Effects of Scrappage Subsidies in the Presence of Asymmetric Information

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The purpose of this paper is to evaluate the effects of accelerated vehicle retirement programs, also known as scrappage programs in the presence of information asymmetry in the used car market.

Scrappage programs are often adopted to reduce the number of highly polluting, used vehicles on the road. In the presence of prohibitively expensive infrastructure to measure emissions, policy-makers cannot observe the pollution levels of cars. However, since car owners have preferences over car quality, the government has some information about how used cars of different quality levels are allocated amongst car buyers. To get around the problem of unobservable emissions, the government aims to remove the majority of polluting cars by targeting low-quality used cars by using information on which car owners get cars of which quality. A scrappage program based on this principle is effective only if car quality and emissions are highly correlated which might not be the case. In other words, if low-quality cars are the ones that are more likely to be the most polluting, then current scrappage programs will succeed in removing most of the polluting cars from the road. However, if a substantial fraction of the high-quality used cars are the ones contributing to air pollution, then the program will not reduce pollution significantly.

Since emissions is unobservable, scrappage programs are voluntary. Individuals are offered a fixed dollar amount to scrap cars that are older than a certain age. The underlying principle of current scrappage programs is that a car's quality or value is negatively correlated to the amount of annual emissions it generates. If a car owner is assumed to have low utility from a low-quality car that is highly polluting, then a suffcient compensation offer would successfully scrap the high-emitting vehicles due to the self-selection mechanism. However, high-quality used cars can be polluting as well, albeit with a lower probability than their low-quality counterparts. Hence, a subsidy that seeks to scrap only the low-quality used cars might not be effective in improving air quality if there exist a substantial proportion of highly polluting high-quality used cars in the fleet.

Moreover, another factor besides the quality of the car affects the scrappage decision. Car owners have different preferences for the quality of cars. A car owner's utility from a car depends on both the quality of the car and the owner's preference for the quality. The allocation of cars to owners with different preferences matters. The scrappage program will scrap the highly polluting cars with a minimum subsidy only if

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the automobile market allocates low quality cars to those with a low preference for car quality, and assigns high quality cars to those with a high preference.

The problem that occurs in achieving an effective subsidy is that the resale market does not always allocate the poorest quality cars to the owners with the lowest preferences for quality. This inefficiency in allocation results from adverse selection in the second hand market. Quality of cars is observable to its sellers, but not to the buyers. This information asymmetry has a significant effect on the amount of the subsidy required to scrap the highly polluting used cars. Our paper shows that the amount of the subsidy needed to scrap the highly polluting cars rises with information asymmetry in the second-hand market for private automobiles.

Scrappage programs have been popular in Europe, and in few geographically-localized regions of Canada and the United States. Most European Union (EU) countries offer country-wide subsidies. France, Greece, Hungary, Ireland, Italy and Spain required scrapped cars to be replaced by a new vehicle. Other countries such as Denmark, Norway, the United States and Canada did not impose any such constraints on the type of replacement vehicle.[3] In our paper we focus my analysis on the effects of an unconstrained subsidy. Little work has been done to identify the implications of such a subsidy on the automobile market as well as on emissions.[4] Recently the possibility of expanding such programs has sparked a debate on their effects on the car market. Adda and Cooper (2000) use a replacement-demand model with a competitive primary market to examine the effects of a scrappage subsidy that required the replacement vehicle to be new. Since their main interest is to study the impacts of such a policy on new car sales, they do not include an active market for used cars. More recently Esteban (2007) also analyzes an unconstrained scrappage subsidy in the presence of monopoly distortions in the new car market. She, however, incorporates a used market without information asymmetry. Thus, our contribution to the literature is to examine the implications of such a program in a theoretical framework with information asymmetry.

To evaluate the effects of information asymmetry in the second hand market on the scrappage subsidy, we use a simplified version of Hendel and Lizzeri's (1999) model of adverse selection. The model is a dynamic framework where agents have heterogeneous preferences for car quality. However, the quality of a used car in my paper is discrete. We first examine the case where used cars' qualities are observable to all traders, and used cars of every quality have a unique price. This second-hand market allocates cars efficiently amongst heterogeneous buyers according to their preferences for car quality. We use this case as a benchmark to examine how adverse selection impacts the level of the subsidy as well its implementation.

Next we examine the case where quality is not observable, and used cars are priced according to the average quality of traded used cars in the market. In this case, a low quality car could be owned by a consumer with a preference for relatively high quality. To scrap the highly polluting poor quality cars, the subsidy must now be larger than the benchmark to compensate the high preference owner. If the subsidy is

[3] See Kahn (1995), EPA (1998), and European Conference of Ministers of Transport (1999) for a comprehensive description of the different scrappage subsidy programs in the United States and Europe.

4 See Alberini et al. (1995, 1996) for empirical work on scrappage programs.

sufficiently higher, some car owners would also be willing to scrap their good quality cars. One key result is that the subsidy can induce effective scrappage by being lower than the without-subsidy used car price in the presence of information asymmetry. Moreover, the subsidy can improve the extent of the inefficiency from information asymmetry. Lastly, with information asymmetry the subsidy tends to favor those at the lower end of the preference spectrum. Hence concerns over this policy being regressive might be mitigated if sufficient information asymmetry exists.

The paper is organized as follows: Section 1 describes the model and its assumptions. Section 2 analyzes the effects of the subsidy when car quality is observable. Section 3 analyzes the relationship between the effects of the subsidy and car allocations when car quality is only observable to its sellers. Section 4 provides some intuition for some welfare implications. Finally, Section 5 concludes.

Section 1: Model

We consider a discrete time, infinite-horizon economy in which individuals can choose to consume either a new car, or a used car. We also assume that a unit mass of infinitely-lived car owners are born at the beginning of time, and that no new consumers are added to the economy. Individuals purchase cars because they value the services from a car of quality w_t . Agents' preferences for car quality are heterogeneous and are denoted by θ, which is distributed uniformly on the interval $[0,1]$. Low-quality used cars are polluting and add to the total quantity of emissions, denoted by Q_E . At time t, a car owner of type θ pays a price $[0,1]$ for a car of quality w_t and enjoys a utility flow from it given by the following quasi-linear function:

$$U(w_t,\theta)=\theta w_t - P_{w,t} - \mu Q_E \tag{1.1}$$

where μ is the marginal environmental damage from emissions.[5] We assume that all consumers are negatively affected by worsening air quality, but each car owner is a very small share of the entire market and so ignores the effects of his or her own actions on total emissions. All consumers at any time t demand at most one car, and all have a discount factor of δ .

New and high-quality used cars are assumed to generate zero levels of pollution. Thus, emissions are generated by low- quality used cars, and we simplify to assume that the aggregate level of emissions is equal to the proportion of low-quality used cars being driven.[6]

Cars last for two periods. A car is new in the first period, and used in the second. New cars may be sold to someone else at the end of the first period, who then uses it for one more period before its value falls to zero at the end of the second period. Car quality is discrete, and can either be a new car (v), a low-quality used car (l), or a high-quality used car (h). All new cars have the same quality level. Quality realizations of used cars is random, but since the realization of v is not relevant to our analysis, we fix v to be equal

[5] All agents have identical income that is normalized to zero.
[6] All agents travel identical distances that are normalized to zero.

to 1. The quality of a used car is realized in the second period, and is unobservable to the buyers in the used car market. A used car turns out to be of high quality with probability p, and that of low quality with probability $1-p$. Moreover $h \leq v=1$, so that a used car always depreciates in quality. Consumers decide whether or not to purchase a car and also choose the type of car based on their preference for car quality and its price.

The government's goal under current scrappage programs is to reduce pollution by getting rid of the high-emissions used cars. However, emissions of cars cannot be observed at reasonable cost, but the government does have some information on how cars of different quality are distributed across car buyers. The policy then uses this information on car quality distribution to reduce pollution by targeting low-quality used cars, working under the assumption that these cars are more likely to be polluting than high-quality used cars. For this purpose, the policy offers a subsidy, S for voluntary scrappage of all such cars.

For notation, the paper follows the convention of using a superscript to denote the case being examined and a subscript either to refer to the type of consumer, or to the type of car. The analysis examines the following five categories: *o* stands for the observable quality case without a subsidy, *os* stands for the observable case with a subsidy, *i* stands for information asymmetry with a subsidy that eliminates the resale market for cars, and *ir* is the case with information asymmetry in the presence of a subsidy that retains a second-hand market for used cars. The case presenting information asymmetry without a subsidy does not have a superscript.

A subscript to a preference parameter, θ refers to the type of consumer, and can be one of the following: *n* stands for owners who purchase new cars every period, *h* stands for buyers of high-quality used cars, *l* stands for low-quality buyers, *u* denotes the used car buyer in the unobservable case, *nk* is new car owner who keeps cars of high quality, and finally a no subscript denotes consumers who choose the outside option of not purchasing a car. Furthermore, a subscript on quality or price refers to the type of car, and can be one of the following: *n* stands for new, *h* stands for high-quality used car, *l* stands for low-quality used car, and *u* stands for a used car whose quality is unknown to the buyer.

To focus on the allocation of used cars and new cars amongst the buyers and sellers we simplify the structure of the new car market by assuming that it is perfectly competitive. Thus, we take the price of new cars P_n as exogenously given. We also assume that the underlying population distribution amongst agents is constant.

Section 2: Quality is Observable to Buyers and Sellers

We first present two benchmark cases with no asymmetric information, one with and the other without a scrappage subsidy. We use these results to compare the effects of adverse selection on the allocation of low-quality used cars and hence on emissions, as well as how it affects the effective subsidy level.

2.1 No Scrappage Subsidy

In this case quality of used cars is observable to both buyers and sellers, but the realizations of used car quality are non-deterministic. In other words, when a new car turns used in the second period, it could be either of high- or low-quality, but which it will be is not known when a new car is bought. This makes the resale value of a new car uncertain at the time of purchase. However, the used car buyer always knows the quality of the car at the time of purchase. The used car market in this case uniquely determines a price for each type of used car. The price of a used car of quality *l* is given by P_l^0, while that of a car of quality of *h* is given by P_h^0.

Following Hendel and Lizzeri (1999), four types of agents exist in this equilibrium. Types in $[0, \theta_l^0]$ do not buy a car at all, types in $[\theta_l^0, \theta_h^0]$ purchase a low-quality used car at the end of every period, types in $[\theta_h^0, \theta_n^0]$ purchase a high-quality used car at the end of every period, and types in $[\theta_n^0, 1]$ purchase a new car and trade it when it turns used after one period.

Lemma 1: θ is always increasing in car quality when car quality is observable.

Proof: See Hendel and Lizzeri (1999), or the Appendix, Section 2.1A for a simpler version.

Thus, consumers with higher preferences for quality choose the high-quality cars, while those with lower preferences choose the low-quality cars. Thus, the secondary market correctly matches the "right" car to the "right" customer. However, those driving a low-quality car generate pollution that is not corrected for by the market, even though the allocation of cars is.

2.2 Comparing the case with no subsidy with case of Subsidy to Scrap All Low-quality Cars

Lemma 2: $S^{os} > P_l^o$.

Proof: See Appendix, Section 2.2A.

Intuitively, in the observable case the subsidy acts as a price floor in the low-quality used car market. To see why this is so, let's assume that $S^{os} = P_l^o$. We know that the low-quality used car price equals the value from derived from driving a low-quality used car for the marginal consumer, θ_l^0. This means that all consumers above θ_l^0 get a positive surplus from driving a low-quality car. Hence, if $S^{os} = P_l^o$ only θ_l^0 will scrap their car, and no one else, and since this consumer is of measure zero, amount of scrappage is zero. Hence, to induce a positive amount of scrappage, the subsidy must be greater than the low-quality used car price.[7]

Proposition 1: $\theta_h^o > \theta_h^{os} > \theta_l^o$; $\theta_n^o > \theta_n^{os}$ and $P_h^{os} > P_h^o$.

[7] This argument has been made in Esteban (2007).

Proof: See Appendix, Section 2.2A.

The above proposition states that the subsidy causes an increase in new car sales, a net increase in the sales of good-quality cars, as well as some consumers with lower preferences switch to not purchasing a car. This pattern of trading matches observations documented in European Conference of Ministers of Transport (1999) for Denmark as a result of country-wide scrappage subsidies put in place since 1990. Moreover, the subsidy reduces pollution from the oldest cars on the road.

Section 3: Quality is observable to sellers, but not to buyers before purchase

In this section we examine the case where used car quality is observed only by the seller and not by the buyer. Due to this information asymmetry used car buyers have a lower expectation regarding the average quality of the traded used car. A high-quality used car is now priced according to this average expectation. Since all used cars in this case are sold at one price, the price of the good quality cars is now lower than it was in the observable case without the subsidy, while that of the bad quality ones is higher. This in turn distorts the behavior of some of the sellers. Some of the consumers who were previously purchasing a new car and reselling the used car after one period do not continue to do so. Instead, they keep their used car if it turns out to be of high quality, and sells it only if it turns out to be of low quality. For these types, the benefit of purchasing a new car is less than the loss of receiving a lower price for their high-quality used car at the time of resale. Thus, these types now enter the new car market less often. Information asymmetry drives out some, but not all of the good cars from the resale market and hence raises the fraction of used cars that are of low-quality.[8]

The highest valuation consumers continue to purchase a new car and sell it when it turns used at the end of one period, even if the car turns out to be of high quality. This is because their utility gain from enjoying the higher services of a new car is greater than the loss in value from selling their used car at a lower price in the used car market.[9] In equilibrium, types in $[0,\theta_u]$ do not purchase a car, types in $[\theta_u,\theta_{nk}]$ purchase a used car every period, types in $[\theta_{nk},\theta_n]$ purchase a new car, keep the used car if it is of good quality and trades if it turns out to be of low-quality at the used car price, P_u and finally types in $[\theta_n,1]$ purchase a new car and trade in the used car at the end of the first period regardless of quality.

A subsidy to induce scrappage of all low-quality used cars can be achieved either by closing all trade in the secondary market, or by allowing for trade in all used cars and inducing buyers to scrap if they get a lemon. Each of these two equilibria have very different effects on the amount of the subsidy, its relation to the without-subsidy used car price, and the effects on car allocations.

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[8] This result was obtained from the Hendel and Lizzeri(1999) model of the secondary market as opposed to the Akerlof story where all good cars are driven out of the secondary market.

[9] This is different from the Hendel and Lizzeri (1999) result. In this paper this result is due to my definition of new and used cars.

Proposition 2: Subsidy with information asymmetry is higher than that without.

3.1 Subsidy with no resale market for used cars

Under a subsidy with no resale market, two types of consumers exist: the highest valuation consumers, who continue to purchase a new car every period and to scrap the used car regardless of its quality, and the relatively lower valuation consumers, who enter the new car market less often, keep their used car if it is of good quality, and scrap it if it turns out to be of poor quality. In equilibrium, types in $[0,\theta_{nk}^{i}]$ do not purchase a car, types in $[\theta_{nk}^{i},\theta_{n}^{i}]$ purchase new cars, keep it if it is of good quality and scrap it if it is of poor quality, and types in $[\theta_{n}^{i},1]$ purchase a new car and scrap it when it turns used in the next period. The subsidy in this case is denoted by S^{i}. However, this equilibrium is not stable as θ_{nk}^{i} can do better as a used car buyer. If θ_{nk}^{i} offers a used car price, $P^{i} > S^{i}$ to the new car sellers, then his/her utility is $\theta_{nk}^{i}ph+(1-p)S^{i}-P^{i}$. This is positive if $\theta_{nk}^{i}l = S^{i} < P^{i} < \theta_{nk}^{i}h$. Hence, closing the resale market for used cars is not sustainable.

3.2 Comparing case with a Scrap-all subsidy, with a resale market for used cars to that of no subsidy

This section compares the subsidy rate to the without-subsidy used car price. Two equilibria occur:

(i) $S^{ir} < P_{u} < P_{u}^{ir}$
(ii) $S^{ir} < P_{u}^{ir} < P_{u}$

We know that S^{ir} is not greater than P_{u} as this would result in the absence of a resale market. Used car buyers with relatively higher preferences would be willing to bid up the price of the used car if the subsidy is not substantially higher than it.

Proposition 3: $S^{ir} < P_{u}$

Intuitive proof: Let's assume that $S^{ir} = P_{u}$. But, the without-subsidy used car price equals the marginal used car buyer's value from a car of average quality, which is higher than his/her value from a low-quality used car, but lower than his/her value from a high-quality car. So any subsidy higher than this marginal consumer's value from a low-quality car induces scrappage of some of the polluting cars. If the quality of the polluting car is low enough relative to the high quality car, then all polluting cars can scrapped as long as the above condition on the subsidy is satisfied. Thus, scrappage of all polluting cars can be achieved with the subsidy amount being less than the without-subsidy used car price. (maybe if h is high relative to l)

Proposition 4: If $P_{u} < P_{u}^{ir}$, then $\theta_{n} > \theta_{n}^{ir}, \theta_{nk} < \theta_{nk}^{ir}, \theta_{u} > \theta_{u}^{ir}$.

Proof: exists.

The subsidy offers insurance to the used car buyers in case they get a lemon. This induces greater demand for used cars from both the higher as well as lower ends of the without-subsidy used car buyers. This higher demand pushes the used car price higher than its without-subsidy level, inducing greater consumers to participate in the new car market. Hence, the subsidy in this case reduces the extent of the inefficiency caused by information asymmetry in the secondary markets. Also, new car sales rise as the drop in demand for new cars is outweighed by the increase in its demand. However, even though there is a greater increase in activity in the used car market than in the new car market, pollution from the oldest cars is reduced.

Proposition 5: If $P_u > P_u^{ir}$, then $\theta_n < \theta_n^{ir}, \theta_{nk} > \theta_{nk}^{ir}, \theta_u > \theta_u^{ir}$.

Proof: exists.

This case is the exact opposite of the previous one. Here, too the subsidy encourages more people at the lower end of the spectrum to participate in the used car market. However, consumers with preferences at the higher end of the without-subsidy used car buyers switch to purchasing a new car and keeping it if it turns out to be a good car in the second period. These consumers switch to a new car as the used car price starts to rise as now their gains from better quality cars far outweighs the monetary loss from the higher price of new cars. This could happen when the high-quality car is not very much better in quality than the low-quality car. This reduction in used car demand is greater than its price causing the with-subsidy used car price to fall below the without-subsidy used car price.

The lower resale value of used cars reduces participation from the new car buyers with the highest preference, thereby reducing the average quality of the used cars being traded. Moreover, the reduction in demand for new cars from the relatively higher end consumers far outweighs the increase in demand for new cars, resulting in a decline in new cars' demand.

Proposition 6: Subsidy with $P_u > P_u^{ir}$ is lower than the subsidy amount with $P_u < P_u^{ir}$.

Intuitive proof.

A natural question to ask is when do either of the above two equilibria exist? Holding values of P_n=0.7, $\delta = 0.5$, $l = 0.1$, let's vary values of h and p. If h is relatively low (<0.3) it is a poor substitute for the new car. If p is relatively low then the high-quality car occurs less often than a low-quality car. In this case, equilibrium in Proposition 5 exists, and that in Proposition 6 does not.

On the other hand, if h is relatively low (<0.3) but more likely to occur than a lemon (p is relatively high), then the equilibrium in Proposition 4 exists, while that in Proposition 5 does not. However, if h is a closer substitute to the new car (h is high) and very likely (p is relatively high) then both equilibria exist, but are very close to each other. When both equilibria exist, the one in Proposition 5 wins as the subsidy amount is lower.

Section 4: Welfare Implications

4.1: Observable: With and without the subsidy

Here we provide some intuition regarding how the scrappage program affects the welfare of each type of consumer in the observable and unobservable cases. We first look at how each type of consumer fares in the presence of a subsidy relative to without it when car quality is observable. Three types of consumers exist here: those who choose not to buy a car, those who purchase a high-quality used car, and those who purchase a new car at the end of every period.

Consumers who choose the no-car option in the presence of the subsidy: Some amongst these types who were choosing this option even in the absence of a subsidy become better offer under the subsidy due to the environmental gain. However, some prior low-quality used car buyers now switch to not purchasing a car. They lose the benefit of driving a car, but can become better off than before if the environmental gain outweighs their loss. Thus, the net effect on this type is ambiguous.

Buyers of high-quality used cars: Amongst this type those who choose the high-quality car with and without a subsidy suffer a monetary loss due to the higher price of the high-quality car. Those who switch from a low-quality to a high-quality used car experience a lower surplus from driving. If they preferred the high-quality car they would've purchased one without the subsidy, but now are forced to as their first best choice is removed from the market. These types might still become better off if the gain from improved air quality outweighs the loss in surplus.

Buyers purchase a new car at the end of every period and the policy might make all types in this category better off. The subsidy makes those who were always choosing this option better off due to a higher resale price for every quality realization of their used car. This higher benefit from driving reinforces the gain from improved air quality. Those who switch to this option under the subsidy from a high-quality used car also benefit from the scrappage policy. These consumers' first best choice was the high-quality car. However, under the subsidy the surplus derived from driving a good-quality used car for these latter types is reduced due to the higher price. Hence, they are better off switching to a new car. Thus, the additional value from a new car to these consumers is not high-enough to justify the price. However, this loss in value is compensated for by the higher resale price for the used car in all states. If the monetary benefits outweigh the utility lost from switching, then they are better off. Also, they enjoy the environmental improvement due to the policy.

Thus, while the highest valuation consumers are likely to be the winners of the scrappage program, the used car buyers and those who choose the no-car option could be worse off. Consequently when quality is observable, aggregate welfare with a subsidy might be lower than that without the subsidy.

4.2: Unobservable with Resale Market: With and without the subsidy

Lastly, we compare how the subsidy affects the welfare of consumers when it can only be implemented with a resale market. First, consider the equilibrium where the with-subsidy used car price is greater than that without the subsidy (Proposition 4). Amongst the used car buyers, those who switch from not purchasing a car to purchasing a used car are better off as otherwise they wouldn't have switched as the option for not purchasing a car is available. These consumers gain in utility from a better choice of car is reinforced by the gain from pollution abatement. The used car buyers who continue to purchase a used car before and after the subsidy could be better off. Even though they pay a higher price for the used car, they are more likely to get a good-quality car with the subsidy as well as reduce their losses in case the car is of poor quality. Also, they gain due to the environmental improvement.

New car buyers who switch to being a used car buyer are better off as the option to be a new car buyer continues to exist. These consumers were originally the ones who wanted to purchase high-quality used cars when car quality was observable. Moreover, these consumers are now more likely to get their first best choice at a lower price than they were paying when car quality was observable. Also, the subsidy provides insurance against the bad outcome, which makes them better off participating in the used car market than in the new car market. Also, they improve by the environmental gain.

Finally, the consumers who switch to purchasing new cars more frequently are also better off as they can sell their resale cars at a higher price as well as enjoy a new car every period. Thus, the subsidy reduces the extent of the inefficiency from information asymmetry, and could potentially be a Pareto improvement over the equilibrium without the subsidy.

Next, let us consider the equilibrium where the with-subsidy used car price is less than that without the subsidy (Proposition 5). Amongst the used car buyers, same arguments as above hold for those who switch from not purchasing a car to purchasing a used car and those who purchase a used car in both equilibria. However, both these types of consumers might do even better in this equilibrium than in that of Proposition 4 as the used car price is lower in this case, albeit they are offered a lower insurance against the bad outcome. The used car buyers who switch to purchasing a new car and keeping the good quality car do so also because they gain from the transaction. This occurs in cases where the good quality car is a poorer substitute for the new car, as well as relatively unlikely to occur. As the used car price starts to rise, the used car becomes an even poorer substitute to the new car. The utility gain for these consumers from the switch to a new car might be greater and could outweigh their monetary loss from the lower resale price.

The new car buyers who switch to purchasing a new car less frequently suffer a utility loss from a lower quality car, but they also cut their monetary losses by not reselling their good-quality cars at a lower price. They also gain from the environmental improvement.

Hence, under information asymmetry the subsidy tends to favor consumers with lower preferences than those higher above. This contradicts the welfare effects from the observable case where the opposite might be more likely to occur. Hence, fears about the subsidy being regressive might be allayed if a large degree of information asymmetry exists in the used car market.

Section 5: Conclusion

We show that information asymmetry has non-trivial effects on the scrappage subsidy and on the welfare implications of the resulting replacement choices. It increases the amount of the subsidy, and also affects allocations in the primary and secondary markets that need to be considered when analyzing its effects. One of the main conclusions of our paper is that if information asymmetry is present in the resale market the scrappage subsidy can induce scrappage of low-quality cars even if it is below the without-subsidy used car price. Moreover, the subsidy can improve the extent of the inefficiency from information asymmetry. Lastly, with information asymmetry the subsidy tends to favor those at the lower end of the preference spectrum. Hence concerns over this policy being regressive might be mitigated if sufficient information asymmetry exists.

A lot of relevant extensions to this paper can be conducted to analyze the robustness of the results obtained. One possibility for future research would be to compare the welfare effects of the scrappage subsidy to other forms of environmental policy, such as taxes on new and used vehicles.

Appendix

Section 2: Quality is Observable to Buyers and Sellers

2.1A: No Scrappage Subsidy

Proof of Lemma 1: First note that $P_l^0 < P_h^0$. Otherwise, nobody would purchase low-quality used cars. We need to show that types who buy high-quality cars do not buy low-quality cars, and vice-versa. For this not to happen, the following incentive compatibility constraints must be satisfied:

$$\theta_h^0 h - P_h^0 = \theta_h^0 l - P_l^0 \Leftrightarrow \theta_h^0 (h-l) = P_h^0 - P_l^0 \text{..................(2.1)}$$
$$\theta_l^0 h - P_h^0 < \theta^0(l) l - P_l^0 \Leftrightarrow \theta_l^0 (h-l) < P_h^0 - P_l^0 \text{.....................(2.2)}$$

Combining the above two conditions, we get: $\theta_l^0 (h-l) < P_h^0 - P_l^0 = \theta_h^0 (h-l)$. If $h < l$, the above condition implies that $\theta_h^0 > \theta_l^0$ since $P_l^0 < P_h^0$. Thus, there exists a $\theta : \theta_l^0 < \theta < \theta_h^0$ who buys low-quality used cars. Similarly $\theta_n^0 > \theta_h^0$ and there exists a $\theta : \theta_h^0 < \theta < \theta_n^0$ who buys high-quality cars. We know that $\theta_n^0 < 1$ for the game to exist, which means there exists a $\theta : \theta_n^0 < \theta < 1$ who buys new cars.

Hence, proved.

2.2A Comparing the case with no subsidy with case of Subsidy to Scrap All Low-quality Cars

Proof of Lemma 2: With a scrap-all subsidy, θ_h^{os} is indifferent between purchasing a car of quality *h* and not purchasing a car. This implies the following:

$$\frac{\theta_h^{os}h - P_h^{os} - \mu Q_E^{os}}{1-\delta} = -\frac{\mu Q_E^{os}}{1-\delta} \Rightarrow \theta_h^{os}h = P_h^{os} \quad \text{.................................(2.3)}$$

However, the marginal consumer θ_h^o without the subsidy is indifferent between purchasing a car of quality *h* and that of *l*. This means:

$$\frac{\theta_h^o h - P_h^o - \mu Q_E^o}{1-\delta} = \frac{\theta_h^o l - P_l^o - \mu Q_E^o}{1-\delta}$$

$$\Rightarrow P_h^o = \theta_h^o(h-l) + P_l^o \text{ ....(2.4)}$$

The marginal consumers indifferent between purchase of a new car and that of a high-quality car in the case with and without the subsidy are given in (2.5) and (2.6) respectively:

$$\frac{\theta_n^{os} - P_n + \delta[pP_h^{os} + (1-p)S^{os}] - \mu Q_E^{os}}{1-\delta} = \frac{\theta_n^{os}h - P_h^{os} - \mu Q_E^{os}}{1-\delta}$$

$$\Rightarrow \theta_n^{os}(1-h) + P_h^{os}(1+\delta p) + \delta(1-p)S^{os} = P_n \text{ ....(2.5)}$$

$$\frac{\theta_n^o - P_n + \delta[pP_h^o + (1-p)P_l^o] - \mu Q_E^o}{1-\delta} = \frac{\theta_n^o h - P_h^o - \mu Q_E^o}{1-\delta}$$

$$\Rightarrow \theta_n^o(1-h) + P_h^o(1+\delta p) + \delta(1-p)P_l^o = P_n \text{ ....(2.6)}$$

The market clearing conditions for high-quality cars in both types of equilibria are as follows:

$$p(1-\theta_n^{os}) = \theta_n^{os} - \theta_h^{os} \text{ ....(2.7)}$$

$$p(1-\theta_n^o) = \theta_n^o - \theta_h^o \text{ ....(2.8)}$$

For the equilibrium with the subsidy to exist, it must be that the consumer with the highest valuation amongst the no car buyers prefers not buying a car than to purchase a used car of low quality. For this to be true, it must be that $\theta_h^{os}l - S^{os} \le 0$. The government selects the lowest level of the subsidy to execute the program at least cost. Using (2.3), this implies:

$$\theta_h^{os}l = S^{os} < P_h^{os} \text{ ....(2.9)}$$

Finally under no subsidies the indifference condition of the θ_l^o gives:

$$\frac{\theta_l^o l - P_l^o - \mu Q_E^o}{1-\delta} = -\frac{\mu Q_E^o}{1-\delta} \Rightarrow P_l^o = \theta_l^o l \text{ ....(2.10)}$$

Combining equations (2.3) and (2.4) and substituting for P_l^o from (2.10), we get:

$$P_h^{os} - P_h^o = h(\theta_h^{os} - \theta_h^o) + l(\theta_h^o - \theta_l^o) \text{..} (2.11)$$

Since the right-hand sides of (2.5) and (2.6) are equal, equating their left-hand-sides we get:

$$(1-h)(\theta_n^{os} - \theta_n^o) + (1+\delta p)(P_h^{os} - P_h^o) + \delta(1-p)(S^{os} - P_l^o) = 0 \text{.....................} (2.12)$$

Subtracting (2.8) from (2.7), we get:

$$(1+p)(\theta_n^{os} - \theta_n^o) + (\theta_h^o - \theta_h^{os}) = 0 \text{..} (2.13)$$

Thus, for the two equilibria to exist equations (2.9) – (2.13) must hold.

To prove the proposition, let's first assume that $S^{os} = P_l^o$. Using (2.9) and (2.10) we know that $\theta_h^{os} = \theta_l^o < \theta_h^o$. The last part of this inequality follows from Lemma 1. If this is true, then for equation (2.13) to hold it means that $\theta_n^{os} < \theta_n^o$. This in turn implies that for (2.12) to hold it must be that

$$P_h^{os} > P_h^o \text{………………………………………………………………} (2.14)$$

From Lemma 1, we know that: $\theta_h^{os} = \theta_l^o < \theta_h^o$, we re-write (2.11) as:

$P_h^o - P_h^{os} = (h-l)(\theta_h^o - \theta_l^o) > 0 \Rightarrow P_h^o > P_h^{os}$ which contradicts (2.14).

Hence, $S^{os} \neq P_l^{os}$.

Let's now assume that $S^{os} < P_l^{os} \Rightarrow \theta_h^{os} < \theta_l^o < \theta_h^o$ ……………………………(2.15)

For (2.13) to hold under this assumption, it must be that $\theta_n^{os} < \theta_n^o$. This implies that in (2.12) the first and the third terms are negative, and for (2.12) to hold it must be that (2.14) must hold again. This means that the left-hand side (LHS) of (2.11) is positive, implying that the RHS of (2.11) is positive. Hence, the following must be true:

$$h(\theta_h^{os} - \theta_h^o) + l(\theta_h^o - \theta_l^o) > 0$$
$$\Rightarrow -h(\theta_h^o - \theta_h^{os}) + l(\theta_h^o - \theta_l^o) > 0$$
$$\Rightarrow l(\theta_h^o - \theta_l^o) > h(\theta_h^o - \theta_h^{os}) > l(\theta_h^o - \theta_h^{os})$$
$$\Rightarrow l(\theta_h^o - \theta_l^o) > l(\theta_h^o - \theta_h^{os})$$
$$\Rightarrow \theta_l^o < \theta_h^{os}$$

which is a contradiction of (2.15).

Hence, proved.

P*roof of Proposition 1:* From Proposition 1, we know that $S^{os} > P_l^o \Rightarrow \theta_h^{os} > \theta_l^o$. This means that either one of the following must be true:

$\theta_h^{os} > \theta_h^o > \theta_l^o$ ....(*i*)

$\theta_h^o > \theta_h^{os} > \theta_l^o$ ....(*ii*)

Let's assume that (i) is true. Then for (2.13) to be true, we know that the following must hold: $\theta_n^{os} > \theta_n^o$. From (2.12) it must then be the case that $P_h^{os} < P_h^o$. This means that LHS of (2.11) is negative, implying that the RHS is < 0. For this to hold, it must be that the first term on the RHS of (2.11) is negative since the second term is positive from Lemma 1. This means $\theta_h^{os} < \theta_h^o$. This contradicts our assumption.

Hence, it must be that (ii) is true. This in turn implies that $\theta_n^{os} < \theta_n^o$ from (2.13). From (2.13) we also know that: $\theta_h^o - \theta_h^{os} = (1+p)(\theta_n^o - \theta_n^{os}) > \theta_n^o - \theta_n^{os}$. This means that the rise in demand for cars of quality *h,* $\theta_h^o - \theta_h^{os}$, is greater than the fall in demand for the same type of car $\theta_n^o - \theta_n^{os}$. This results in a higher price for high-quality used cars with the subsidy than without it.

Hence, proved.

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