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Abstract

A concomitant of the rapid development of the automobile industry in China is the serious air pollution and carbon dioxide emission. There are various regulation instruments to reduce the air pollution from automobile sources. China government chooses a small-displacement oriented consumption tax as well as fuel tax to alleviate the worse air pollution. This paper evaluates the effects of both policy instruments on fuel consumption and social welfare. Our empirical results show that fuel tax decreases the total sale of new cars, which leads to a decline of total consumption of fuel from the new cars, but does not change the sale distribution over various fuel efficiency models; while consumption tax adjustment results in a skewed sale distribution toward more efficient new cars but increases the total consumption of fuel due to an enlarged sale. The effects of these two taxes on pollution depend on our assumption about the average fuel efficiency of outside goods. On the other hand, consumption tax leads to less social welfare loss; in particular, consumer surplus decreases in an order of magnitude less than that caused by fuel tax. Fuel tax actually transfers more welfare from private sector to the government.

Key words: China auto industry, welfare analysis, tax incidence, BLP model, tax progressivity

I. Introduction

China automobile industry has developed rapidly in the last two decades. In 2009, China overtook the United States as the biggest auto market; the passenger car sales soared to 10.3 million and total vehicle sales were estimated at 13.6 million. However, a concomitant of the rapid development of the automobile industry in China is the serious air pollution and carbon dioxide emission. China topped the list of sovereign states and territories by carbon dioxide emissions 2007 provided by the CDIAC for the United Nations. Its emission accounts for 22.3% of the global total, while emissions from motor vehicles have become the main source of air pollution in China's large- and medium-sized cities, according to China Vehicle Emission Control Annual Report 2010 by the Ministry of Environmental Protection. This report shows that the volume of pollutants generated by motor vehicles across China in 2009 amounted to 51.4 million tons, with cars contributing most of it. Furthermore, Walsh (2000) estimates that mobile sources are contributing approximately 45–60% of the NOx emissions and about 85% of the CO emissions in typical Chinese cities.

China government has realized the serious problem of air pollution and carbon dioxide emissions, and formulated policies to increase energy conservation initiatives and pollution control projects. In particular to reduce automobile emissions, China Ministry of Finance and the State Administration of Taxation adjusted consumption tax on vehicles twice on Apr 1st, 2006 and Sep. 1st 2008, respectively (Table 1). In short, these policy adjustments raise the consumption tax on passenger vehicles with high displacement and cut the consumption tax on low-emission passenger vehicles. Obviously, the purpose of this adjustment is to curb high-emission cars and promote small ones, in an effort to reduce pollution and save energy. The current tax is similar to the gas guzzler tax in the States, while the difference is it is paid by consumers.

This paper investigates the effectiveness of these adjustments in tax scheme on total consumption of fuel and fleet average fuel efficiency, using comparative statics ex ante and post tax adjustments[2]. Previous studies show that an effective emission-reducing policy may be costly (Crandall 1992, Greene and Liu 1988, Crandall and Graham 1989, Kleit 1990 about Corporate Average Fuel Economy (CAFÉ) and fuel tax, White 1982 and Bresnahan and Yao 1985 about air-pollution standards of the Clean Air Act). Therefore, we apply Berry, Levinson and Pakes (1995,

[2] Harrington (1997) shows that better fuel economy can strongly contribute to lower emissions of CO and hydrogen carbonate. Therefore, most of the literatures use the average fuel economy to measure the effectiveness of alternative policies on reducing emissions. This paper follows this measurement standard.

BLP hereafter) methodology to China automobile industry data to estimate the social welfare loss as a measurement of the consumption tax cost, and compare its effectiveness and cost to that of a hypothetical fuel tax[3]. Our study shows that neither consumption tax nor fuel improves fuel efficiency significantly, but the consumption tax lowers market share weighted average fuel consumption in a bigger magnitude than fuel tax does. More importantly, fuel tax decreases the total sale of new cars, which leads to a decline of total consumption of fuel from the new cars, but does not change the sale distribution over various fuel efficiency models; while consumption tax adjustment results in a skewed sale distribution toward more efficient new cars but increases the total consumption of fuel due to an enlarged sale. The effects of these two taxes on environment depend on our assumption about the average fuel efficiency of outside goods. On the other hand, consumption tax leads to less social welfare loss; in particular, consumer surplus decreases in an order of magnitude less than that caused by fuel tax. Fuel tax actually transfers more welfare from private sector to the government. In conclusion, fuel tax is more likely to lower the total consumption of fuel, sacrificing more social welfare on new cars. On the contrary, consumption tax only improves the new-car fleet average fuel efficiency, but enlarges total consumption of fuel the total sale with a moderate decrease of social welfare.

The effectiveness of emission-reduction policies have been discussed for a long time. Most extant literatures compare the tax policies such as fuel tax (Dahl 1979, Parry and Small 1995, Fullerton and Gan 2005, Feng, Fullerton and Gan 2005, Bento et al 2009), and other more stringent non-tax regulations such as CAFÉ (Crandall 1992, Koopman 1995, Agras 1999, West 2004, Sterner, Dahl and Franzén 1992). Although ambiguous conclusions have been drawn on their effectiveness, most studies found that fuel tax is more efficient in decreasing the Vehicle Miles Traveled (VMT), while CAFÉ is efficient in improving the average fuel economy of new cars[4]. But few empirical studies to date have estimated the environmental and welfare effect of an excise tax

[3] Fuel tax adjustment was effective in January 2009, but our sample period ends in December 2008, so such a fuel tax adjustment is hypothetical. Based on the price for 93# gasoline in the mass market, the tax rate is about 30%.

[4] Parry and Small (2005) also conclude that fuel tax causes greater shifts in fuel economy than VMT reduction.

on the car. China's automobile consumption tax is such a Pigovian excise tax. Tax rates vary in car displacement of engine. This tax is not as stringent as CAFÉ. Manufacturers do not need to restrict their average fuel efficiency; instead, they can choose to share some tax burdens to sustain their market shares. In this way, manufacturers partially internalize the marginal social cost of less fuel efficiency, rather than downsize the cars to satisfy the compulsory requirement[5]. Therefore, this tax may be a better policy to solve the safety issue caused by CAFÉ. This paper is the first study to empirically investigate the efficiency and cost of this tax.

This paper differs from the previous studies in the following aspects. First, China's automobile consumption tax on displacement is unique; no related literature has investigated the consequence of this tax. It sets different tax rates over displacement tiers. So tax payment is based on both displacement tiers and car values. Fullerton, Gan and Hattori (2004) studied a similar annual automobile tax levied by prefecture government of Japan. Japanese automobile tax is a fixed amount tax based on displacement, not varying over car value, which results in a regressive tax scheme for each displacement tier since high-income households purchasing more expensive cars just need to pay the same tax. But whether the consumption tax with progressive tax rates over displacement actually has the property of progressivity merits empirical measurement.

Second, this paper simultaneously estimates the impacts of tax adjustment on both demand and supply sides, while most empirical studies to date have focused on the demand side estimation (Greene and Liu 1988, Bento et al 2009, West 2004). BLP (1995) framework models the price competition between manufacturers, so it can be used to analyze the profit variation as well as consumer surplus changes due to exogenous tax changes, which makes this study capable of estimating the total social welfare changes rather than consumer surplus changes only.

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[5] Downsizing may cause serious safety problem and results in higher costs for a regulation policy. Greene and Liu (1988) find that for a gallon fuel saving, the welfare loss is \$0.3; Crandall and Graham (1989) estimate that welfare losses per gallon is \$0.41~0.63 considering the safety issue caused by downsizing due to CAFÉ.

Third, the current empirical model in this study endogenizes the response of the equilibrium automobile prices to tax changes. The previous research usually ignores this while studying the effectiveness of emission-reduction policies (Fullerton, Gan and Hattori 2004, West 2004). Since firms are heterogeneous in their costs, they may respond quite differently to a tax policy change. Firms with lower productivity have to forward all the tax addition to consumers, while those with higher productivity can absorb some tax burden to sustain sales. Without considering the competition effect on car prices status quo, the consumer welfare changes due to a tax change may be under-estimated[6]. Welfare and environmental consequence analysis in this paper take account of this equilibrium price change, so my study gives a more precise estimate.

Besides, this paper investigates the tax incidence. Without considering the supply side tax burden sharing effect, we may overestimate the welfare loss on the demand side due to a tax change. Also, this paper tries to measure the progressivity of this consumption tax, and makes a comparison to the fuel tax.

The rest of the paper is organized as follows. Section II briefly introduces the automobile industry and the consumption tax system in China, and describes the data for the empirical model, which is laid out in section III. Section IV presents the empirical results and welfare analysis. Finally, section V summarizes this paper.

II. Description of the automobile industry and tax adjustments

China automobile industry

In the last two decades, China automobile industry has been in rapid development. By the end of 2009, the vehicle population in China is 62 million, and the new car sale for 2009 is 13.6 million, which makes China the largest auto market in the world[7]. The development of this industry is asymmetric; in particular, the market share of passenger vehicles has increased from 8.3% in 1990 to 75.7% in 2009, while the

[6] For example, Petrin (2002) estimates that gains from increased price competition due to the entry of Minivan may explain 43 percent of total consumer benefits.

[7] News release Sep. 4th, 2010, National development and reform commission of China.

market share of trucks declined from 52.8% to 16.5%, which reflecting a switch of this industry toward private cars[8].

The automobile industry of China is highly competitive. There are 171 manufacturers in this market and the total market share of the largest 5 firms accounts for 66.1 percent of sales in 2008 (see Table 2 for details). Among the top ten manufacturers, eight are joint-ventures with foreign car makers such as Volkswagen, BMW, Mercedes Benz, General Motors, Hyundai, Nissan, Honda, Toyota etc. Local brand only accounts for 25.92% of the market in 2008. Figure 1 displays the cooperation structure of China automobile market. The complex market structure and the nature of multi-ownership for the top manufacturers make it difficult for them to collude with each other. A strategic competition framework can model this market properly.

Our empirical analysis focuses on the light-duty passenger vehicle market, consisting of sedan, MPV, and SUV. This market accounts for 75.3% of the industry output of China. Most of the productions are for domestic consumption. The export of light-duty passenger vehicle is .24 million in 2008, which is less than 4.8% of the total production[9]. The import is about .15 million, which is negligible.

The consumption tax system and fuel tax

The final payment on a car includes three categories of tax in china: consumption tax, value added tax and vehicle purchases tax. These taxes are levied on manufacturers, retailers, and consumers respectively, although almost all taxes will be forwarded to consumers finally. Consumption tax started from 1994, targeting on goods with high values or resource consuming. The tax rates vary over the displacement tiers. Value added tax has been fixed at 17% since 1993 for the entire retailing sector. Vehicle purchase tax has also been fixed at 10% since 2001 until 2010 for all tiers of passenger vehicles. The computation for these three taxes is given below,

[8] China Automotive Industry Yearbook 2010.
[9] Annual report on automotive industry in China 2009.

$$p^m(1+t^c)\times(1+t^r)=p$$
$$Vpt=p^m(1+t^c)\times t^v$$

Where, t^c, t^v and t^r are tax rates for consumption, vehicle purchase, and value added tax respectively. p^m is the manufacture price, p is the list price, and Vpt is the extra vehicle purchase tax consumers have to pay on top of the list price. Since vehicle purchase and value added tax rates do not vary over different car models, and stay unchanged over time, so we ignore their impact in our study.

Fuel tax took effect in January 2009, after 15 years debate on it since 1994. In the 1990s, National People's Congress rejected proposals to use fuel tax to replace the road toll, which is collected by local governments. Local governments were concerned that they would lose out financially. Since 2000, implementation of fuel tax has been delayed because of sharp rises in the international oil price, with policymakers expressing concern that the tax will increase inflation. As air pollution has become a significant concern in China, the government finally decided to implement the fuel tax, aimed at facilitating energy saving and emission cut as well as the economic structural adjustment.

Therefore, both tax adjustments target on emission reduction, but their effectiveness has never been investigated. We will use the following empirical method to analyze their effects on environment and measure their social costs.

III. Empirical model and estimation method

Empirical framework

Consumers are assumed to choose a car from *N* models to maximize their utilities. The indirect utility function for consumer *i* purchasing product *j* is as follows,

$$\begin{aligned}u_j^i = const + (\beta_{ge}+\alpha_{ge}v_{ge}^i)GE_j + (\beta_{pw}+\alpha_{pw}v_{pw}^i)POWER_j + (\beta_{wg}+\alpha_{wg}v_{wg}^i)WEIGHT_j \\ +(\beta_p+\alpha_p v_p^i+\eta_{ge}inc^i)PRICE_j + \beta_{br}BR\_DUM_j + \xi_j + \varepsilon_j^i\end{aligned}$$

This indirect utility function assumes that consumers will make comparison in characteristics of the cars in their choice set. Some key car features, such as horsepower (POWER), weight, price, fuel efficiency and the place of origin of their brands (BR_DUM) are observable, while other features are not. So, we use ξ_j to indicate those features consumers will consider while making purchase decision, but are not observable in my data, and assume it follows a distribution with mean zero. Given the fact that consumers usually evaluate fuel efficiency in the way of expenditures on gas, it is assumed that their utility depends on gas expenditure (GE) which is the product of fuel consumption and the gas price measured in Chinese currency RMB yuan/liter, rather than fuel efficiency. By its construct, GE records consumers' expenditure on gas for a hundred-kilometer drive. If the average driven distance for a representative consumer is standardized to 100 kilometers per year, GE actually measures the total expenditure of a representative consumer on gasoline per year. Since consumers are heterogeneous in their driving patterns, we take into account this difference using variable v_{ge}, which is the ratio of an individual's idiosyncratic driven distance to the mean level. Similarly, individuals have idiosyncratic tastes on the other product characteristics, we denote these taste variations on power, weight, and price using v_{pw}^i, v_{wg}^i, and v_p^i respectively. Model parameters $\phi = (\alpha, \beta, \eta)$ describe consumer's preference on the car characteristics. Finally, we assume the idiosyncratic consumer taste ε_j^i follows a traditional type I extreme value distribution; therefore, the probability for consumer *i* to choose product *j* is given as,

$$S_{ij}\left(x_j, \theta \middle| v^i, inc^i\right) = \frac{e^{u_j^i}}{\sum_{k=0}^{N} e^{u_k^i}}$$, where x_j is a vector of all product characteristics.

And the market share for product *j* is given as,

$$S_j\left(x_j,\theta\right)=\int_B S_{ij}\left(x_j,\theta\middle|v^i,inc^i\right)dP(v)dP(inc) \qquad (1)$$

where, *B* is the set of consumers whose idiosyncratic tastes and income drive them to purchase product *j*.

On the supply side, manufacturers conduct differentiated Bertrand competition, so the profit maximization problem for manufacturer *f* producing J_f models can be formalized as,

$$\max_p \prod_f = \sum_{j\in J_f}\left(\frac{p_j}{\left(1+t_j\right)}-mc_j\right)MS_j\left(x_j,\theta\right)$$

Here, market size *M* is constant. Since car models with different displacement are exposed to different tax rate t_j, so the net income for manufacturers is $\frac{p_j}{\left(1+t_j\right)}$. The marginal cost mc_j does not change in output, but it varies across different car models, so it is a function of product characteristics w_j,

$$\ln(mc_j)=w_j\gamma+\omega_j$$

Since this function is in the log-linear form, so the parameters γ indicate the percentage change of marginal costs due to a particular car characteristic change.

The first order condition of the profit maximization problem gives the following equation,

$$\ln\left(\frac{p_j}{(1+t_j)}-\varpi_j(x,\theta,t)\right)=\ln mc_j=w_j\gamma+\omega_j \qquad (2)$$

where, $\varpi_j(x,\theta,t)$ is the markup of product j, and it should be a function of demand side variables, parameters and taxes for all car models. Equation (1) and (2) give rise to the equilibrium conditions in the market.

Estimation issues

We apply GMM estimation method proposed by BLP (1995) to estimate the parameters in equation (1) and (2) simultaneously. In short, we use the observed market share to recover the mean utility in equation (1), which is a function of consumers' mean preference β, the observed product characteristics, and unobserved product characteristics ξ_j. Then, our moment condition is $E\left(\begin{bmatrix}\xi(\beta,\alpha)\\ \omega(\eta)\end{bmatrix}\middle| Z\right)=0$, where Z is a set of instrumental variables described below. For the details of this method, readers can refer to BLP (1995). We will only discuss some important issues involved in the estimation process.

An important issue of this method is the computation of aggregate market shares. Following Nevo (2001), we make *ns* random draws from standard normal distribution to simulate the idiosyncratic consumer tastes, and make the same amount of random draws for a vector of household income and annual driven distance from a survey data. These random values are used to calculate the conditional choice probability for each individual, and then the unconditional market shares are derived using the average of the individual market shares given by $S_j\left(x_j,\theta\right)=\frac{1}{ns}\sum_{i=1}^{ns}S_{ij}\left(x_j,\theta\middle|v^i,inc^i\right)$.

Another issue is the choice of instrumental variables for the endogeneity problem of the price. In this study, we use three sets of instrumental variables: the product characteristics, the sum of corresponding characteristics over all the firms' other models, and sum of product characteristics over other firms' car models in a market. Nevo (2001) shows that these are valid instrumental variables which are independent of the unobservable characteristic terms but correlated with prices.

Finally, given the estimates of structure parameters, we use compensating variation

(CV) to calculate consumer surplus changes due to tax changes. For a logit discrete choice model on the demand side, Nevo (2000) shows that CV can be calculated as follows,

$$CV = \frac{M}{ns}\sum_{i=1}^{ns}\frac{\ln\{\sum_{j=0}^{N}\exp u_{j,post}^{i}\} - \ln\{\sum_{j=0}^{N}\exp u_{j,pre}^{i}\}}{(\beta_p + \alpha_p v_p^i + \eta_{ge} inc^i)}$$

IV. Data and summary statistics

This section describes three main sources of data used in this paper: 1) monthly car model sales from China Association of Automobile Manufacturers (CAAM); 2) product attributes collected from *Car Market Guide*; and 3) consumer demographic characteristics from a survey conducted to vehicle owners in Beijing by Guanghua School of Management at Beijing University of China in 2005. The summary statistics are listed in Table 3 - 4, respectively.

Households' income is reported as categorical data in interval scales as listed in Table 5. We use the average of each interval to represent the income of consumers falling into that interval. For the first and last interval, we choose RMB 1,000 and 100,000 respectively. In this way, the average household income corresponding to the mean statistics in Table 3 amounts to RMB8,300 per month[10]. The average distance travelled per year by Beijing car owners is about 22,000 kilometers, and 60% of the drivers travelled less[11]. This supports our intuition that the main purpose of purchasing a car is for daily commute in China. Therefore, the driving pattern is relatively inelastic to some exogenous shocks such as fuel price changes. These survey data are used to simulate the consumers in the China auto market. Considering the computation burden, we finally randomly draw a thousand vectors of these two variables to represent individuals' demographic information.

[10] The average household income is RMB4395 per month in Beijing 2005 (National Statistics Bureau of China). Given the fact that the survey targets on vehicle owners, this statistic is reasonable.

[11] Another survey conducted in Beijing, Shanghai, Guangzhou, Jinan and Hangzhou 2005 by Sinotrust, which is a leading consulting firm in China, shows that the 66.7% consumers mainly use car for business travel or daily commute from home to working place.

Product features are reported by *Car Market Guide*. We define a car model by the product characteristics including brand and the following model features. Horsepower is measured by Kilo-watts. $WEIGHT_j$ is the logarithmic of the car weight measured in Kilograms. Fuel consumption is a ratio given in liters/100km, which is used to construct the gas expenditure variable as described in the model section. Place-of-origin dummy variables for brands show that European, Japanese and American cars are most popular in China.

Monthly sale and price data from January 2004 until December 2008 are available from CAAM. Since the car feature data for 2006 is missing, so we have to drop the sales data for 2006 in our estimation. The total sale of car models for 2008 in our sample is 5.49 million, which accounts for 81.3% of the total passenger vehicles sale in China market. To derive the market share for each car model, we set the market size at the number of city-households who owned a house with more than three rooms, published in the Fifth National Population Census (2000) by the National Bureau of Statistics of China. This number is 17,963,399[12].

A stylized fact is most entry and exit of car models occurred in January or some month in the second half year. In other words, the competition structure over half-year interval is quite stable. Therefore, we aggregate the data into half year level and use the average monthly price and sale during each half year to measure their sale and price. In this way, we can include the truncated data and make comparison over 1297 car models. Large variation in both sale and price is observed. The most popular car model has a monthly sale of over nineteen thousands, while the minimum sale is only 12 units per month. The standard deviation in price is 123311.7, which is high relative to the average price of 168454.8.

V. Empirical results

[12] This number is arbitrary. Setting the market size at different number will mainly change estimate of the constant coefficient on the demand side since that will change the relative market share of each car model to the outside goods; however, the ratios of market share between different car models will not change.

In this section, we will first present the estimation results; then, we will report the empirical results for a counterfactual experiment to illustrate the impact of both consumption and fuel tax.

A. Estimation results

Estimates of the model parameters are listed in Table 6. All estimates for the mean utility function are significant with expected sign. Consumers prefer more powerful and larger size, but less fuel consuming cars. These findings coincide with most of the previous research (Bresnahan 1987, Greene and Liu 1988, BLP 1995 etc). In particular, the data statistic on driving distance shows that VMT is relatively inelastic in China; hence, it is assumed unchanged with vehicle choice and other exogenous factors such as fuel price. Therefore, variation of fuel expenditure on different car models reflects the physical difference in cars' fuel efficiency. The negative coefficient of fuel expenditure shows that efficient cars are more favorable.

On the cost side, all estimates are significant. Unlike the demand side, fuel consumption rather than fuel expenditure is incorporated into the marginal cost function. This is because cost per se only depends on the car features and production technology, but not on fuel prices. A negative sign indicates that a more fuel consuming cars costs less than a fuel efficient car. Coefficients of brand dummies are also positive and significant. This may imply that foreign brands invest more on characteristics other those included in our analysis.

Almost all the estimates for the idiosyncratic tastes and household demographic variation are insignificant, implying consumers are not so different in the car features in our study. But consumers do show variation in their sensitivity to price, although the estimate for standard deviation on the tastes for price (-0.1105) is less than one third of that for price in the mean utility (-0.3894). Estimation results also show that households with higher income are less sensitive to price changes, but this effect is not significant.

B. Counterfactual experiments

While studying the effectiveness and welfare effect of tax changes, it is necessary to control the market structure changes and keep technical surface unchanged pre and after tax changes. However, associated with tax changes, new entry of car models is observed. To disentangle the tax effect on the equilibrium prices and market shares from changes in competition environment, we conduct counterfactual experiment using the data for the period from September to December 2008, in which duration there are 252 car models in the market. We assume the market structure stay unchanged but tax scheme is set as before tax adjustment in April 2006, and then solve the equilibrium prices and market shares. Similarly, we also solve the equilibrium set for a scenario while gasoline is subject to a 30% fuel tax, while assuming consumption tax scheme unchanged.

a). Equilibrium price analysis

Figure 2 displays the simulated tax-inclusive price changes before and after tax adjustments. Apparently, the price of most fuel-efficient cars declines after consumption tax adjustment, while the price of those extremely fuel-consuming cars increases dramatically. However, similar trend is not observed for fuel tax. On the contrary, manufacturers of fuel-consuming cars either undercut their prices or keep them unchanged to compete with efficient cars after fuel tax.

A summary of price changes is listed in Table 7. Cars are categorized into various groups by their fuel consumptions; then, we calculate the average price changes due to tax adjustments for each group. Consumption tax adjustment has embodied in the auto prices: the average price for efficient cars lowers since the consumption tax rate for this section is lowered, while the average price for fuel consuming cars increases due to a higher consumption tax rate. Although manufacturers have already shared some tax burden (we will show the tax incidence below in detail), they have no capability to absorb all the tax, so the final prices for inefficient cars increases by a notable scale. Fuel tax causes adverse pattern in price changes. The reason is fuel tax affects fuel expenditures on different car models disproportionally. It raises the fuel cost on inefficient cars much more than the efficient models. To sustain their market share, the fuel-consuming manufacturers have to lower their prices. On the other hand, the efficient cars obtain advantage after fuel tax, so they can charge higher prices.

b). Tax incidence

Before investigating the impact of tax adjustments, we analyze the tax incidence first since this will give a rough picture about welfare transfer between consumers and manufacturers.

Since the tier of tax rates is set by displacement levels, we plot the percentage change of tax-inclusive prices versus car displacement in Figure 3. For cars with displacement lower than 1.5 liters, their effective tax rate is lower after adjustment. Consequently, we observe a negative change in price for most car models in this category. For cars with displacement between 1.5 to 2.5 liters, their tax-inclusive prices are not supposed to change since they are exposed to barely changed tax rates. However, the intensive competition in this category drove the prices of most models down more or less. So, actually manufacturers in this segment shared some tax burdens. For cars falling into the category of 2.5-3, 3-4 and above 4 liters, we are supposed to see their tax-inclusive price to increase by 4%, 16% and 30%, respectively, if manufacturers do not share any tax burden. Figure 3 shows that most manufacturers for cars below 4 liters just forwarded the tax burden to consumers directly. Only those producing large cars shared moderate taxes to sustain their market shares. Therefore, we expect to see consumers lose more than the producers from tax rate increases.

c). Impact and welfare analysis

The environmental effects of these two tax adjustments are expected to be different. Since the tax-inclusive prices benefit efficient cars in their market shares under consumption tax adjustment, so the market share weighted average fuel consumption is expected to decrease for this case. But it is ambiguous for fuel tax since the price changes reversely to the fuel expenditure. We summarize the share weighted average fuel consumption in the first column of Table 8.

Our results show that neither fuel tax nor consumption tax has significant effect on fuel efficiency[13]. However, the mean of fuel consumption decreased by .2% after consumption tax adjustment, while that for the fuel tax increased by .5%.

An interesting finding is the total consumption of fuel under various scenarios displays completely opposite trend (column 2)[14]. Fuel tax reduces total consumption of fuel by 16 billion liters, while consumption tax leads to an increase by .16 billion liters. How to reconcile the result on fleet average fuel consumption with that on the total fuel consumption? To answer this question, we need to look into the definition of these two measurements. The fleet average fuel consumption is a sale weighted average fuel consumption conditional on purchase; therefore, when the realized total sale decreases on a relatively larger scale than the average fuel consumption does, then the conditional average increases. In the case of fuel tax, consumptions on all fuel efficiency levels have dropped after tax since the expenditure on gas go beyond consumers' budgets, leading to sharp decline of total sale of cars while the sale distribution over fleet average fuel consumption does not change much (column 6 in Table 7). In the case of consumption tax, however, the decreased tax rate for the small displacement cars attracted more sales, leading to an increase of total sales, while the sale distribution skewed to efficient cars (column 5 in Table 7). Therefore, we observe an increase in the total consumption of fuel due to the decline of fleet size and an increase of average fuel consumption due to the drop off of marginal consumers under fuel tax, but observe completely opposite trends under consumption tax.

A natural question is: which measurement should we use to make a judgment on the

[13] The t-statistic for the difference in the mean of fuel consumption between the scenario pre and after consumption tax adjustment is .3.

[14] We use the randomly drawn annual vehicle miles driven in our demographic data part to calculate the market share weighted average total consumption of fuel for each car model and then sum them up to derive this number.

policies? The answer of this question depends on the assumption of the outside goods. When a consumer chooses not to purchase a car in our dataset, he may choose not to purchase, in which case his fuel consumption is zero, or choose to purchase a used car or any car outside of our data, in which case his fuel consumption may be even higher. Given the unavailability of used car data, we calculate the thresholds of fleet average fuel consumption for the outside goods, which makes the total consumption of fuel under the scenario of both taxes adjustment indifferent to each other, using below equation,

$$TFC_n^f + AMT_o * AFCO * (1 - \sum_j S_j^f) * M = TFC_n^c + AMT_o * AFCO * (1 - \sum_j S_j^c) * M$$

where, TFC_n^f and TFC_n^c are the total fuel consumption for new cars subject to fuel tax and sale tax respectively (as shown in column 3), AMT is the average distance traveled, $AFCO$ is the average fuel consumption of outside goods, $(1 - \sum_j S_j^f)$ and $(1 - \sum_j S_j^c)$ are the market shares of outside goods under fuel and consumption taxes respectively. Since AMT is available from our demographic data sample, so $AFCO$ can be solved from above equation. Similarly, we solve the threshold of average fuel consumption for consumption tax to reduce total consumption of fuel relative to no-tax case.

Figure 4 illustrates the savings in total consumption of fuel under both taxes. Our results show that when the average fuel consumption for the outside goods is above 3.30 liters/100km, then consumption tax is effective to lower the total consumption of fuel, compared to the case without tax; when it is below 6.62 liters/100km, then fuel tax can save total consumption of fuel. When the average fuel consumption of the outside goods is below 6.55liters/100km, fuel tax works better than consumption tax in lowering total consumption of fuel. Intuitively, if consumers who choose the outside options are more likely to consume an inefficient car, then policy leading to less total sale of new cars will become worse even if it saves the consumption of fuel on new cars. For instance, assuming the average fuel consumption for used cars is 10 liters/100km, then only if the chance for an outside goods consumer to choose a used car is below 65.5% will make fuel tax more efficient than consumption tax.

On the other side, both taxes lead to consumer welfare loss, but they are quite different in magnitude and welfare re-distribution (column 3-6). The welfare loss due to consumption tax adjustment (4 million) is about four orders of magnitude less than that caused by fuel tax (13.1 billion). More importantly, fuel tax leads to a consumer welfare loss (8.07 billion) in an order of magnitude more than the loss from a consumption tax (199 million). Same pattern is observed to the manufacturers' profit, while the government's tax income increases by 562 million from fuel consumption, even using the number of fuel tax for one year. In other words, both taxes result in welfare re-distribution among economic principals, but fuel tax transfers welfare from private sector to the government in a much larger magnitude.

d). Tax progressivity

Policy makers are usually concerned about the distributional effect of a tax. Most economists and policy makers support a progressive tax system, since 'it is not very unreasonable that the rich should contribute to the public expense, not only in proportion to their revenue, but something more than in that proportion'[15]. To measure the progressivity, we construct the Lorenz curves proposed in Suits (1977). Figure 5 illustrates the distributional effect of both taxes over household income. It shows that the percentage of tax burden borne by the lowest income groups is higher than their share of total income for both taxes, so the curves arch above the diagonal equity line, which is similar to the sales and excise taxes in the States shown in Suites (1977).

Our findings coincide with West (2004) in that both consumption tax and fuel tax are regressive[16]. However, West (2004) finds that gas or miles taxes are significantly less

[15] Adam Smith, *The Wealth of Nations.*

[16] West (2004) concludes that fuel tax is progressive over the bottom half of the income distribution but regressive over the wealthiest half of the income distribution. Since our study is targeted on car owners, who belong to the wealthy group in China, so our findings actually support his.

regressive than size taxes, but our findings suggest that consumption tax based on the size of displacement is less regressive than the fuel tax for lower income group, and this relationship reverses for higher income group.

VI. Conclusion

We found that fuel tax is more costly than sale tax in increasing the fuel efficiency level because the consumption tax leverages tax payment on different displacement automobiles: subsidizing small displacement cars with tax income from large cars while fuel tax equates the marginal costs of reducing fuel consumption across all uses (Crandall 1992). So, the consumption tax is more efficient to induce consumers to choose fuel efficiency cars, making the sale distribution skewed toward efficient cars; while the sale distribution over fuel efficiency keeps unchanged in the case of fuel tax adjustment. However, fuel tax decreases the total sale of new cars, while consumption tax adjustment actually enlarges the total sale a little bit. Therefore, they have opposite effect on the total consumption of fuel. Their total effects on the environment, however, depend on the average fuel efficiency of the outside goods. As long as the portion of outside-goods consumers who finally purchase a more fuel-consuming car is not large, then fuel tax works better in lowering the total consumption of fuel.

Our fairness study shows that consumption tax is less regressive than the fuel tax for low income consumers. Moreover, it does not reduce consumer surplus as much as fuel tax. But considering the externality of savings in fuel consumption, the welfare loss due to fuel tax should be much lower.

However, our conclusion relies on one assumption: we assume the driving pattern will not change even when consumers are exposed to 30% fuel tax. Considering the fact that main purpose of driving in China is business transportation, the first assumption is reasonable. Kahn (1996) finds that "emissions reduction has occurred even though total vehicle miles travelled has more than doubled," and his explanation about this phenomenon is that emissions fall when new-car emissions regulation becomes more stringent. This also supports our assumption about travel pattern since his finding proved that regulation on fuel efficiency is more efficient than policies affecting driving patterns in reducing emissions.

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Table 1 Adjustments of Consumption Tax Rates on Vehicles in China

Effective since	Displacement (L)						
	≤1.0	1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-4.0	≥4.0
1994	3%	5%	5%	5%-8%	8%	8%	8%
Apr. 1st 2006	3%	3%	5%	9%	12%	15%	20%
Sep. 1st 2008	1%	3%	5%	9%	12%	25%	40%

Table 2 The market shares for top 10 manufactures in China auto industry

Rank	Manufacturers	Market Share (%)
1	SAIC(Shanghai Auto Industry Cooperation)	18.3
2	FAW	16.3
3	DFM(Dongfeng Motor Cooperation)	14.1
4	CHANA(Changan Automobile)	9.2
5	BAW(Beijing Automobile Works Co.,Ltd)	8.2
6	GAIG(Guangzhou Auto Industry Cooperation)	5.6
7	Cherry	3.8
8	Brilliance Auto	3.0
9	Hafei Automobile Group	2.4
10	Geely Holding Group	2.4

Table 3 Summary statistics for households' income and annual vehicle miles travelled

Variable	Obs	Mean	Std.	Min	Max
Household income (RMB yuan)	7809	6.65	2.37	1	12
Annual mileage (kilometers)	7809	22096.02	13717.84	2880	105000

Table 4 Summary statistics for key product characteristics and sale

Variable	Obs	Mean	Std.	Min	Max
Horsepower (kw)	1297	92.19	33.44	26.50	257.00
Displacement (liters)	1297	1.90	0.62	0.80	4.70
Weight (kg)	1297	1342.23	297.34	645.00	2590.00
Fuel Consumption (litres/100km)	1297	6.94	1.96	3.60	21.70
American	1297	0.12	0.32	0.00	1.00
Japanese	1297	0.24	0.43	0.00	1.00
Korean	1297	0.08	0.27	0.00	1.00
European	1297	0.26	0.44	0.00	1.00
Sale	1297	2335.30	2751.26	12.00	19185.40
Price (yuan)	1297	168454.80	123311.70	28800.00	856300.00

Table 5 Interval scales for household income

M1 What is your monthly household income before tax? (RMB)	
1. 2,000 or below	2. 2,001-3,000
3. 3,001-4,000	4. 4,001-5,000
5. 5,001-6,000	6. 6,001-8,000
7 .8,001-10,000	8. 10,001-15,000
9. 15,001-20,000	10. 20,001-50,000
11. 50,001-80,000	12. 80,000 or above

Table 6 Estimates of the full model

Variables	Utility function (β, α, η)	Marginal cost function (γ)
Mean	β	
Constant	-23.3938** (3.9116)	-15.6213** (3.6280)
Power	0.0263** (0.0063)	0.0075** (0.0009)
Weight	2.5476** (0.6906)	2.4769** (0.5055)
Gas expenditure	-1.0251** (0.2701)	
Fuel consumption		-0.3561** (0.0890)
Price	-0.3894** (0.0895)	
American	1.2617** (0.1678)	0.4462** (0.0813)
Japanese	1.3903** (0.1718)	0.5110** (0.0779)
Korean	0.4670* (0.2246)	0.3976** (0.0770)
European	1.5093** (0.1979)	0.7267** (0.1056)
Standard deviation of idiosyncratic tastes	α	
Power	0.0010 (0.0100)	
Weight	0.0015 (0.1216)	
Gas expenditure	0.0011 (0.1349)	
Price	-0.1105** (0.0306)	
Interactions with household income	η	
Price	0.0013 (0.0014)	

Note: * and ** indicate 5% and 1% level of significance, respectively. In bracket are the standard errors.

Table 7 Summary of price changes due to tax adjustments

Fuel consumption category (liters/100km)	**# of car models**	**Price changes due to (%)**		**Total sale changes due to (%)**	
		Consumption tax	Fuel tax	Consumption tax	Fuel tax
(0,5]	18	-0.6192	0.3272	0.98	-22.68
(5,6]	57	-0.4657	0.1983	1.18	-21.92
(6,7]	74	-0.2341	0.1225	0.44	-21.51
(7,8]	54	0.0212	-0.1297	-0.14	-20.48
(8,max)	49	1.8531	-0.2305	-1.19	-18.31

Table 8 Impacts of consumption and fuel tax

(FT, CT)[a]	**Mean fuel consumption** (liters/100km)	**Total fuel consumption** (10 billion liters)	**Firm profit**	**Consumer surplus**	**Consumption Tax** (unit: RMB 10 billions)	**Fuel tax**	**Social welfare[c]**
(1,0)[b]	6.6612	5.9563	1.8612	3.4204	0.3163	.1310	5.5979
(0,0)	6.6264	7.5581	2.2891	4.2274	0.3911	--	6.9076
(0,1)	6.6071	7.5744	2.2791	4.2075	0.4206	--	6.9072

Note: a. FT – fuel tax, CT – consumption tax; b. the binary variable indicates whether a tax is imposed: 1 yes, 0 no. c. since fuel tax is a transfer from consumers to government, so it is not included in social welfare.

Figure 1 The joint-venture structure for the major auto manufacturers

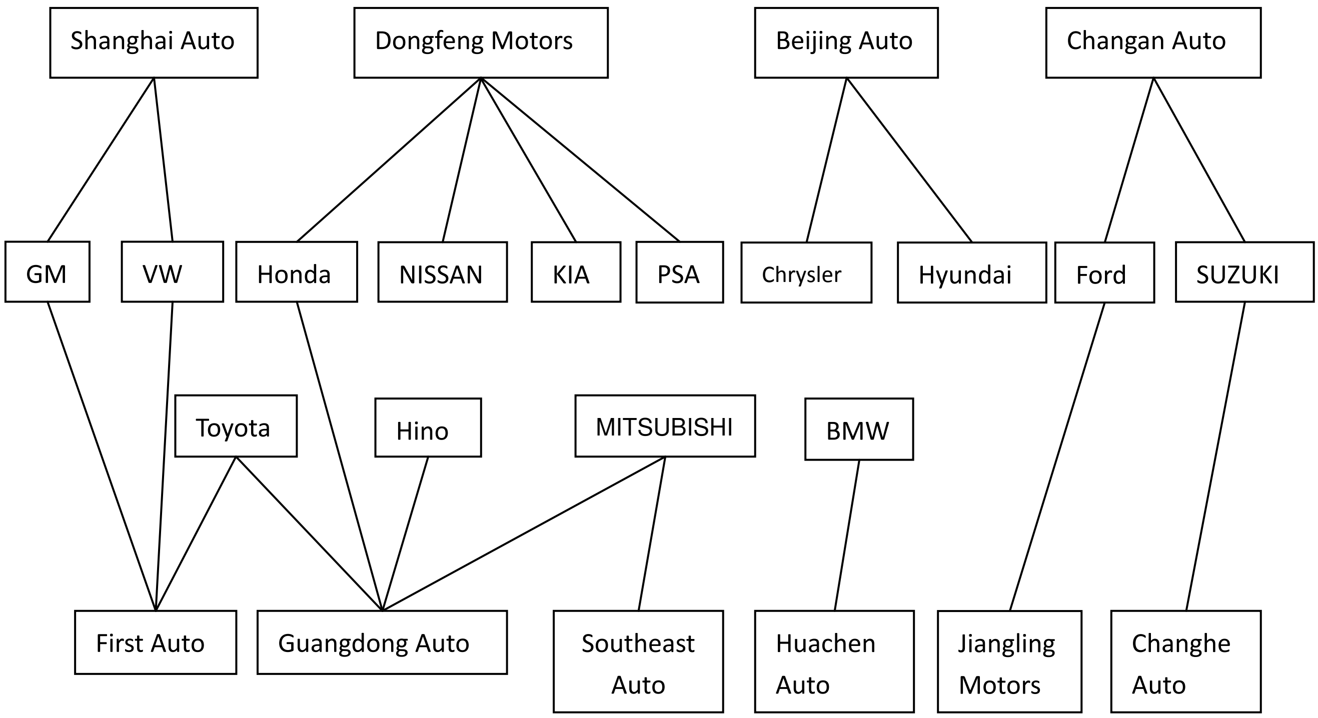

Figure 2(a) Percentage price changes due to consumption tax adjustment by fuel consumption levels

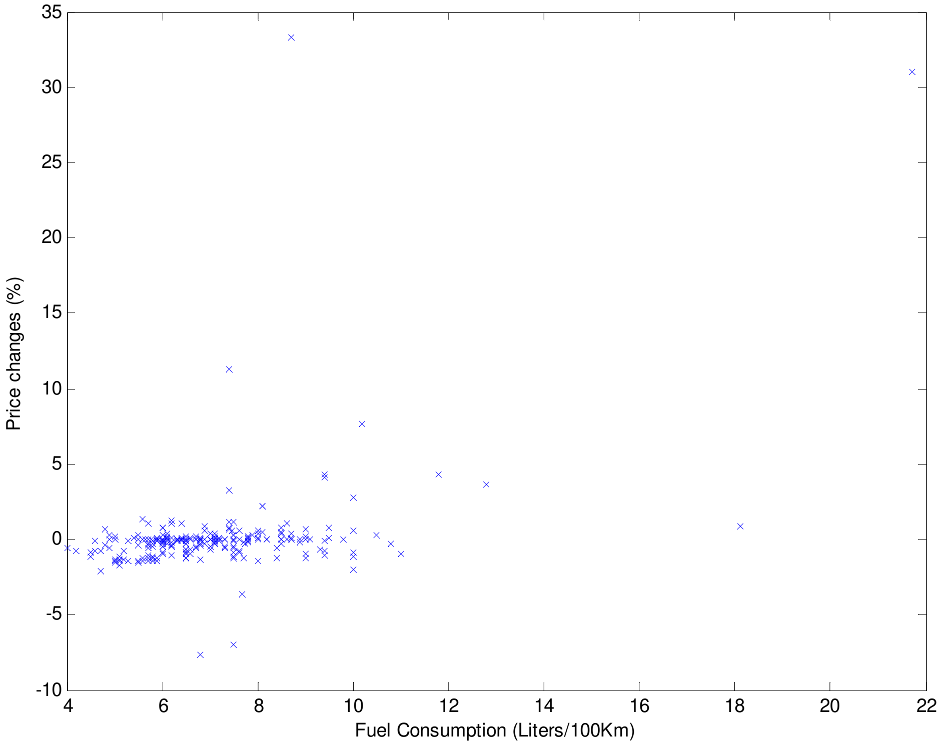

Figure 2(b) Percentage price changes due to fuel tax adjustment by fuel consumption levels

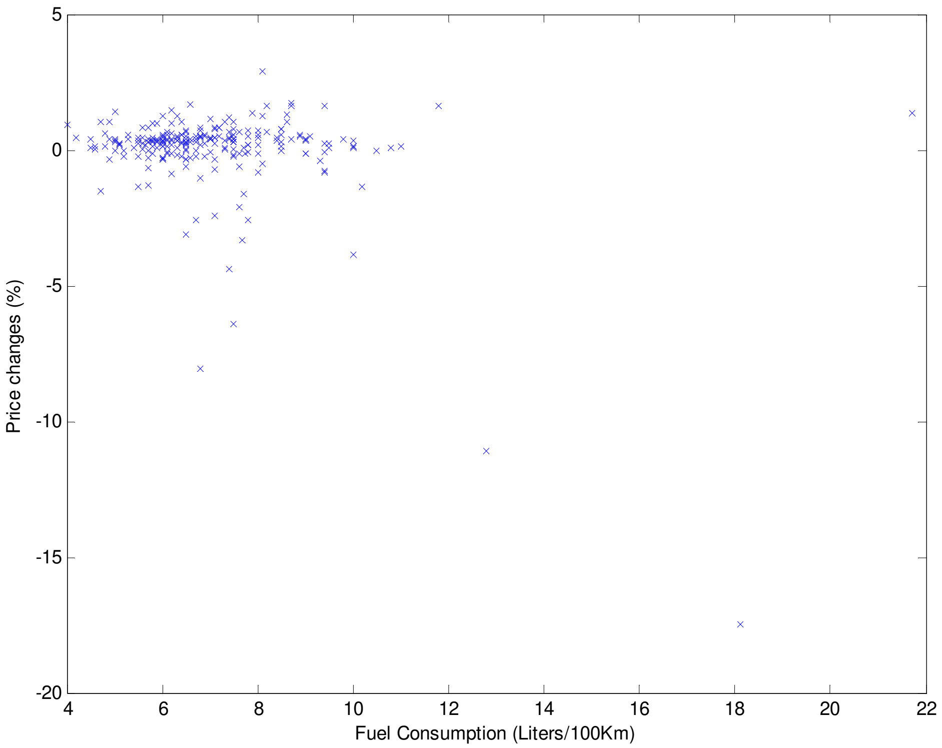

Figure 3 Tax-inclusive price changes due to consumption tax by displacement

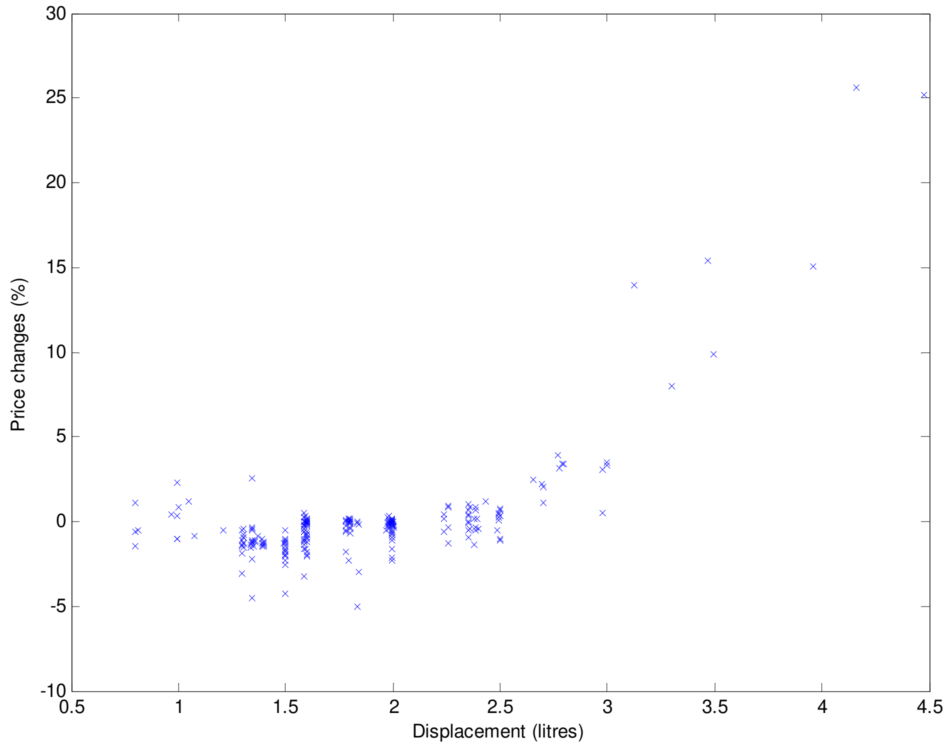

Figure 4 Savings of total consumption of fuel due to taxes

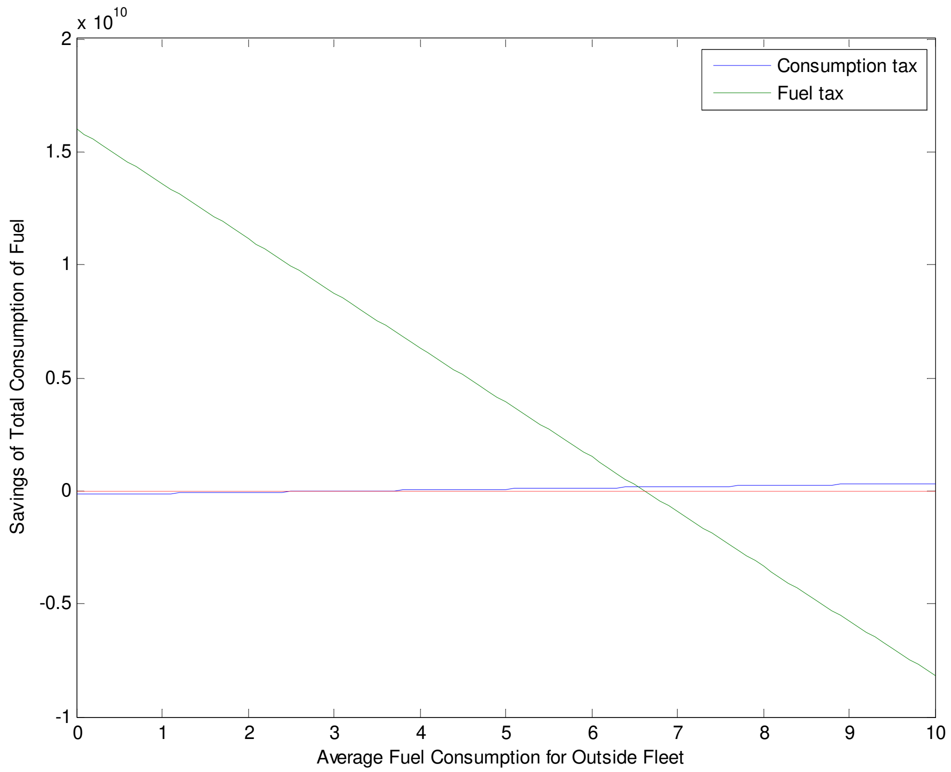

Figure 5 Lorenz curves for consumption tax and fuel tax