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Policies on end-of-life passenger cars in China: dynamic modeling and cost-benefit analysis

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ABSTRACT

The expansion of motor vehicle fleet in China during the past decade has produced a cascade of challenges, including dealing with end-of-life passenger cars. To date, these cars have not been effectively collected or recycled. Policies must be deliberately devised and reformed to facilitate state-of-the-art vehicle recycling and minimize waste arising from end-of-life cars. In this study, dynamic modeling and cost-benefit analysis have been employed to investigate how polices, including government subsidies, a value added tax and a deposit-refund system, may affect recycling of end-of-life passenger cars. The results indicate that a combination of deposits and subsidies will surpass all of the other independent policies in terms of the recycling rate. This combination is expected to lead to a recycling rate of 80% of end-of-life passenger cars by 2050. However, the government will have to pay an annual 62 billion Chinese Yuan in the middle of the century for old-for-new replacement subsidies, posing a heavy burden on public finance. Comparatively, the deposit-only scenario will cost the government 4.7 billion Chinese Yuan and elevate the recycling rate to 46% in 2050. These policies may help curb the black market and promote the legitimate business of dismantling and recycling in the long run. Moreover, the prospect of vehicle remanufacturing will play another key role in diminishing the black market. The results in China are compared with policies and practices in Europe, Japan and South Korea to help decision-makers develop the most appropriate strategies for end-of-life vehicle management.

1. Introduction

China has been the world's largest manufacturer and market for motor vehicles since 2009. The stocks of registered vehicles in use have risen to 121 million as of 2012, with some 19 million new vehicles sold in that year (China Statistical Yearbook, 2013). The rapid expansion of the vehicle fleet will lead to a significant amount of end-of-life (EOL) passenger cars in years to come (Wang and Chen, 2013; Hu, 2009). The Automotive Industry Research (2013) estimated that approximately 4.8 million EOL passenger cars were generated in 2012, nonetheless only one-fourth of them were formally recycled. The majority of EOL passenger cars possibly escaped into the black market. In a developing country, Chinese vehicle owners like to use their vehicles as long as possible, until reaching the end of product life. Only a limited number of old or end-of-life vehicles (ELVs) go directly from customers to formal dismantling and recycling enterprises (Wang and Chen, 2013). Most of the ELVs are sold on the black market; many are refurbished and delivered to rural areas as second-hand cars, creating a list of challenges to be resolved. Not only does this process lower the recycling rate for end-of-life vehicles (mostly passenger cars) and the embodied useful materials, but the informal and often illicit disposal of scrap automobiles also causes serious consequences for safety and environmental pollution. This situation calls for a transparent business model and competitive recycling value chain for EOL passenger cars, in which the principles of a circular economy and the strategy of “Reduce, Reuse, and Recycle” (3Rs) can be effectively and efficiently realized (Wang and Chen, 2011).

The future generation of EOL passenger cars can be estimated by dynamic modeling of vehicle stocks in use and their lifetime (Button et al., 1993; Kobos et al., 2003; Wang et al., 2006). In these studies, the stocks of vehicle ownership per population are often connected with socioeconomic indicators, e.g., per capita income or GDP (gross domestic product). Dargay et al. (2007) proposed that the relationship between vehicle ownership and per capita GDP may present an S-shaped Gompertz curve. Empirical analyses and

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projections were conducted for 45 countries (representing approximately 75% of the world's population) for their automobile stocks and ELVs until 2030.

After estimating generation of EOL passenger cars, implications for material recycling and management of secondary resources can be explored. A recycling model was developed by Zhang and Chen (2013) for typical exterior plastic components of EOL passenger cars. The optimum strategies for recycling were assessed by using an SWOT (strengths, weaknesses, opportunities, and threats) matrix. Suzuki et al. (2001) examined dismantling technologies to improve ELV recycling rate and appropriate treatment technologies for ensuring environmental protection. Farel et al. (2013) focused on the recycling of EOL passenger cars' glazing. A system dynamics model was developed to investigate the potential costs and benefits of value-chain stakeholders under different scenarios. Density separation processes were presented by Malcolm Richard et al. (2011) as an important potential method for increasing capacity of plastics recycling. Simic (2015) proposed a fuzzy risk explicit interval linear programming model for ELV recycling planning in the EU. Proposed model had advantages in reflecting uncertainties presented in terms of intervals in the ELV recycling systems and fuzziness in decision makers' preferences. A Network management was used by Manomaivibool (2008) which integrated the Dutch approach to policy network analysis to explain the environmental effectiveness of the ELV programmes in the United Kingdom and in Sweden between 1990 and 2005.

Policies including government subsidies, a value added tax, and a deposit-refund system may play a key role in promoting formal and transparent business for the recycling of EOL passenger cars. Many studies have been carried out in this area. Wang and Chen (2013) explored and classified the existing policies and regulations in the European Union, Japan, South Korea, and China. The EOL passenger car recycling laws and policies based upon the principle of extended producer responsibility (EPR) in developed countries were considered to be informative for Chinese policy makers. Gerrard and Kandlikar (2007) evaluated expected outcomes since the establishment of the ELV Directive in European, finding that legislative factors and market forces have led to innovation in recycling, increased hazardous substance removal and improved information dissemination. Hu (2009) carried out extensive surveys and found that the difference in recycling prices between legal enterprises and black markets has an important impact on ELV recovery rate. Zhao and Chen (2011) briefly reviewed Japanese and Chinese laws on ELVs; they also compared the status quo of scrap automobile management between Japan and China. Bellmann and Khare (2000) analyzed how financial resources can be organized for the ELV recycling system, highlighting the importance of economic feasibility for success of recyclables' markets. Duval and MacLean (2007) developed a financial and life cycle assessment model and applied it to current and proposed recycling business operations.

And vehicle remanufacturing is expected to play an important role in realizing the country's sustainable development goals (Subramoniam et al., 2009, 2010). Wang and Chen (2011) found that while at present, vehicle remanufacturing is still in its infancy in China, a window of opportunity might be already open for the adoption of EPR. Seitz (2007) made a critical assessment of motives for product recovery based on in-depth case studies within the remanufacturing facilities of a major European Vehicle Manufacturer.

The ELV recycling policies and their effects have been investigated using both qualitative and quantitative approaches. The existing studies are noted to focus on ELV recycling in developed countries. Most of them made a qualitative interception or quantitative analysis based upon a single research method. Accordingly, our research offers some new contributions: First, we combine dynamic modeling with cost-benefit analysis, and use this integrated approach to investigate ELV polices including government subsidies, a value added tax and a deposit-refund system. Second, we make a case study for China, the world's largest developing country and largest automobile markets. In additional to national references and data, ELV recycler surveys and expert interviews were also conducted to enhance the credibility of the research. The feasibility and validity of this dynamic model have been tested by comparing the simulation results with time series data of EOL passenger cars.

Moreover, we employ cost-benefit analysis to evaluate the economic efficiency of car recycling policies (Final Report to DG Environment, 2006). In addition to economic values, social and environmental implications of the recycling of EOL passenger cars are also quantitatively assessed by incorporating cost-benefit analysis with a triple bottom line (TBL, Elkington (1998)) measurement. The results, we believe, will be useful for stakeholders in the government, recycling enterprises, consumers, and the black market (Kotchen et al., 2011).

2. Dynamic modeling of end-of-life passenger cars and policies

The dynamic model consists of three subsystems: EOL passenger cars, recycling policies, and cost benefit analysis, as shown in Fig. 1. In the EOL passenger car subsystem, the generation of obsolete cars per year can be estimated by passenger car stocks and sales. The results are then used in the policy subsystem, where five policy scenarios are developed to explore future trends and effects on the recycling rate of EOL passenger cars. Based upon the policy modeling results, a cost-benefit analysis has been implemented to examine the economic efficiency and other implications of different policies. The external variables, including GDP, population, the tax rate, passenger car sales per year, the recovery price and the black market price are underlined in Fig. 1. Internal variables, including the car stock per year, ELVs per year, recycled ELVs per year, the recycling rate and policies, are italicized in the figure.

The legitimate recycling rate of EOL cars is mainly determined by the pricing difference between formal recycling enterprises and the black market. A decrease in the price difference will lead to more EOL cars recycled by legitimate dismantling and recycling enterprises. The government and enterprises should center on construction of infrastructure and diminish the gap between formal and informal recycling.

2.1. EOL passenger cars subsystem

GDP per capita and passenger vehicle ownership are two major factors in the model. Their relationship can usually be depicted with an s-shaped growth curve. In this study, the nonlinear Gompertz model was selected to interpret this relationship on a time scope between 1980 and 2050, as shown in the following equation:

$$V_t = V \cdot e^{ae^{bGDP_t}} \tag{1}$$

where V_t indicates the vehicle ownership in year t (stocks of passenger cars per 1000 people), and GDP_t is the per capita GDP in year t. V is the saturation level of future maximum passenger vehicles per 1000 people, and a and b are negative parameters that determine the shape of the S-shape curve of vehicle ownership growth over economic growth. According to previous studies (Dargay et al., 2007; Wang et al., 2006), we set up the parameters at: $a = -5.897$ and $b = -0.0003$. Two scenarios are proposed for the growth of car