above car transaction decisions: dynamic programming models that use discrete time

periods (following Rust, 1987) and duration models that use continuous time (e.g. Gilbert, 1992 or de Jong, 1996). Dynamic programming models yield the optimum car fleet for a household in each discrete time period, such as a year. Duration models yield the amount of time that a household will own a certain vehicle fleet (e.g. until it scraps a vehicle). Households can also decide to wait (e.g. because a scrappage scheme will be introduced in the future, or to see how fast the car will deteriorate or how car and fuel prices will develop). Only a few models take this into account (e.g. Moretto, 2000, included an option value).

2) The substitutes that decision-makers use to replace the mobility that the scrapped car provided. This could in practice include using public transport and non-motorised modes more, but the models reviewed usually assume that the substitute is another car. For situations where the scrapped car will be replaced, a car type choice model (see for instance Train, 1986 or the review in de Jong et al., 2004) is needed, to determine the attributes (age, size) of the replacement car as that may influence the emission rates. Some studies use an explicit car type choice model for this, most use one or more assumptions on the replacement car (e.g. average car, average new car).

3) The car use (km driven). A few studies use a car use submodel, that explains car use from household attributes (as in Train, 1986 or de Jong, 1991), but most use assumptions on car use (often that the replacement car will drive the same amount of km as the scrapped car). Another assumption is that the use of the replacement car will be the average for that car age (which will exceed that of the older scrapped car). So the question is whether acquiring a newer car will lead to extra car use. The most likely outcome is that there will be some growth in car use but not up to the average car use level of the new(er) car (see section 2)

4) If many older cars were scrapped, this could lead to an increase in the prices of used cars. The model system should ideally contain a used car market model with endogenous prices, but this is very exceptional (Manski, 1983, Berkovec, 1985 and Hensher et al., 1992 developed demand and supply models of the car market with endogenous prices for used cars; Berry et al. (1995) model supply and demand for new cars). Also, the replacement car might come from another household that subsequently also purchases another (used) car, etc. The available models however do not predict which households will be trading which each other, and these indirect car market effects remain invisible.

5) Emission factors for local pollutants and greenhouse gases (grammes per km driven per car type differentiated at least by age).

6) To predict the lifecycle emissions, an estimate of emissions from car production and car scrappage (but usually not included).

7) Estimates of program costs, other external effects and economic effects.

The papers were scored on the presence or absence or these components. Items 5 and 6 were covered in Table 6, the outcomes for the other components are in Table 5.

(Table 5 about here).

5. A review of the effects included and results

Table 6 gives an overview of environmental effects included in the studies (if reported), and results.

All studies that consider polluting emissions include HC and NO_x. CO_2 and PM10 (PM2.5) are only considered in more recent studies. This might be explained by the fact that climate change and health risks due to PM10 did not have the attention in the 90s that they have now.

We only found one study which paid attention to non-tailpipe use-stage emissions (HSU and Sperling, 1994). All studies reported the implications of emissions only, ignoring the quantitative effects of scrapping schemes on concentrations and related health effects, although a few studies addressed the importance of at least concentrations. Some papers have at least qualitatively addressed the importance of other effects, such as safety and congestion effects.

Not all studies focusing on emissions include the relationship between vehicle age and the annual distance driven and therefore overestimate the environmental benefits of accelerated scrapping because it is likely that replacing an old car with a new(er) car will have some effect on car use. This effect will on average be smaller than suggested by Table 2 because Table 2 shows the empirical relationship between car age and annual miles driven, ignoring that a person replacing her vehicle for a newer vehicle may only slightly change annual mileage driven. The dynamic effects of preliminary scrapping on the car fleet are addressed in only a few studies. And if so, these effects generally focus on fleet changes over time, but not on the second and third (and further) order effects of vehicle transactions (see above). Some of the more advanced modeling papers related the characteristics of consumers to those of the vehicles, and a few even addressed the importance of self-selection for the relationship between owners' characteristics and vehicles, and related that to the characteristics of the scrapped vehicles (e.g. Alberini et al., 1995; Chen and Niemeier, 2005). Those who addressed this self-selection hypothesize or even show that cars in a relatively poor condition are more likely to be offered for scrapping (Alberini et al., 1995; Chen and Niemeier, 2005).

Most studies only report the separate effects of the indicators included. We found only one study that did a CBA on scrapping schemes: Washington's (1993) study, which is a CBA on the Sacramento metropolitan scrapping program showing that the program was not justifiable on economic grounds based on all the scenarios considered.
Cost-effectiveness (in terms of government costs per reduced ton of HC or NO_x) is often considered. There is no study that clearly states scrapping schemes to be more cost-

effective than alternative options. At best, some studies consider scrappage schemes to be competitive with alternative reduction options, at least for CO and HC (Washington et al., 1993), or under optimistic conditions (Hsu and Sperling, 1994), or if focused on very old LDVs only (Kavalec and Seitiawan, 1997) or in selected, polluted, urban areas only (Hahn, 1995). Several researchers (e.g. Lin 2008, Dill 2001, Hahn 1995) point to the fact that the scrapping schemes are at best viewed as a cost-effective short-term strategy to reduce part of the air pollution problem, as cost-effectiveness worsens over time: cars manufactured more recently on average have lower per kilometer emissions of pollutants due to sharpened emissions regulations. As a result one would expect decreasing cost-effectiveness of scrapping schemes in more recent studies (compared to older studies). Surprisingly, one of the most recent study (Stut and De Jong, 2009) yields the best cost-effectiveness for NOx ($1200/tonne). Most studies with relatively favorable cost-effectiveness are studies focusing on accelerated scrappage programs in which the petrol cars that were scrapped were all lacking a three-way catalytic converter. The cost-effectiveness of recent schemes such as those in Germany that resulted in the accelerated scrapping of cars with such equipment must therefore be much lower.

6. Conclusions and discussion

Methodologies

The literature on accelerated scrappage started in the mid 1990s. We distinguish two categories of studies: (a) studies that aim to improve our understanding of vehicle replacements / consumer behavior, and (b) studies that focus on the effects and/or cost-effectiveness of scrapping at the car fleet level. A first conclusion is that we have not found studies that focused on both categories of insights.

Secondly, studies that focus on the effects generally do not include all the dominant determinants for those effects. For example, some studies ignore the relationship between vehicle age and annual kilometers driven, most studies ignore self-selection with respect to the cars offered for scrapping (see above). Ignoring these dominant determinants generally leads to an overestimation of environmental impacts of scrappage schemes.

Thirdly, studies aiming to estimate emissions effects are generally limited in scope. Most of them focus on one or a few pollutants, whereas a whole range of pollutants can be influenced by scrapping schemes (as shown by Lin *et al.*, 2008). PM10, PM2.5 and CO_2 emissions received attention in only a few cases, as did assessments of scrapping schemes at the life cycle level.

Effects

Studies that focus on emission effects generally conclude that emissions will decrease, though in several cases only marginally. Those studies that looked at the effects over time conclude that emissions reductions will mainly occur in the short term. After stopping a program the effects rapidly diminish.

Some of the studies that focused on cost-effectiveness just present the costs per ton. Others which evaluate those values are often quite critical: accelerated scrappage is often found to be not very cost-effective. Those studies that show that earlier scrapping might have been cost-effective have two things in common. Firstly they covered accelerated scrappage in large metropolitan areas. We think the focus on large metropolitan areas makes sense, firstly because of the short distance between road traffic and people exposed, secondly because the concentrations of pollutants in such areas are relatively high and will exceed the limit values for concentrations relatively frequently, and thirdly because of the high contribution that cars in such areas make to the emissions and concentrations of pollutants. The second thing they have in common is that they generally analyzed programs that included the scrapping of vehicles with, to a large extent, old emission control technologies. In the case of petrol cars, the cars scrapped earlier did not have three-way catalytic converters. Thanks to successful emissions regulations in western (and increasingly also other) countries, the absolute decrease in emissions due to accelerated scrapping will decrease over time. Therefore from the point of view of air pollution the cost-effectiveness of scrapping schemes will decrease over time.

Accelerated scrapping might increase life cycle greenhouse gases (CO_2) and thus be counterproductive as regards climate change. Van Wee et al. (2000) state that the optimal age of a car is dependent on (i) the energy it takes to manufacture and to operate and (ii) the fuel efficiency improvement per year (the decrease in energy use per kilometre). Cars older than the optimal age could be considered for scrapping.

The more energy it takes to manufacture a car and the smaller the yearly decrease in energy use per kilometer per year, the older a car should be before scrapping can be considered effective. In the Netherlands, a considerable shift towards more fuel efficient cars has taken place in recent years, due to the economic crisis and greener taxation. This results in a newer cars to be scrapped efficiently. On the other hand, hybrid cars cost more energy to manufacture than non-hybrid ones. A rising market share of hybrid cars increases the optimal srappage age. All in all, it calls for customized scrapping schemes that take the nature of the vehicle into account.

Several studies have mentioned the fact that a large part of the subsidies will probably be given to free riders. We have not found a study that quantitatively addressed this issue. A few studies did estimate the number of years that vehicles were scrapped earlier than without the scrapping scheme probably would have been the case.

Some studies looking at the financial implications have textually addressed the issue that it is not only the program costs that matter for governments, but also the implication based on new sales and related VAT. We did not find studies discussing the implications based on yearly taxes and fuel taxes.

None of the studies we reviewed aimed to give a more or less complete overview and analysis of the effects of scrapping schemes, using an MCA or CBA. We found one study using a CBA. We can understand this because of the complexity of such an evaluation. On the other hand this is surprising because even if less advanced models were used, we think a quick scan MCA or CBA can certainly be made. There are either no studies that give a more or less complete overview of the separate dominant effects.

Discussion

A major conclusion is that a full overview of the pros and cons of scrapping schemes, including all the dominant effects and their determinants in an advanced way is lacking. An important question is: how serious is this omission? The studies do give an overview of partial insights into the effects and cost-effectiveness. We think that the conclusions that (a) emission effects are modest and occur in the short term, (b) cost-effectiveness is often quite poor, and (c) the most favorable cost-effectiveness scores occur in large densely populated areas, and if only (or mainly) cars with old (or no) emissions control technologies are scrapped, are quite robust. Overall we are quite skeptical with respect to scrapping schemes in the sense that it is very difficult to design a scheme with positive welfare effects or at least with substantial environmental benefits, certainly if introduced in the future at the national level (as was recently the case in Germany and the Netherlands). One could argue that in addition economic benefits might occur. This might be true, but we have not found underpinnings for the idea that scrapping schemes are the best (or at least a favorable) way of stimulating the economy, even though countries like Germany and the Netherlands legitimate scrappage policies for economic reasons.

How come that despite the negative conclusions several countries have introduced scrapping schemes even quite recently? We have the impression that the lobby for such schemes from the car industry was quite strong and successful. Secondly, politicians felt they had to do at least something to reduce the pain of the crisis. And car sales were immediately and strongly affected by the crisis, so they drew the attention of the public, the media, and policy makers. A third reason is derived from Public Choice Theory: policy makers want to do ‘something’ visible, that attracts the attention of the media and the wider public, to ‘score points’ in order to be re-elected. A scrapping scheme is a very visible way of doing something for the economy and (at least seemingly) also for the environment.

Do our conclusions mean that we think scrappage schemes are ‘bad’ *per definition*? The answer is: no. There may be future scenarios in which they could play a role. This might be the case if the dependency on oil becomes a structural problem, or if stringent climate policies are introduced. Especially if new very energy efficient technologies at the life cycle and well-to-wheel level become available (EVs using sustainably produced electricity might be candidate vehicles) scrappage schemes could be considered. But in such cases, an alternative could be to leave it to the market (for economic reasons vehicles might last less long under such conditions), or to introduce other economic incentives, such as a CO_2 tax.

Acknowledgements

We thank three anonymous reviewers for their useful suggestions for improvements and additional stdies.

Literature

Adda, J., and Cooper. R. (1999), Balladurette and juppette: a discrete analysis of scrapping subsidies. Journal of Political Economy 108(4) pp. 778-806.

Alberini, A., Harrington, W. and McConnell. V. (1995), Determinants of participation in accelerated vehicle retirement programs. RAND Journal of Economic 26 (1), pp. 93-112.

Allan, A., Carpenter, R and Morrison, G. (2010), Abating Greenhouse Gas Emissions through Cash-for-Clunker Programs. Transportation Research Record: Journal of the Transportation Research Board, No. 2191, pp. 111–118.

Baltas, N.C. and Xepapadeas. A. (1999) Accelerating vehicle replacement and environmental protection. Journal of Transport Economics and Policy, 33-3, pp. 329-342.

BenDor, T. and Ford, A. (2006), Simulating a combination of feebates and scrappage incentives to reduce automobile emissions. Energy 31 pp. 1197-1214.

Berkovec, J. (1985), Forecasting automobile demand using disaggregate choice models. Transportation Research-B, 19B-4, pp. 315-329.

Berry, S., Levinsohn, J. and A. Pakes (1995), Automobile prices in equilibrium. Econometrica, 63, (4), pp. 841-890.

Chen, C. and Niemeier, D. (2005), A mass point vehicle scrappage model. Transportation Research Part B 39 pp. 401-415.

Cooper, A, Chen, Y. and McAlinden, S (2010). The Economic and Fiscal Contributions of the “Cash for Clunkers” Program— National and State Effects. An Arbor, Michigan: Centre for Automotive Research.

Davis, S.C., Diegel, S.W. and Boudny, R.G. (2010), Transportation Energy Data Book. Tenessee: Oak Ridge National Laboratory

De Jong, G.C. (1991), An indirect utility model of car ownership and car use. European Economic Review, 34, pp. 971-985.

De Jong, G.C. (1996), A disaggregate model system of vehicle holding duration, type choice and use. Transportation Research B (Methodological), 30-4, pp.263-276.

De Jong, G., Vellay, C. and Fox, J. (2001), Vehicle scrappage: literature and a new stated preference survey. Paper presented at the European Transport Conference 2001, Cambridge.

De Jong, G.C., Fox, J., Pieters, M, Daly, A. and Smit. R. (2004), A comparison of car ownership models, Transport Reviews, 24 (4), pp. 379-408.

Deysher, B. and Pickrell. D. (1997), Emissions reductions from vehicle retirement programs. Transportation Research Record 1587 pp. 121-127.

Dill, J. (2001), Design and administration of accelerated vehicle retirement programs in North America and abroad. Transportation Research Record 1750 pp. 32-29.

Dill, J. (2004), Estimating emission reductions from accelerated vehicle retirement programs. Transportation Research D, 9, pp. 87-106.

Fontana, M. (1999). Cleaner vehicles: Fleet renewal and scrappage schemes. ECMT, Paris.

Gilbert, C.S. (1992), A duration model of automobile ownership. Transportation Research B (Methodological), 26-2, pp. 97-114.

Hahn, R.W. (1995) An economic analysis of scrappage. Rand Journal of Economics, 26-2, pp. 222-242.

Hensher, D.A, Barnard, P.O., Smith, N.C. and Milthorpe, F.W. (1992), Dimensions of automobile demand; a longitudinal study of automobile ownership and use. North-Holland, Amsterdam.

Hsu, S-L, Sperling, D. (1994), Uncertain air quality impacts of automobile retirement programs. Transportation Research Record 1444, pp. 90-98.

Kavalec, C. and Setiawan, W. (1997) An analysis of accelerated vehicle retirement programs using a discrete choice personal vehicle model. Transport Policy, 4-2, pp. 95-107.

Kim, H.C., Ross, M.H. and Keoleian, G.A. (2004), Optimal fleet conversion policy from a life cycle perspective. Transportation Research D, 9, pp. 229-249.

Lelli, M. Pede, G., Valentini, M.P. and Masoni, P. (2010), Car scrappage incentives policies: A life cycle result study on GHG emissions. *WIT Transactions on Ecology and the Environment* 131 pp. 121-131.

Lenski, S.M., Keoleian, G.A. and Bolon, K.M. (2010), The impact of `Cash for Clunkers' on greenhouse gas emissions: a life cycle perspective, Environ. Res. Lett. 5 (October-December 2010).

Li, S., Linn, J. and Spiller, E (2010), Evaluating “Cash-for-Clunkers” Program Effect on Auto Sales, Jobs and the Environment. Resources for the Future. Discussion paper RD DP 10-39.

Licandro, O. and Sampayo A.R. (2005), The effects of replacement schemes on car sales: The Spanish case. Working paper ECO 2005/20, European University Institute.

Lin, J., Chen, C and Niemeier, D.A. (2008), An analysis on long term emission benefits of a government vehicle fleet replacement planning northern illinois. Transportation 35 pp. 219-235.

Manski, C.F. and Goldin, E. (1983) An econometric analysis of automobile scrappage. Transportation Science, 1983-4, pp. 365-375.

Mian, A. and Sufi, A. (2010), The effects of fiscal stimulus: evidence from the 2009 ‘Cash for Clunkers’ Program. Working Paper 16351 http://www.nber.org/papers/w16351, Cabridge, MA: National Bureau of Economic Research.

Moretto, M. (2000) Participation in accelerated vehicle-retirement programs: an option value model of the scrappage decision. International Journal of Transport Economics 27 (1) pp. 99-110.

Nemry, F, Vanherle, K, Zimmer, W., Uihleim, A, Genty, A, Rueda-Cantuche, J.-M., Mongelli, I, Neuwahl, F, Delgado, L., Hacker, F, Seum, S., Bucher, M. and Schade, W (2009), Feebate and scrappage policy instruments. Environmental and economic impacts for the EU27. Brussels: European Commission

Rust, J. (1987) Optimal replacement of GMC bus engines: an empirical model of Harold Zurcher. Econometrica, 55-5, pp. 999-1033.

Schiraldi, P. (2006), Automobile replacement: a dynamic structural approach. http://www.ssc.wisc.edu/econ/workshop/Schiraldi_paper.pdf

Spitzley, D.V., Grande, D.E., Keoleian, G.A. and Kim, H.C. (2005), Life cycle optimization of ownership costs and emission reductions in US vehicle retirement decisions. Transportation Research D, 10, pp. 161-175.

Stut, W. and De Jong, G.C. (2009), Effecten van een sloopremieregeling op de uitstoot door personenauto's – een case-study voor Amsterdam. Tijdschrift Vervoerswetenschap, 45[e] jaargang, December 2009, pp. 159-165.

Train, K. (1986), Qualitative choice analysis: Theory, econometrics and an application to automobile demand. The MIT Press, Cambridge, MA.

Van den Brink, R.M.M. and Van Wee, B. (2001), Why has car-fleet specific fuel consumption not shown any decrease since 1990? Quantitative analysis of Dutch passenger car-fleet specific fuel consumption. *Transportation Research D,* 6, pp. 75-93.

Washington, S. (1993), Benefit-cost analysis of a vehicle scrappage program. Proceedings of the 35[th] Annual Transportation Forum.

Wee, B. van, Moll, H.C. and Dirks, J. (1999) Environmental impact of scrapping old cars. Transportation Research-D, 5D-3, pp.137-143.

Yamamoto, T., Madre, J-L. and Kitamura, R. (2004), An analysis of the effects of French vehicle inspection program and grant for scrappage on household vehicle transaction. Transportation Research Part B 38 pp. 905-926.

Table 1: an overview of effect categories

Environmental impacts	Use stage
	Non-use stage
	Concentrations
	Exposure
	Health
	Other
Travel behaviour changes	Car use
	Use of other modes
Non-environmental impacts	Economy
	Cultural heritage
	Prices of cars
	Safety and congestion

Table 2: Average annual miles per household vehicle by vehicle age

Vehicle age (years)	Self-reported miles, 2009
Under 1	12,800
1	13,800
2	13,500
3	12,500
4	11,800
5	11,700
6	11,300
7	11,000
8	10,300
9	9,900
10 and older	7,300
All household vehicles	10,100

Source: Davis *et al.*, 2010

Table 3: Items included for the review; evaluation framework

Effects	Emissions use stage
	Emissions non-use stage
	Concentrations
	Exposure
	Health effects
	Economic impacts
	Other impacts
Determinants	Emissions per kilometre
	Replacements dynamics
	Emission characteristics non-use stage
	Relationship between age of car and annual kilometres
	Dynamics effects over time
	Scrapping versus early scrapping
Evaluation framework	Effects
	Cost-effectiveness
	Other (e.g. CBA, MCA)

Table 4: an overview of selected studies on vehicle scrappage models and/or the environmental impacts of accelerated scrappage schemes

Author(s)	Year of publication	Country / region of scrapping scheme	Year of scrapping schemes studied	Type of paper
Washington	1993	Sacramento region (California)	Worked out hypothetical example based on 1990 data	Cost-benefit analysis using data from previous scrapping schemes
Hsu and Sperling	1994	California	1990+	Review and discussion of uncertainties in air quality impacts of scrapping schemes
Hahn	1995	California / Los Angeles	1990+	Evaluation of benefits and costs of scrapping schemes
Alberini et al.	1995	USA / Delaware	Not given in the paper	Model for participation in scrapping program
Kavalec and Setiawan	1997	California / Los Angeles region	Simulations for future years (1999-2010)	Simulations of replacements and retirements, emissions and cost-effectiveness,
Deysher and Pickrell	1997	Eastern Massachusetts	Not related to a specific scrapping scheme	Analysis of emissions reductions of a scrapping program
Baltas and Xepapadeas	1999	Greece/Athens	1991-1993	Model for optimal car replacement
Van Wee et al.	2000	Netherlands	Not related to a specific	Life-cycle analysis of

			scrapping scheme	preliminary scrapping
Adda and Cooper	2000	France	1994-1996	Dynamic discrete choice model of car ownership at the household level
Moretto	2000	Numerical example based on US data	Not related to a specific scrapping scheme	Model for participation in scrapping program including option value
Dill	2001	USA/Canada	Multiple scrapping schemes, 1990 - ongoing	Overview of scrapping schemes in the USA and Canada
De Jong et al.	2001	UK	Hypothetical scheme	Vehicle scrapping model
Kim et al.	2004	US	Hypothetical scheme	Life cycle analysis of car fleet over time
Yamamoto et al.	2004	France	1994-1996	Vehicle transactions model
Chen and Niemeier	2005	California	Not related to a specific scrapping scheme	Mass point duration model for survival rates
Spitzley et al.	2005	US	Not related to a specific scrapping scheme	Dynamic optimal replacement model
Licandro and Sampayo	2005	Spain	1994-1997	Household vehicle transaction model
Schiraldi	2006	Italy	1997-1998	Dynamic model of consumer choices including transaction

				costs
BenDor and Ford	2006	California	Not related to a specific scrapping scheme	Simulation analysis of a combination of feebates and scrapping incentives
Lin et al.	2008	Illinois	2001+	Model to evaluate long term emission effects of a government vehicle replacement plan
Stut and de Jong	2009	Amsterdam	Hypothetical example	Model of car scrappage and emissions
Nemry et al.	2009	EU 27	Hypothetical example	Application of the TREMOVE model for market responses, emissions and some more effects.
Lenski et al.	2010	US	2009	Life cycle analysis of GHG emissions
Li et al.	2010	US	2009	Evaluation of impacts of scheme on jobs, sales and the environment
Allan et al.	2010	US	Design of a scheme for the reduction of GHG emissions	Model useful for designing a scheme for the reduction of GHG emissions.
Lelli et al.	2010	Italy	Hypothetical scheme for	Life-cycle effects on

			1996-2020	GHG emissions

Table 5. Treatment of car ownership and use in vehicle scrappage models

Paper	Scrappage decision	Replacement vehicle	Car use	Endogenous used car market price
Washington (1993)	Participation rate from previous scheme	Various assumptions (as in previous scheme, proportional to existing fleet)	Age class specific car use.	-
Hahn (1995)	Scrap vs keep rule based on value of the car and the bounty	Replace by average car	Use km of scrapped car (base), average km or average km of a specific vintage	-
Alberini et al. (1995)	Participation (=scrap) rule based on reservation price for the car and bounty; eq. for remaining lifetime	Various assumptions (e.g. replace by average car)	Km taken from survey (average)	-
Deysher and Pickrell (1997)	Assumption that all cars above 20 years of age are replaced (maximum effect)	3 scenarios for replacement options to do the old km	Use km of scrapped car	-
Baltas and Xepapadeas (1999)	Dynamic programming model for optimal replacement	Only representative old versus representative new car	Car use included in the model	-
Adda and Cooper (2000)	Replace/scrap/keep from dynamic programming model (dynamic discrete choice)	-	-	-
Van Wee et al. (2000)	No car ownership or participation model, but eq. for car life that minimises energy use	-	Notion that car use of replacement car could be higher than that for scrapped car	-
Moretto (200)	Participation (=scrap) rule based on reservation price (including option value) for the car and bounty;	-	-	-

De Jong et al., (2001)	Scrap vs keep or sell models (stated preferences) and survival model	From vehicle type choice model	-	-
US Environmental Protection Agency (EPA; see Dill, 2004)	Assumption that the schemes accelerate scrappage by 3 years on average	Assumption that replacement by fleet average	Average per car age class	-
California Air Resources Board (CARB; see Dill, 2004)	Assumption that the schemes accelerate scrappage by 3 years on average	Assumption that replacement by fleet average	Average per car age class	-
BenDor and Ford (2004)	Vehicle market model plus survival functions; participation rule as in Alberini et al (1996)	From vehicle type choice model	From car use model	-
Kim et al. (2004)	Existing car survival function	No car type model, but assumption that scrapped car is replaced by average new car	Average per car age class	-
Yamamoto et al. (2004)	Competing risks duration model for keep/replace/scrap and timing	-	-	-
Chen and Niemeier (2005)	Duration model for car survival (mass point estimation)	-	-	-
Licandro and Sampayo (2005)	Duration model for vehicle transactions	-	-	-
Spitzley et al. (2005)	Dynamic programming model for optimal replacement schedule	No car type model, but uses generic vehicle	Constant at 12,000 miles/year	-
Schiraldi (2006)	Dynamic programming model for optimal replacement	From vehicle type choice model	-	included in indirect way
Lin et al. (2008)	Duration model for vehicle survival	No car type model, but assumptions (e.g. replace by average car).	Average km	-
Stut and de Jong (2009)	Age and fuel type specific survival rates; Participation rate from survey	Age specific replacement rates from survey	Age and fuel type specific annual km	-

Nemry et al. (2009)	Discrete choice model keep/remove vehicle	From new sales model	From multimodal transport demand model	-
Lenski et al. (2010)	Observed scrappage from official statistics	Replacement vehicle from observed statistics	Age specific; car use increase in sensitivity analysis	-
Li et al. (2010)	Aggregate car sales model on time series for US (treatment group) and Canada (control group)	From the same car sales model (is by car type)	Age specific	-
Cooper et al. (2010)	Aggregate car sales model on time series for US	-	-	-
Mian and Sufi (2010)	Time series model for car sales by city in the US (using cities with very few clunkers as control group)	-	-	-
Lelli et al. (2010)	Not included but assumed	New car	-	-

Notes:

- Hsu and Sperling's (1994) paper contains no new model, but a discussion of the large uncertainties in remaining lifetime, the replacement car, car use and emission rates.
- Adda and Cooper (2000) focus in terms of outputs on car sales and government revenues, not on emissions.
- Moretto (2000) focuses in terms of outputs on the rate of participation in the scheme.
- Dill (2001) is a review paper on scrappage schemes, focussing on the level of the incentives and on the eligibility conditions.
- Dill (2004) is a review paper on the methods used to estimate emission reductions from scrappage subsidies.
- Yamamoto et al. (2004) focus in terms of outputs on car holding duration, not on emissions.
- Chen and Niemeier (2005 focus in terms of outputs on car survival rates.
- Licandro and Sampayo (2005) focus in terms of outputs on car sales and car age, not on emissions.
- Schiraldi (2006) focuses in terms of outputs on car sales and government revenues, not on emissions.
- Allan et al. (2000) do not present a calibrated model, but use various assumptions on the use of scrapped and replacement vehicle.
- Lenski et al. (2010) and Li et al. (2010) are about the US 2009 'Cash for Clunkers' scheme that provided a subsidy for trading in an older car (that was then dismantled) for a new car.
- Cooper et al. (2010) and Mian and Sufi (2010) focus on effects of the US 2009 'Cash for Clunkers' scheme on the economy.

Table 6: effects included in the studies and results

Author(s)	Emissions use stage[1]	Emissions non-use stage	Other effects mentioned	Results
Baltas and Xepapadeas (1993)[2)]	HC, NO_x, CO	-	congestion and safety concentrations	emission reduction: HC 8-10 %; NO_x 3-5 %; CO 15-17 %; cost-effective way of controlling emissions
Washington et al. (1993)	HC, NO_x, CO		safety	HC: $1303-1353/ton CO $187/ton NO_x $5619-5652/ton Competitive for CO and HC with alternative reduction options, costs for NO_x 5 – 20 times higher than alternatives
Deysher and Pickrell (1997)	HC, NO_x, CO	-	-	LDV[4]s: HC : $10.000-80.000/ton NO_x - $18.000-200.000/ton Overall impacts on emission reduction small, cost-effectiveness for HC better than for NOx; in general best for old vehicles (before 80s)
Dill (2001)[3]	air pollution	-		Review article, cost effective in short term. Middle and upper class may benefit more from the programmes than lower classes. -
Hsu and Sperling (1994)	NO_x, CO, HC	non-tailpipe emissions: textual	-	VOC-$2260-$13289/ton, US, cost-effectiveness varies highly per region and per programme, uncertainty high. Under optimistic conditions, cost-effectiveness of scrapping schemes are comparable with alternative reduction options
Hahn (1995)	HC, NO_x	-	-	HC and NO_x: $2800-$10200/ton cost-effective in selected, polluted, urban areas; mostly short term, reducing ca. 10% of total emissions of HC and NO_x; if bounty exceeds $1000 net economic benefits are unlikely, inspection and maintenance programs have big impact on cost-effectiveness: in general, stringent Inspection and Maintenance (I&M) programs worsen cost-

				effectiveness because scrapping costs remain the same, but emission reduction is smaller, as well-maintained old cars are cleaner than badly-maintained old cars. Cost-effectiveness worsens over time, therefore best viewed as a cost-effective short-term strategy to reduce part of the air pollution problem
Kavalec and Setiawan (1997)	NO_x, HC	-	Congestion and noise	LDV >10 yr: $4827-6713/tonne LDV > 20 yr $3437-5054/tonne more cost-effective if very old cars (20+) are being scrapped than 10 + cars. Welfare losses highest (but still modest, i.e. $2/hh/year) for low income groups.
Van Wee et al. (2000)	CO_2; NO_x, CO and HC mentioned	Life cycle emissions included	Use of raw materials	Scrapping schemes may increase life-cycle CO_2 emissions, depending on fuel efficiency improvement and energy needed for manufacturing and operating. Scrapping of petrol cars less cost-effective than retro-fitting
Lin et al.(2008)	CO, NO_x, HC, CO_2 PM2.5	-	-	Short-term effects only, no long term effects expected. Effect highly dependent on external factors like oil price
Stut and de Jong (2009)	CO, NO_x, HC, PM10	-	Congestion, safety	HC: $1000/ton NOx:$1200/ton CO: $300/ton economically not viable
Nemry et al. (2009)	CO_2,, CO, VOC, PM, NO_x	Life cycle emissions included	Material flow, economic impacts -	13 Mton CO_2 (i.e. 1% reduction) Scrappage scheme comes too late with regard to air pollution and too early with regard to GHG emissions to be effective. 4.4 Mton
Lenski et al. (2010)	CO_2	Life cycle emissions included		CO_2 (0.4 % of total US-LDV emissions) at a cost of $600/ton, low cost-effectiveness
Li et al. (2010)	CO_2 CO VOC, PM, NO_x	-	Employment, car sales	Reduction of 8.6-28.3 Mton CO_2 at a cost of $91-294/ton. Low cost-effectiveness. Co-benefits by reducing other pollutants are taken into account

Lelli et al. (2010)	CO_2, N_2O, CH_4	Life cycle emissions included	-	Small increase in GHG emissions, within calculations errors

[1] HC refers to HC and VOC, regardless of the abbreviation the authors used
[2] This model paper is included because it explicitly mentions specific effects
[3] Dill gives an overview of scrapping schemes, no calculations of any effects
[4] LDV: light duty vehicles