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Energy pricing reform and energy efficiency in China: Evidence from the automobile market☆

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ABSTRACT

Promoting energy efficiency by undertaking a market-oriented reform of the energy-pricing mechanism is one of the top priorities of China's ongoing reform effort. In this study, we examine the impacts of China's gasoline-pricing reform implemented in January 2009 on the fuel economy of the country's new automotive fleet. In particular, we distinguish the effects of two common elements of China's energy-pricing reform packages: the effects of the energy tax increase (i.e., the gasoline tax increase) and the effects of the energy-pricing mechanism reform (i.e., the adoption of a market-oriented pricing scheme for gasoline). By exploiting a rich dataset of monthly new passenger vehicle sales at the vehicle-model level in China between 2008 and 2013, we are able to control for potential correlations between unobserved product and consumer characteristics and products' fuel efficiency. Our empirical results infer that fuel costs have a significant influence on new vehicle sales in China, while the presented policy simulations suggest that the gasoline-pricing reform in China has led to an approximately 6.25 percent increase in new vehicle fuel economy. Moreover, the two major elements of the reform, the gasoline tax increase and expedited adjustment cycles for gasoline prices, make similar contributions to the increase in the new vehicle fleet's fuel economy, with the former contributing 3.43 percent and the latter, 2.82 percent.

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1. Introduction

Although China has been reforming toward a market economy for more than 30 years, such reforms have only just begun in certain sectors. The energy sector is one example of where the government still heavily regulates prices, such as those of electricity and natural gas (Fan et al., 2007). However, China has started to reform its energy-pricing scheme with the aim of letting the market have greater influence and therefore giving consumers suitable economic incentives for their energy consumption decisions (Zhou et al., 2010). How these reforms to the energy-pricing scheme affect energy efficiency in downstream sectors has important implications for policies that aim to address the host of challenges related to energy consumption in China, such as energy independence, air pollution, and climate change (Adams and Shachmurove, 2008).

In this study, we investigate how the market-oriented reform of the energy-pricing mechanism in China affects its energy efficiency in the context of the country's automobile industry. Specifically, by using a dataset of monthly new passenger vehicle sales in China from January 2008 to August 2013, we study how gasoline-pricing mechanism reform affects the fuel efficiency of China's new vehicle fleet. We first estimate the sensitivity of new vehicle sales to changes in gasoline prices and then evaluate through simulations how the reform of the gasoline-pricing mechanism affects the average fuel efficiency of the country's new automotive fleet. Specifically, we quantify the effects of two elements of China's major gasoline-pricing reform implemented in January 2009: gasoline tax changes and the adoption of expedited adjustment cycles for gasoline prices.

We use gasoline prices and the automobile market in China as our research context for two reasons. First, China is the world's second largest oil consumer after the United States, while its oil market was one of the first in the country's energy sector to undergo market-oriented pricing reforms (Lin and Liu, 2013). Therefore, the gasoline-pricing scheme in China provides us with an ideal opportunity to study the impact of a market-oriented pricing-scheme reform in China's energy sector.

Second, the effect of gasoline prices on the fuel economy of new automobiles is central to the evaluation of the ongoing efforts to reduce gasoline consumption in China. China's new automobile market has grown dramatically during the past 15 years, surpassing that of the United States in 2009 to become the world's largest (Hu et al., 2014). Oil consumption by automobiles is expected to account for two-thirds of the country's total oil consumption by 2020 (Lin and Liu, 2013). As a response to such a rapid increase in oil consumption by automobiles, China has steadily raised gasoline tax in the past several years.[1] Evaluating such energy-saving measures requires the accurate estimation of the effect of gasoline prices on the average fuel economy of the country's new automotive fleet.

With our analysis, our work makes two main contributions to the growing body of research studying the effect of energy-pricing reforms on energy efficiency in China. First, to the best of our knowledge, we are among the first studies to distinguish the effects of two common elements of China's energy-pricing reform packages: the effects of energy tax changes (e.g., the gasoline tax increase) and the effects of the energy-pricing mechanism reform (e.g., the adoption of a market-oriented pricing scheme for gasoline).

Second, by using a rich dataset of new passenger vehicle sales in China, we are able to examine the impacts of China's energy-pricing reform on energy efficiency at the *product* level, and we are able to circumvent one major challenge faced by most existing studies that use aggregated industry-level data to quantify the effects of energy-pricing reforms on energy efficiency in China (e.g., Hu and Wang, 2006; Jiang et al., 2014; Wei et al., 2009). Studies using aggregated data are not able to account for the possible correlation between energy efficiency (e.g., vehicles' fuel economy) and unobserved consumer and product (e.g., vehicles) characteristics (Li et al., 2009). For example, in the context of automobile demand, as household incomes increase, consumers tend to prefer vehicles with higher power and better functionality (e.g., SUVs), which are typically fuel inefficient. Ignoring such correlations would result in biased estimates of the effects of energy prices on energy efficiency. Our study, as we elaborate on later, follows Klier and Linn (2010) by using a simple yet flexible strategy to

[1] The Chinese government raised gasoline tax from 0.2 to 1.0 RMB\l in January 2009, and increased it further to 1.12, 1.40, and 1.52 RMB\l in November 2014, December 2014, and January 2015, respectively.

account for such correlations between vehicles' fuel economy and unobserved consumer and vehicle characteristics, which have been ignored in most previous works.

In this study, we estimate a simple linear regression in which the monthly sales of individual new vehicle models depend on vehicle and consumer characteristics as well as on expected fuel costs. The expected fuel costs of each vehicle model are determined by both gasoline prices and the model's fuel economy, while changes in gasoline prices lead expected fuel costs for each vehicle model to vary. Therefore, we quantify the effects of changes in gasoline prices on each vehicle model's sales by using the estimated sensitivity of vehicle sales to expected fuel costs. The changes in individual vehicle sales due to gasoline price changes then lead to changes in the composition of the new vehicle fleet and therefore in its average fuel economy.

Using a linear regression allows us to control for unobserved product and consumer characteristics because, in the automobile industry, neither observed (e.g., vehicle size) nor unobserved characteristics (e.g., interior design) vary within a model-year. For example, the observed and unobserved characteristics of the 2011 Volkswagen Passat sedan did not change during the entire 2011 model-year (i.e., before the 2012 Passat was available). Our empirical specification thus exploits such a feature to estimate the effects of gasoline prices on the sales of individual vehicle models by using within model-year changes in monthly gasoline prices and vehicle sales.

We find that the major gasoline-pricing reform implemented in 2009 in China has significantly affected new vehicle sales. Specifically, we find that new vehicle sales in China became more sensitive to gasoline prices after the implementation of the gasoline-pricing reform that raised gasoline tax and increased the adjustment frequency of gasoline prices. The simulation results show that the reform has led to an approximately 6.25 percent increase in the fuel economy of China's new automotive fleet. Meanwhile, we find that the 0.8 RMB/l increase in gasoline tax has generated a 3.43 percent increase in fleet fuel economy, while the expedited adjustment frequency of gasoline prices since 2009 has led to a 2.82 percent increase in fleet fuel economy.

The remainder of the paper is organized as follows. Section 2 briefly reviews the related literature. Section 3 describes the background of the 2009 gasoline-pricing reform in China. Section 4 outlines our empirical and identification strategies. Section 5 describes our data. Section 6 presents our empirical results. Section 7 concludes.

2. Literature review

Our study is related to two bodies of literature. First, it is related to the small body of work that studies the effects of gasoline prices on fuel efficiencies in China's automobile market using *aggregate*-level data. These studies usually estimate reduced-form models, where the fuel consumptions or efficiency measures of the vehicle fleet are regressed on gasoline prices by exploiting aggregate time-series data (Lin and Liu, 2013; Wang et al., 2007), or panel data at China's province level (Auffhammer and Carson, 2008; Wei et al., 2009). As discussed above, following Klier and Linn (2010) and by using panel data at the *product* level, our study extends previous research by allowing for the possible correlation between energy efficiency (e.g., vehicles' fuel economy) and unobserved consumer and product (e.g., vehicles) characteristics, which have been ignored in the studies mentioned above. Moreover, we extend the previous works by studying the effects of the expedited adjustment cycle of gasoline prices in China on new vehicles' fuel efficiency. Such government-regulated, "semi"-market based adjustment mechanism of energy prices is a unique feature of China's energy market.

Second, our study also contributes to the body of knowledge on the features of China's automobile industry, such as its market structure (Deng and Ma, 2010), the ownership structure of manufacturers (Hu et al., 2014), vehicle price evolution (Li et al., 2015), and vehicle tax changes (Xiao and Ju, 2014). The study most closely related to ours is Xiao and Ju (2014), which examine the effects of a gasoline tax increase on fleet fuel economy and consumer welfare in China. Our research differs from theirs in two major aspects. First, Xiao and Ju (2014) only consider the effects of a gasoline tax adjustment on vehicles' fuel economy, while we extend their study by also examining the effects of another important element of gasoline-pricing reform in China, i.e., the expedited adjustment cycle of gasoline prices after 2009. Second, we relax the assumption in Xiao and Ju (2014) that vehicles' fuel efficiency is exogenous

Table 1
Overview of the gasoline-pricing reform in 2009.

Elements of the reform	Before the 2009 oil pricing reform (before January 2009)	Since the 2009 oil pricing reform (since January 2009)
How gasoline is priced	Gasoline prices are adjusted if the oil price in the international market changes by more than 8 percent, but the government has not strictly committed to such a schedule.	Gasoline prices are adjusted when the oil price in the international market changes by more than 4 percent over 22 working days. The adjustment schedule is much more strictly enforced.
Fuel tax	0.2 RMB\l	1.0 RMB\l
Road maintenance fees	Varies across provinces, but it is a fixed amount per vehicle per month, independent of driving distance. National average: 170 RMB/month per vehicle.	None

Note: The oil price in the international market refers to the average price for Brent, Dubai, and Cinta crude oils.

and allow it to be correlated with vehicles' unobserved characteristics and unobserved consumer characteristics.

Finally, our study is related to those that examine the effects of various factors on vehicles' fuel efficiencies using *product*-level data, such as government support for hybrid vehicles (Beresteanu and Li, 2011), obesity rate (Li et al., 2011), and gasoline taxes (Li et al., 2014). These studies, however, all focus on the automobile market in the United States, and we contribute to this stream of research by studying the effect of gasoline-pricing reforms on vehicles' fuel efficiency in China, which has the largest automobile market (Li et al., 2015) and is the second largest oil consumer (Lin and Liu, 2013) in the world.

3. Background

In the past two decades, China has conducted several market-oriented reforms on its gasoline-pricing mechanism. Before 1998, the retail price of gasoline was controlled by the government and was *not* adjusted according to market conditions (Fan et al., 2007). In 1998, China started to reform the gasoline-pricing mechanism, allowing the domestic gasoline price to adjust when the oil price in the international market changed by more than 8 percent. However, as the Chinese government was concerned about the negative impacts of a higher gasoline price on the economy, this pricing reform was not strictly enforced. For example, the oil price in the international market increased by more than 50 percent from approximately 90 to 140 dollars per barrel from January and June 2008, during which time the Chinese government only raised the domestic oil price once (in June and by only 20 percent) to about 80 dollars per barrel. Later, the oil price in the international market decreased to about 40 dollars per barrel from June to December 2008, while the Chinese government only lowered the domestic oil price once (in December 2008) to about 45 dollars per barrel. Therefore, throughout 2008, the domestic oil price in China was only adjusted twice even though the oil price in the international market rose by 50 percent and declined by 70 percent during the same period.

In January 2009, the Chinese government introduced a much more comprehensive reform package for the gasoline-pricing mechanism, including two important measures (see Table 1). The first was to abolish the road maintenance fees fixed for each vehicle regardless of driving distance and instead raise gasoline tax from 0.2 RMB to 1 RMB\l. Therefore, the tax burden was no longer fixed for each driver but instead proportional to driving distance. The second measure was to introduce a gasoline-pricing scheme with a much more expedited adjustment cycle. This measure allowed domestic prices to be adjusted when oil prices in the international market changed by more than 4 percent over 22 working days.[2] Further, such an adjustment cycle was much more strictly enforced than before, resulting in much more frequent adjustments to the gasoline price in China after 2009 (see Fig. 1).

[2] In March 2013, the adjustment cycle was shortened to 10 working days.

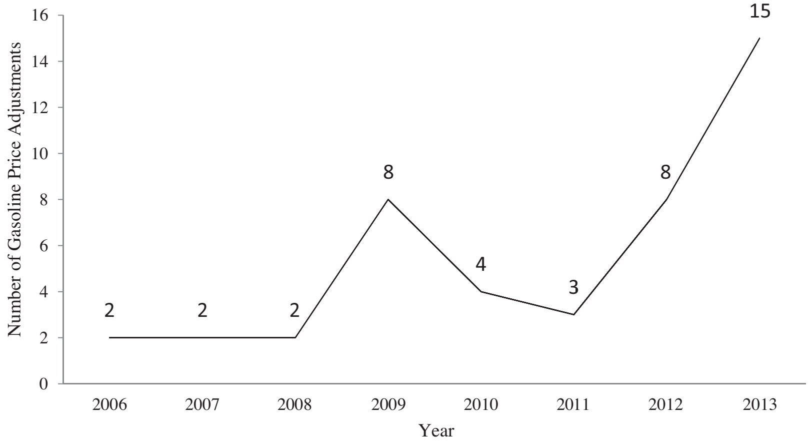

Fig. 1. Gasoline price adjustment in China: 2006–2013. *Note*: The figure depicts the number of gasoline price adjustments in China between 2006 and 2013. The data are compiled according to the announcement by the National Development and Reform Committee of China.

4. Empirical framework

In this section, we first describe the econometric model that we use to estimate the sensitivity of new vehicle sales to changes in gasoline prices, which is the starting point of our empirical analysis.

4.1. Econometric specification

4.1.1. Vehicle sales

We follow Klier and Linn (2010) by estimating the sensitivity of vehicle sales to gasoline prices through the following reduced-form equation between new vehicle sales, vehicle and consumer characteristics, and fuel costs:

$$\ln\,(q_{jt}) = X_{jt}\beta + \gamma FuelCost_{jt} + \xi_{jt} + \mu_{jt} \tag{1}$$

where q_{jt} is the sales of vehicle model j at time t (i.e., a month); X_{jt} is a vector that contains observed vehicle characteristics such as vehicle manufacturers' suggested retail prices (MSRPs), weight, length, and horsepower; $FuelCost_{jt}$ is expected fuel costs during the entire lifecycle of vehicle model j in month t; ξ_{jt} represents vehicle characteristics that are observed by consumers and manufacturers but not by the researcher (e.g., vehicle quality, handling, and safety features); and μ_{jt} represents the effects of unobserved consumer characteristics on vehicle sales (e.g., households with children tend to have larger vehicles). β and γ are coefficients. Our central interest is the identification and estimation of γ, the sensitivity of vehicle sales to fuel costs.

4.1.2. Expected fuel costs

To estimate Eq. (1), we first specify how we model expected fuel costs $FuelCost_{jt}$. First, for vehicle model j, its expected fuel costs in any particular period s equal the distance (in kilometers) driven in that period, D_s, multiplied by its fuel costs per kilometer, CPK_{js}. Its lifetime expected fuel costs at time t, $FuelCost_{jt}$, therefore equal the total discounted expected fuel costs in all periods during the T periods of the vehicle's lifecycle:

$$FuelCost_{jt} = \sum_{s=t}^{t+T} \frac{1}{(1+r)^s}(CPK_{js})D_s \tag{2}$$

where r is the discount rate.

Second, vehicle j's fuel costs per kilometer, CPK_{js}, equal the expected gasoline price in period s, $GasPrice_s^e$, divided by the fuel economy of vehicle j in terms of kilometers per liter of gasoline, KPL_j. Therefore, Eq. (2) can be further written as

$$FuelCost_{jt} = \sum_{s=t}^{t+T} \frac{1}{(1+r)^s} \left(\frac{GasPrice_s^e}{KPL_j} \right) D_s \tag{3}$$

To simplify Eq. (3), we follow the literature on automobile demand (e.g., Berry et al., 1995; Li et al., 2009) by assuming that the gasoline price follows a random walk, meaning that, at time t, the expected gasoline price in any period $s > t$, $GasPrice_s^e$, equals the gasoline price at time t, $GasPrice_t$.[3] Therefore, from Eq. (3), total expected fuel costs $FuelCost_{jt}$ are proportional to the current gasoline price, $GasPrice_t$, divided by the fuel economy of the vehicle, KPL_j, while the ratio is actually the fuel costs per kilometer of vehicle model j at time t, CPK_{jt}:

$$FuelCost_{jt} \propto \frac{GasPrice_t}{KPL_j} \equiv CPK_{jt} \tag{4}$$

By replacing $FuelCost_{jt}$ in Eq. (1) with Eq. (4), we obtain

$$\ln\ (q_{jt}) = X_{jt}\beta + \gamma CPK_{jt} + \xi_{jt} + \mu_{jt} \tag{5}$$

4.2. Identification

The key parameter to estimate in this study is γ in Eq. (5), and the major challenge to the identification of γ is that expected fuel costs per kilometer CPK_{jt} in Eq. (5) may be correlated with either unobserved vehicle characteristics ξ_{jt} or unobserved consumer characteristics μ_{jt}. For example, vehicles with higher fuel economy (i.e., higher KPL_j) have lower fuel costs, but they also tend to have smaller engines and thus less satisfactory vehicle handling performance, which is an unobserved characteristic and therefore included in ξ_{jt}. Meanwhile, households with children tend to purchase larger and heavier vehicles, which tend to be safer but less fuel-efficient compared with smaller vehicles. However, whether a household has children is unobserved in our dataset and therefore included in μ_{jt}.

Previous research on the automobile market in China largely avoids these issues by assuming that vehicles' fuel costs are uncorrelated with either observed and unobserved vehicle or consumer characteristics. In this study, we adopt the identification strategy put forward in Klier and Linn (2010) to account for the presence of unobserved vehicle and consumer characteristics.

Automobile manufacturers usually change the characteristics of a vehicle model once a year, from a minor interior make-up to a complete overhaul. Meanwhile, manufacturers also adjust the MSRP of the vehicle model along with these changes. These changes in MSRP and other characteristics separate the so-called model-year for the same vehicle model, such as the 2009 and 2010 Volkswagen Passat sedans. However, between two consecutive model-years, the MSRP and features of a vehicle model remain constant. For example, the features of the 2009 Volkswagen Passat (i.e., the 2009 model-year) remain the same until the 2010 Passat (the 2010 model-year) is launched into the market. Therefore, if we introduce the model-year fixed effects θ_{jy} for each vehicle model j and model-year y, the variable should absorb both observed and unobserved vehicle characteristics as well as the mean (unobserved) consumer characteristics over the model-year. That is,

$$\theta_{jy} = X_{jt}\beta + \xi_{jt} + \bar{\mu}_j \tag{6}$$

On the contrary, throughout a particular model-year, which is usually 12 months, the gasoline price varies month to month and the fuel costs of the vehicle model thus also vary. Therefore, introducing θ_{jy} does not absorb CPK_{jt} in Eq. (5). Finally, we also include in Eq. (5) month dummies, τ_t, to control for the seasonality of vehicle demand.

[3] We relax this assumption later in our estimation and obtain similar results to those under the random walk assumption.

Table 2
Summary statistics.

Variable	Observation	Mean	Standard deviation	Min	Max
Monthly sales	131,872	330.54	1056.15	1	70,593
Real gasoline price (RMB/l, 93# unleaded gasoline, CPI = 1 in January 2008)	131,872	6.79	3.36	5.34	7.63
Fuel economy (liter/100 km)	131,872	8.71	2.03	4.30	19.70
Fuel costs (RMB\km, CPI = 1 in January 2008)	131,872	0.60	0.15	0.27	1.55

Substituting Eq. (6) into (5) and adding month dummies τ_t yields our estimating equation:

$$\ln(q_{jt}) = \theta_{jy} + \gamma CPK_{jt} + \tau_t + \varepsilon_{jt} \quad (7)$$

where $\varepsilon_{jt} = \mu_{jt} - \bar{\mu}_j - \tau_t$. Note that $\bar{\mu}_j$ is time-invariant within a model-year and τ_t is the same across all vehicle models in a given month. Therefore, ε_{jt} measures the effects of unobserved consumer characteristics that are both time-variant within a model-year and that disproportionally affect demand for different vehicle models in a given month. Therefore, the assumption we maintain to estimate Eq. (7) consistently is that ε_{jt} is exogenous to changes in fuel costs CPK_{jt} within a model-year.

The coefficient of interest γ therefore is identified by both the time-series variations in gasoline prices ($GasPrice_t$) and the cross-sectional variations in a vehicle's fuel economy (KPL_j). For example, when $GasPrice_t$ increases, the rise in expected fuel costs (CPK_{jt}) because of higher KPL_j is smaller than that for vehicles with lower KPL_j.

One concern related to our identification strategy is that we do not observe actual transaction prices for the vehicles sold during our sample period, but only the MSRPs for each vehicle model, which are constant within a model-year. Indeed, the real transaction prices of fuel-inefficient vehicle models may decrease when gasoline prices are higher because of a tax increase or when consumers are more sensitive to gasoline prices because of their expedited adjustment cycles. In this case, ignoring the effect of actual transaction prices would underestimate the impacts of the fuel cost on sales, as the reduced vehicle prices would stimulate sales. Therefore, our estimated impacts of vehicles' fuel cost on sales are the *lower* bounds of the actual effects. Nevertheless, the potential price decrease for vehicles in China is mitigated by the fact that automobile dealers in China have very limited room to set prices (Li et al., 2015) because of retail price maintenance in order to restrain price competition among dealers and push dealers to compete on other dimensions such as service quality.

5. Data

We obtained our dataset of new vehicle sales from R. L. Polk & Company, a leading market research firm specializing in the automobile industry. The dataset contains monthly sales as well as the specifications (including fuel economy) of all new passenger vehicle models sold in China at the model-year level[4] from January 2008 to August 2013. The fuel economy measure in our dataset is in terms of "liters of gasoline per 100 km," which we convert into our measure of "kilometers per liter of gasoline."

We obtain the monthly (nominal) price of 93# unleaded gasoline and the consumer price index (CPI) in China from the database of the National Bureau of Statistics of China. The real gasoline price is the nominal price divided by the CPI, with the CPI normalized to one in January 2008.

Table 2 presents the summary statistics of the variables we use in this analysis. In total, we have 138,172 observations of monthly sales at the model-year level. Moreover, the vehicle models in our dataset significantly differ in terms of their fuel economy, with the most fuel-efficient model

[4] In fact, our dataset reports vehicle sales and characteristics at the *trim* level (e.g., 2011 BMW 528Li vs. 2011 BMW 535Li sedans) within each vehicle model-year (e.g., 2011 BMW 5 series sedan). Therefore, in our analysis, we actually use the more detailed *trim-year*-level data. However, in order to remain consistent with industry practice, we still refer to our data as being at the *model-year* level despite this more detailed dataset.

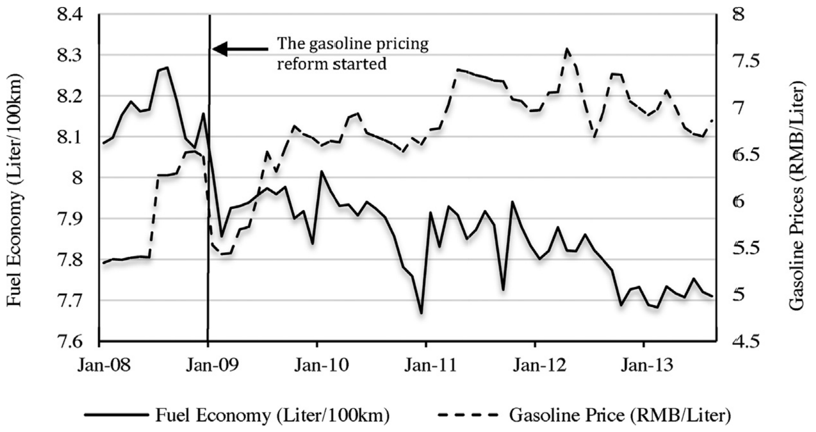

Fig. 2. Monthly average fuel economy (l/100 km) and gasoline prices: 2008–2013. *Notes*: Average fuel economy is the sales-weighted liter per 100 km by month. The gasoline price is the average monthly price of 93# unleaded gasoline divided by the CPI, which is normalized to one for January 2008.

achieving 4.3 l/100 km and the least fuel-efficient one reaching 19.7 l/100 km. Meanwhile, fuel costs per kilometer also vary significantly, from 0.27 RMB/km to 1.55 RMB/km.

Fig. 2 shows the time series of monthly gasoline prices and the monthly sales-weighted average fuel economy of the new vehicles sold from January 2008 to August 2013. It shows that after the gasoline-pricing reform in January 2009, the gasoline price was adjusted much more frequently than in 2008, during which time gasoline prices increased significantly by about 30 percent, while the monthly average fuel economy of new vehicles increased by about 5 percent. Although the contemporaneous correlations between the gasoline-pricing reform and increased automobile fuel efficiency after January 2009 are suggestive, it needs to be recalled that many factors other than fuel costs could explain these trends. Therefore, we conducted a formal estimation and simulation to explore the causal effects of the gasoline-pricing reform and automobile fuel efficiency and present the results in the next two sections.

6. Results

6.1. Estimation results

Table 3 presents the estimation results from several specifications of Eq. (7). The key parameter of interest is γ, the sensitivity of vehicle sales to changes in fuel costs. Column (1) presents the results from the fixed effects estimation. The estimate of γ is −5.843 with a standard error of −0.462, which is significant at the 1 percent level, suggesting that fuel costs negatively affect vehicle sales.

The autocorrelation function of the residuals from the fixed effects estimation in column (1) indicates significant serial correlation in vehicle sales.[5] For this reason, in column (2), we estimate Eq. (7) by using a first-difference estimation. The estimate of γ is similar to that in column (1), −4.185, with a standard error of 0.419, which is again significant at the 1 percent level.

The specifications in columns (1) and (2) both assume that the gasoline price follows a random walk, implying that the expected future gasoline price equals the current price. In column (3), we relax this assumption and use the average gasoline price in the following six months as the expected gasoline price. The first-difference estimation yields a point estimate of γ at −4.637, which is similar to the estimate in column (2) and also significant at the 1 percent level.

[5] The standard AR(1) regression using the residuals from column (1) of Table 3 yields an estimated autocorrelation parameter of 0.835 with a standard error of 0.001.

Table 3
Estimation results.

Dependent variable: log sales	(1) Fixed effects	(2) First difference	(3) First difference	(4) First difference	(5) First difference
RMB\km (CPK_{jt})	−5.843*** (−0.462)	−4.185*** (0.419)	−4.637*** (0.474)	–	−3.483*** (0.492)
RMB\km (CPK_{jt}) × 2008	–	–	–	−1.901* (1.033)	–
RMB\km (CPK_{jt}) × 2009–2013	–	–	–	−6.728*** (0.447)	–
Model-year fixed effects	Yes	Yes	Yes	Yes	Yes
Month dummies	Yes	Yes	Yes	Yes	Yes
The measure of the expected gasoline price	Current gasoline price	Current gasoline price	The average of the gasoline price in the next six months	Current gasoline price	Six-month futures price of New York Mercantile Exchange's oil future contract
R^2	0.032	0.079	0.075	0.079	0.072
N	131,872	119,876	119,876	119,876	119,876

Notes: Standard errors are in parentheses, clustered by vehicle model. The dependent variable is log sales by model and month. All variables are in first difference in columns (2)–(4).
*** Statistical significance at the 1 percent level.
* Statistical significance at the 10 percent level.

Table 4
Effects of a 1 RMB/l increase in gasoline prices on the sales of selected vehicle models.

Vehicle model	Fuel economy (l/km)	Sales change
2011 Honda Fit 1.5L Automatic	5.7	Reference
2011 Ford Focus 1.8L Automatic	6.4	−4.71%
2011 Toyota Camry 2.5L Automatic	7.8	−14.13%
2011 BMW 535Li Automatic	8.7	−20.19%
2011 Toyota Highlander 3.5L Automatic	12.1	−43.06%

Notes: Calculation is based on Eq. (7) and the estimate of γ is taken as −6.728, the value during the post-reform period as in column (4) of Table 3.

In column (4), we separate the sample period into two intervals: 2008, during which the gasoline-pricing reform considered in this study was not implemented, and 2009–2013. We then interact ($GasPrice_t/KPL_j$) in Eq. (7) with the two period dummies. Therefore, we allow the sensitivity of vehicle sales to changes in fuel costs to vary between the pre- and post-reform periods. The estimation results show that the estimate of γ is −1.901 in the pre-reform period, which is significant at the 10 percent level, while γ is estimated to be −6.728 in the post-reform period, significant at the 1 percent level. Taken together, the results suggest that vehicle sales were more responsive to changes in fuel costs during the post-reform period, during which gasoline prices changed much more frequently.

In column (5), we relax the assumption that the gasoline price follows the random walk, by using the six-month futures price of New York Mercantile Exchange (NYMEX)'s oil future contracts instead of the current gasoline price as a measure of expected future fuel cost. The estimation result shows that, under this alternative assumption of gasoline prices, γ is estimated to be −3.483 and is significant at the 1 percent level. The smaller magnitude of estimated coefficient γ reflects the fact that the volatility of oil futures price is larger than that of the retail gasoline price in China.

6.2. Interpretation of γ

The estimate of γ in Eq. (7) directly measures the percentage change in sales if fuel costs per kilometer increase by 1 RMB. To interpret the magnitude of γ in a straightforward way, we compare the changes in the sales of vehicle models with different levels of fuel economy had the gasoline price increased by 1 RMB\l. Table 4 presents the results of such a comparison for selected vehicle models. The calculation is based on $\gamma = -6.728$, which is the estimated post-reform value of γ from column (4) of Table 3. Our estimate implies that, for example, a 1 RMB/l increase in the gasoline price would reduce the sales of the 2011 Toyota Camry 2.5L (8.7 l/100 km) by about 14 percent compared with the sales of the 2011 Honda Fit 1.5L (5.7 l/100 km).

6.3. Simulation

In this section, we quantify the effects of the reform of the gasoline-pricing mechanism through a simulation using the estimates obtained in column (4) in Table 3, in which we separate the sensitivity of new vehicle sales to fuel costs into the pre- and post-reform periods.

Specifically, we ask two questions. First, what would the average fuel economy of China's new automotive fleet have been after January 2009 had gasoline tax not have increased?[6] Second, what would the average fuel economy of China's new automotive fleet after January 2009 have been had the adjustment cycle of gasoline prices not been expedited? By answering these two questions, we can quantify the effects of these two major reform measures on the fuel efficiency of the automobile market in China.

To answer these questions, we first calculate the counterfactual gasoline price under each counterfactual scenario (i.e., without the reform on gasoline tax or without the expedited adjustment cycle

[6] As road maintenance fees are the same for all passenger vehicles and independent of driving distance, they comprise the fixed costs associated with vehicle ownership and are thus the same for all vehicle models. Therefore, as our model is static, we do not consider their effects in either the estimation or the counterfactual analysis.

Table 5
Effects of the gasoline-pricing reform on fuel efficiency in China's automobile market.

	(1)	(2)	(3)
Observed average fuel economy during Jan. 2009–Aug. 2013 (in liter/100 km)	7.90	7.90	7.90
Effect of counterfactual changes in the gasoline-pricing scheme on average fuel economy in China's automobile market (in liter/100 km)	0.271*** (0.037)	0.223** (0.107)	0.494*** (0.125)
Effect as a percentage	3.43	2.82	6.25
Counterfactual scenarios	Without a gasoline tax increase, but with an expedited adjustment cycle for gasoline prices	With a gasoline tax increase, but without an expedited adjustment cycle for gasoline prices	With neither a gasoline tax change nor an expedited adjustment cycle for gasoline prices

Notes: Each column reports the effect of the corresponding counterfactual scenario on average fuel efficiency, which is sales-weighted in all columns. The calculation is the based on specification (4) in Table 3, and it uses the predicted market shares of the vehicle models sold between January 2009 and August 2013. The standard error in parentheses is based on 500 parametric bootstrapping.

*** Statistical significance at the 1 percent level.

** Statistical significance at the 5 percent level.

of gasoline prices). Then, we simulate the counterfactual market share of each vehicle model by using the counterfactual gasoline price and our estimation results. Finally, we calculate the average fuel economy of the fleet by using the fuel economy and counterfactual market share of each vehicle model.

To calculate the counterfactual gasoline price without a gasoline tax increase, we subtract 0.79 RMB/l from gasoline prices after January 2009, which is the real price of the 0.8 RMB/l hike in gasoline tax in January 2009, with the CPI being normalized to one in January 2008.

To calculate the counterfactual gasoline price without the expedited adjustment cycle, we recalculate the gasoline price after January 2009 by applying the pre-reform adjustment rule. That is, gasoline prices in China after January 2009 could only change if the oil price in the international market changed by more than 8 percent.

The counterfactual market share of each new vehicle model under counterfactual gasoline prices were computed by estimating the change in sales from their observed levels in each month between January 2009 and August 2013. The counterfactual market share of each vehicle model in each month equals the ratio of its counterfactual sales to the sum of the counterfactual sales of all vehicle models in the market.

Table 5 presents the simulation results. The results in column (1) show that the sales-weighted average fuel economy of new vehicles sold between January 2009 and August 2013 would have been about 0.27 liter/100 km lower had the gasoline tax rate have been kept at the pre-reform level (i.e., 0.2 instead of 1.0 RMB/l), with such a change significant at the 1 percent level. Put another way, the results in column (1) suggest that a rise in gasoline tax resulted in an approximately 3.43 percent increase in fleet-wide fuel economy in China from January 2009 to August 2013.

The results in column (2) show that the sales-weighted average fuel economy of new vehicles sold between January 2009 and August 2013 would have been about 0.22 l/100 km higher had the adjustment cycle of gasoline prices not have been expedited but rather kept at the pre-reform level. Again, such a difference is significant at the 5 percent level, and its magnitude is equivalent to an approximately 2.82 percent increase in average fuel economy.

The result in column (3) shows the aggregate effects of the gasoline-pricing reform. It demonstrates that the reform, which includes the increase in the gasoline tax rate and expedited adjustment cycle of gasoline prices, resulted in an approximately 6.25 percent increase in fleet-level average fuel economy in China between January 2009 and August 2013.

7. Conclusion

In this study, we estimate the effects of the gasoline-pricing reform in January 2009 on the sales and thus fuel economy of individual new vehicle models in China. By using product-level (i.e., vehicle model) data in a particular market, we are able to control for the correlation between energy efficiency (i.e., the fuel economy of individual models) and unobserved product and consumer characteristics, using a simple linear regression framework with model-year interactions. We find that the gasoline-pricing reform in 2009 had modest but significant effects on the average fuel economy of China's new vehicle fleet, resulting in an approximately 6.25 percent increase in average fuel economy for vehicles sold between January 2009 and August 2013. Furthermore, our simulation results also suggest that the two major elements of the gasoline-pricing reform contribute similarly, with the increase in gasoline tax generating a 3.43 percent increase in fuel economy and the expedited adjustment cycle for gasoline prices another 2.82 percent increase.

Our empirical results have important implications for energy policy in China. Our results suggest that although the ongoing gasoline-pricing reform has achieved its goal of promoting energy efficiency in the automobile sector in China, the magnitude of its effects (6.25 percent) has been relatively modest compared with the fuel efficiency target set by the government in the short and medium run.[7] Therefore, more policy measures need to be considered to promote fuel efficiency in the automobile market as well as in other sectors in China further.

As with any other research, our paper is not without limitations. This study adopts a *static* framework to study the *short-run* effects of gasoline-pricing reform on the fuel economy of new vehicles in China, because we assume that distance traveled (D_s in Eqs. (2) and (3)) as well as vehicle characteristics (e.g., fuel economy) are fixed. However, the gasoline pricing reform may also have *long-run* effects, for example, if gasoline prices increase in the long run, consumers may choose to drive less and manufacturers may redesign vehicles to achieve better fuel economy. Therefore, in the future, one could adopt models that allow consumers to choose vehicle ownership as well as distance traveled (e.g., Bento et al., 2009), or models that allow firms to change vehicle characteristics (e.g., Klier and Linn, 2012) to further quantify the impacts of gasoline pricing reform on vehicles' fuel economy in the long run.

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[7] For example, the corporate average fuel economy standard in China is to achieve an average fleet-level fuel economy of 6.9 L/100 km by 2015 and 5.0 L/100 km by 2020, which are equivalent to 13 and 37 percent increases relative to the level in 2013, respectively.

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