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Research article

Role of vehicle inspection policy in climate mitigation: The case of Japan

Yuya Nakamoto[a,*], Shigemi Kagawa[b]

[a] *Graduate School of Economics, Kyushu University, 6-19-1 Hakozaki, Higashi-ku, Fukuoka, 812-8581, Japan*
[b] *Faculty of Economics, Kyushu University, 6-19-1 Hakozaki, Higashi-ku, Fukuoka, 812-8581, Japan*

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ABSTRACT

In 1951, the Japanese government introduced a vehicle safety inspection system and this system has an effect of shortening the 'economic' lifetimes of automobiles and increasing CO_2 emissions associated with vehicle lifecycle. This study develops an integrated assessment framework by combining dynamic discrete choice analysis with life-cycle environmental accounting analysis based on a dynamic stock model. From the empirical results, we found that (1) the economic lifetime of a Prius in the benchmark model is surprisingly short, 5.07 years, due to the strict car inspection system, and this replacement cycle has contributed to increasing CO_2 over time; and (2) abolishing car inspections at the third and fifth years would considerably contribute to reducing life-cycle CO_2 emissions associated with Prius sold during the study period, 1997 to 2016, accounting for approximately one million tons-CO_2 eq. over 20 years. Thus, we conclude that modifying the regulation policy with a focus on the car inspection system to induce car owners to keep their automobiles longer would have environmental benefits.

1. Introduction

Vehicle safety inspection systems have been introduced in many countries, among them Japan, which introduced such a system in 1951 (Hirota and Minato, 2001). Under the Japan's car inspection system, testing for conformity to strict exhaust regulations and many other maintenance regulations are conducted three years after initial purchase and every two years thereafter, and the cost of such comprehensive inspections is a big burden on car owners (National Agency for Automobile and Land Transport Technology, 2016). Car owners would like to avoid the burden of car inspections and sell currently owned vehicles with higher market values before their next inspection and replace them with new vehicles. The cost burden motivates car owners having 'greener' current cars with good fuel economy to frequently replace them with new cars. As a result, the car inspection system hinders long-term use of the 'greener' cars and contributes to the increase in CO_2 emissions associated with the vehicle life-cycle, including manufacturing and disposal (Kagawa et al., 2011). Therefore, it is important to determine to what extent the car inspection system has increased CO_2 emissions over time, as well as how we can modify the current car inspection system in keeping with a climate mitigation policy.

Previous life-cycle studies focused on the motor vehicle sector have successfully specified the lifetime distribution of vehicles, both in Japan and overseas (Oguchi and Fuse, 2015), and demonstrated that extending vehicle lifetime contributes to CO_2 emissions reduction (Kagawa et al., 2011). To show the environmental benefit of introducing a subsidy system, Kagawa et al. (2013) compared the amount of life-cycle CO_2 emissions from vehicles (only new vehicles) under a subsidy system in which all vehicles are simultaneously replaced to the amount of life-cycle CO_2 emissions without a subsidy system, whereby vehicles are replaced slowly in accordance with a normal vehicle lifetime distribution. Lenski et al. (2010) showed the environmental benefit of the 'cash for clunkers' policy introduced in the United States in 2009. In this kind of life-cycle study focused on the motor vehicle sector, vehicle replacement purchase has been modeled according to the physical lifetime distribution of vehicles (e.g., Weibull distribution). Typically, physical lifetime distributions have been employed widely in studies on material flow analysis (e.g., Nakamura et al., 2014; Pauliuk et al., 2017) and on estimating the amount of stock of various materials (e.g., iron (Daigo et al., 2007), aluminum (Chen and Graedel, 2012), and copper (Spatari et al., 2005)).

However, previous studies that have modeled vehicle replacement purchases based on physical lifetime distribution have not evaluated social lifetime influences on the reasons of the owner and economic lifetime influences on maintenance costs, such as gasoline, property tax, and car inspections of vehicles. Kim et al. (2003, 2006) and De Kleine et al. (2011) estimated the lifetime of durable goods using life-cycle

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[*] Corresponding author.
E-mail address: y.nakamoto0527@gmail.com (Y. Nakamoto).

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optimization analysis, to minimize the environmental burden, but they did not consider consumer behavior, which maximizes utility level over time. In other words, such studies have *not* adequately described the social lifetime or economic lifetime of vehicles based on the choice behavior of consumers—that is, how consumers decide every term to either continue driving the same vehicle or to make a replacement purchase. Thus, studies to date have been unable to make effective policy proposals in relation to vehicle demand policy. Numerous studies have been carried out on commodity markets using discrete choice models based on consumer theory (random utility theory)—e.g., Rust (1987), Chevalier and Goolsbee (2005), Gordon (2009), Schiraldi (2011), and Gavazza et al. (2014)—but thus far few studies have tried to assess the influence of adopting or modifying demand policy for durable goods on global warming.

In this study, we set out to estimate the impact of a car inspection system on CO_2 emissions derived from vehicles and to propose a vehicle life-cycle analysis using a dynamic discrete choice (DDC) model based on optimal consumer behavior. In the dynamic discrete choice model proposed in this study, the probability of a consumer choosing to continue driving the same vehicle without making a replacement purchase, versus making a replacement purchase of a new vehicle, depends on the expected cost (utility level). Incorporating the vehicle replacement purchase rate estimated by the DDC model into a vehicle life-cycle CO_2 emissions analysis based on the dynamic stock accounting model (Müller, 2006; Kagawa et al., 2006; Nishijima, 2016), we conducted a scenario analysis of the impact of a car inspection system on the amount of CO_2 emissions derived from vehicles.

By estimating the economic lifetime of vehicles based on consumer behavior that maximizes utility level over time, we were able not only to specify the replacement purchase rate based on a DDC model but also to quantitatively analyze the environmental impact of changes in consumer behavior due to the adoption of policies—e.g., a car inspection system. The proposal of this new integrated analysis framework is expected to be quite useful in formulating a CO_2 emissions reduction policy targeted at the transport sector. We also clarified the role of policy change for a car inspection system in achieving Japan's emissions reduction. Finally, we discuss further policies that may be effective in achieving the target for CO_2 emissions reduction in the transport sector.

2. Methodology

2.1. Definition of utility function

Rust (1987), Chevalier and Goolsbee (2005), and Rapson (2014) all formulated durable goods replacement purchase consumer behavior (e.g., for automobiles or household air conditioners) that considers expected utility (in this study, expected cost) as a DDC model. Based on these earlier studies, we formulated a dynamic replacement purchase behavior model for specific motor vehicles, based on a maximization of expected utility. In period t, a single motor vehicle owner makes a decision whether to continue owning their current vehicle or to replace it by purchasing a new vehicle. The replacement purchase choice of a car owner in period t is formulated using the control variable i_t as follows (Rust, 1987):

$$i_t = \begin{cases} 1 & \text{if a car owner replaces in period } t \\ 0 & \text{otherwise.} \end{cases} \tag{1}$$

In this study, we focused on one particular model of car, a relatively green car, the Toyota Prius, that has rapidly established a large market presence over the past 10 years. Prius cars are assumed to be homogeneous and independent in the sense that the choice to make a replacement purchase of a Prius i is not influenced by the replacement purchase choice of a Prius j.

As in Rust (1987), in accordance with random utility theory (McFadden and Train, 2000), the utility of a car owner in period t can be formulated as a parametric function:

$$\begin{aligned} u(x_t,\ d_t,\ \varepsilon_{it},\ i_t;\ \theta_{11},\ \theta_{12},\ \theta_{13}) &= u(x_t,\ d_t,\ \varepsilon_{it},\ i_t;\ \boldsymbol{\theta}_1) \\ &= (1-i_t)(\theta_{11}x_t + \theta_{12}d_t) + i_t\theta_{13} + \varepsilon_{it} \end{aligned} \tag{2}$$

x_t is the cumulative travel distance of a car from the new car purchase at the start of period 1 to the end of period t. Dummy variable d_t takes value 1 in the third period after the new car purchase (i.e., $d_3 = 1$), after which it takes the value 1 every two further periods (e.g., $d_5 = 1$ and $d_7 = 1$); for all other periods, $d_t = 0$. Under Japan's *shaken* car inspection system, testing for conformity to strict exhaust regulations is conducted three years after purchase and then every two years thereafter, and the cost of such inspections is a big burden on car owners. For this reason, the car inspection system induces consumers to replace their cars (Clerides, 2008). ε_{it} is an unobservable error that influences the utility of consumers in making choice i in period t. In this study, this variable is assumed to follow a type I extreme value distribution with independent and identically distributed (i.i.d.) characteristics (Train, 2003). One interpretation of why we are unable to observe the error is that the replacement choice when there is no error is $i_t = i^*(x_t,\ d_t;\ \boldsymbol{\theta}_1)$, from the state variable that we obtained. This shows that the replacement purchase behavior of a single car owner must be explained completely by the cumulative travel distance and car inspection dummy in period t. However, since it is not necessarily the case that a single car owner follows an optimal solution when guided by this model, in most cases the behavior cannot be explained only by observed state variables.

In Eq. (2), when a car owner chooses not to make a replacement purchase in period t (i.e., $i_t = 0$), we obtain $u_t = \theta_{11}x_t + \theta_{12}d_t + \varepsilon_{0t}$, and the cumulative travel distance and car inspection dummy influence utility. In this case, utility decreases not only because of cumulative travel distance but because of the additional costs incurred at car inspection time. Therefore, the values of θ_{11} and θ_{12}, which represent utility function parameters, can be expected, in theory, to be negative. On the other hand, when a car owner chooses to purchase a new car in period t (i.e., $i_t = 1$), we get $u_t = \theta_{13} + \varepsilon_{1t}$. In this case, θ_{13} represents the consumer's replacement purchase cost, including opportunity cost, and if replacement cost increases then utility decreases. As a result, the parameter θ_{13} can be expected to be negative in theory.

Car owners (i.e., consumers) make replacement purchase choices $\{i_1, i_2, i_3, \cdots, i_T, i_{T+1}, \cdots\}$ so as to maximize the expected discounted value of the (infinite) series of periods ($t = 1,2,3, \cdots, T,\ T+1, \cdots$):

$$\max_{\{i_1, i_2, \cdots\}} E\left[\sum_{t=1}^{\infty} \beta^{t-1} u(x_t,\ d_t,\ \varepsilon_{it},\ i_t;\ \boldsymbol{\theta}_1)\right] \tag{3}$$

where β is the discount rate, which takes a value between 0 and 1, and the state variables in Eq. (3) are observable travel distance x_t, car inspection dummy d_t, and unobservable error ε_{it}.

The corresponding value function of this maximization problem (3) is formulated as:

$$\begin{aligned} V(x_t, d_t, \varepsilon_{it}; \boldsymbol{\theta}_1) = \max_{\{i_{t+1}, i_{t+2}, \cdots\}} E_{x,\varepsilon}\Bigg[& u(x_t,\ d_t,\ \varepsilon_{it},\ i_t;\ \boldsymbol{\theta}_1) \\ & + \left\{\sum_{\tau=t+1}^{\infty} \beta^{\tau-t} u(x_\tau,\ d_\tau,\ \varepsilon_{i\tau},\ i_\tau;\ \boldsymbol{\theta}_1) | x_{\tau-1}\right\}\Bigg] \end{aligned} \tag{4}$$