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The Effects of Changes in Gasoline Prices on Hybrid Car Sales in the U.S.

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a thesis submitted to the Faculty of Emory College of Arts and Sciences
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Abstract

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Since automobiles generate about 25 percent of the greenhouse gas emissions in the U.S., increasing the use of alternative fuel vehicles can greatly help ease the problem. This paper employed a vector error correction model to examine the relationship between hybrid car sales and gasoline prices in the U.S. by using a time series monthly dataset on car sales, gasoline prices and average miles traveled per capita from January 2000 to December 2013. I find that there exists a long-run equilibrium between hybrid car sales and gasoline prices, and that gasoline prices, in the long term, have a large positive effect on hybrid car sales. Furthermore, compared with total car sales, hybrid car sales are more sensitive to changes in gasoline prices.

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1. Introduction

The United States Environmental Protection Agency reported that in the U.S., the transportation sector generates nearly 30 percent of the total greenhouse gas emissions, and that automobiles contribute 85 percent of the emissions from the transportation sector. One of the ways to reduce the greenhouse gas emissions from the automobiles is to increase the adoption of alternative fuel vehicles, such as hybrid cars. Hybrid cars are a type of alternative fuel vehicles that use two distinct power sources. A hybrid car uses its internal combustion engine like other regular cars when it is running at a high speed, but once its speed is below a certain threshold, the hybrid car will switch to its electric motor. In this way, using hybrid cars can help cut the use of gasoline and thereby reduce greenhouse gas emissions. Both hybrid car sales and gasoline prices have been increasing since 2002 in the U.S. (Beresteanu 2011), and the potential correlation between hybrid car sales and gasoline prices has been gaining attention among researchers (Beresteanu 2011). Since the government has control over gasoline taxes, it is feasible for the government to influence the gasoline prices in order to reduce the greenhouse gas emissions. Because of this, studying the relationship between hybrid car sales and gasoline prices can help policy makers find an effective method to ease the greenhouse gas emission problem.

This paper studies the relationship between hybrid car sales and gasoline prices in the U.S., and it also looks at the long-run and short-run effects of the changes in gasoline prices on the hybrid car sales. I employ time series data to construct forecasting models for both hybrid car sales and total car sales. Because hybrid cars were first introduced to the U.S. automotive market in the late 1990s, the time span of the data on hybrid car sales is limited. Therefore, I use monthly data to ensure the abundance of data points. In my models, gasoline prices are used as an independent variable, and I also account for the deterministic seasonality in car sales. Moreover, the vehicle miles traveled per capita and its interaction with gasoline prices are taken into consideration in the models as well.

My study finds that unit roots exist in both hybrid car sales and real gasoline prices. This means that both hybrid car sales and real gasoline prices are not stationary, and if a shock or development were to happen to hybrid car sales, it would permanently affect the hybrid car sales. Similarly, real gasoline prices can be affected permanently by an exogenous shock as well. Furthermore, the Johansen test results indicate that the hybrid car sales and real gasoline prices have cointegration. This implies that although hybrid car sales and real gasoline prices are not stationary, there exists a linear combination of hybrid car sales and real gasoline prices such that the linear combination is stationary (Stock and Watson 2011). The cointegration indicates that there exists a long-run equilibrium between hybrid car sales and real gasoline prices, i.e. even if a shock affected one of the variables, e.g. hybrid car sales, the other variable gasoline prices would pull hybrid car sales back to maintain the equilibrium. Due to cointegration, I employ a vector error correction model to analyze the relationship between the change in hybrid car sales and the change in gasoline prices (Diebold 2008). A moving average model is used for the regression analysis for total car sales. The average miles traveled per capita and an interaction term with real gasoline prices are included in a second model for total car sales.

I compare the model for hybrid car sales with the model for total car sales to investigate the different effects of gasoline prices on each of them, and I find that the change in hybrid car sales are more responsive to the changes in gasoline prices than the growth rate of total car sales. In the short run, the gasoline prices approximately 7 months before the sales will influence both the change in hybrid car sales and the growth rate of total car sales. However, compared with the growth rate of total car sales, the change in hybrid car sales are more sensitive to recent gasoline prices. In the long run, hybrid car sales and gasoline prices have a long-run equilibrium, and gasoline prices have a large positive impact on hybrid car sales. Gasoline prices, however, can only modestly affect the growth rate of total car sales in the long term. These findings indicate that we can increase gasoline prices in order to encourage the purchase of hybrid cars. Based on this relationship between hybrid car sales and real gasoline prices, policy-makers can control gasoline prices to promote hybrid car sales, and therefore, reduce greenhouse gas emissions.

The paper proceeds as follows: Section 2 discusses existing studies that are related to car sales and gasoline prices. Section 3 describes the models and the empirical strategy employed in this paper. Section 4 introduces the data for car sales, gasoline prices and average miles traveled per capita. Section 5 presents the estimate of the models and the interpretation of the regression results. In Section 6, we summarize the main results and present directions for possible future research.

2. Literature Review

Several studies have indicated that changes in gasoline prices will influence consumer behaviors and the automotive market structure. Knittel and Sandler (2010) use a biennial dataset from California's Smog Check program from 1996 to 2010 to study the effects of carbon prices on consumer behaviors. They construct two models focusing on the changes in the extensive margin and the intensive margin as gasoline prices change. The extensive margin model uses the individual consumer's vehicle purchase and scrapping decisions as the dependent variable and gasoline prices as the independent variable. The intensive margin model studies the effects of the change of gasoline prices on the vehicle miles traveled. Knittel and Sandler's study indicates that the rise of gasoline prices encourages consumers to choose fuel efficient vehicles and scrap low mileage vehicles. Another finding shows that the increase of gasoline prices causes consumers to drive significantly fewer miles. However, Knittel and Sandler's study does not examine the correlation between the extensive and intensive margins. The distance traveled by vehicles can possibly affect consumers' purchase decisions on vehicles, but Knittel and Sandler overlooked the possible causality between the extensive and intensive margins under the increase of gasoline prices. My research takes such potential causal relationship into consideration, and my models incorporate the effects of vehicle mileages on car sales. In addition, I use an interaction term between average miles traveled per capita and real gasoline prices in my models.

Klier and Linn (2010) use a monthly dataset of new vehicle sales in the U.S. from 1978 to 2007. They use panel data that combines the time series data on gasoline prices and the cross-sectional data based on car models to investigate the influence of gasoline prices on different car model sales. For each car model, the log of sales is the dependent variable, the fuel cost is the independent variable, and they also control for unobserved vehicle and consumer characteristics. Klier and Linn's research finds that as gasoline prices increase, the sales of lighter vehicles increase and the heavier car sales decrease. In particular, the increase in gasoline prices from 2002 to 2007 accounts for nearly half of the decline of U.S. manufacturers' market share. Klier and Linn study the effect of changes in gasoline prices on only gasoline-powered vehicles, and their model categorizes the sales by car models with different fuel efficiencies and sizes. However, my study is interested in comparing the hybrid vehicle market with the total automotive market. Therefore, I differentiate the car sales by power sources, construct models for both hybrid car sales and total car sales, and compare the different effects of gasoline prices on both sales. Klier and Linn use panel data in their study, but I will use time series data on the U.S. gasoline prices and car sales to study the effect of the changes in gasoline prices on hybrid car sales.

In 2013, Klier and Linn examine the relationship between fuel prices and the new vehicle fuel economy from 2002 to 2007 for the eight largest European markets as well as the U.S. market. The dependent variable of their model is the log of sales of each model-fuel type. The independent variables are the lifetime discounted fuel costs and time-fixed effects. They also control for the taxes and policies in different countries. Their study shows that the new vehicle fuel economy is significantly affected by the change of gasoline prices in both Europe and the U.S. On average, the U.S. fuel economy responds more than twice as much to the change in fuel prices compared to Europe's economy. Klier and Linn compare the impact of gasoline price changes on the new fuel economy among different countries. Their study generalizes different car models within each country and therefore could not compare the effects of the change in gasoline prices on different models. My study, however, uses time series data on the U.S. car sales and gasoline prices. The models constructed in my paper are all based on the U.S. market, and I compare the sales of hybrid car sales and total car sales within the U.S.

Compared to previous studies, my research has several improvements. My study is interested in the effects of changing gasoline prices on hybrid car sales, and I compare the effects of changes in gasoline prices on car sales based on the power sources of vehicles. My research uses a time series dataset focusing on the U.S. automotive market. Since it is a monthly data, the model looks at the effects of seasonality as well. I compare different car models from different angles, e.g. long-run effects and short-run effects. While studying the effects of changes in gasoline prices on car sales, I also take the effects of vehicle mileages and its interaction with real gasoline prices on car sales into account.

3. Methodology

3.1 Hybrid Car Sales Model

Before constructing the model, the variables need to be checked for stationarity. The Dickey-Fuller test results indicate that both the hybrid car sales and the real gasoline prices have unit roots. This means that a shock or an important development can cause a permanent effect on hybrid car sales. Similarly, a shock will also cause a permanent effect on gasoline prices. Because of the existence of unit roots, cointegration tests are required. In order to run the Johansen test, both variables need to be first difference stationary (Gonzalez-Rivera 2013). The Q-statistics of the first difference of hybrid car sales and the first difference of the real gasoline prices are all significant at the 1 percent level. This means that the hybrid car sales and the real gasoline prices are both stationary after converted to their first differences. Hence, the Johansen test can be applied here. The Johansen test result is given in Table 6. The first column of Table 6 gives the maximum rank of each test. Since both the trace statistics and the maximum-eigenvalue statistics reject the null hypotheses of the maximum rank 0 and 1 at the 5 percent level, cointegration exists between the hybrid car sales and the real gasoline prices. Thus, there is a long-run equilibrium between hybrid car sales and gasoline prices (Enders 2004). This implies that although a shock causes a permanent effect on individual variables, the long-run equilibrium will tie the variables together.

A vector error-correction model (VECM) is used:

$$dH_t = \sum_{i=1} \beta_{1i} dH_{t-i} + \sum_{i=1} \tau_{1i} dP_{t-i} + \omega_1(H_{t-1} + \rho_1 P_{t-1} + \sigma_1) + c_1 + \varepsilon_{1t}, \tag{1}$$

$$dP_t = \sum_{i=1} \beta_{2i} dH_{t-i} + \sum_{i=1} \tau_{2i} dP_{t-i} + \omega_2(H_{t-1} + \rho_2 P_{t-1} + \sigma_2) + c_2 + \varepsilon_{2t}, \tag{2}$$

where the subscript t denotes time, dH_t is the first difference of hybrid car sales, dP_t is the first difference of real gasoline prices, $H_{t-1} + \rho_i P_{t-1} + \sigma_i$ is the lagged error-correction term, ε_{it} is the error term, σ_i and c_i are constant, and β_{ij}, τ_{ij}, ω_i, and ρ_i are coefficients. The number of lags are chosen based on the Akaike Information Criteria (AIC) and Bayes' Information Criteria (BIC) values.

3.2 The Growth Rate of Total Car Sales Model

The total car sales data demonstrates the obvious deterministic seasonality throughout the time period under study. Therefore, the dummy variables are incorporated in the equation to account for the seasonality. Since total car sales does not have a unit root, the log of total car sales is taken first and then a first difference of the logs is taken to get constant mean and constant variance, i.e. to make the data stationary. We can interpret the log difference of total car sales as the growth rate of total car sales.

3.2.1 Use gasoline prices and average miles traveled per capita as independent variables

Based on the assumption that the gasoline prices and the miles traveled per capita will influence consumers' purchase decisions and therefore affect the total car sales, a forecasting model for the total car sales is constructed. Since the regression results show that none of the lagged growth rate of total car sales is significant, a moving average (MA) model is employed here:

$$dlnT_t = \alpha_1 P_t + \alpha_2 M_t + \alpha_3 P_t \times M_t + \sum_{i=1}^{11} \gamma_i d_i + \sum_{i=1} \theta_i \varepsilon_{t-i} + k_1 + \varepsilon_t, \quad (3)$$

where T_t denotes the total car sales at time t, $dlnT_t$ is the first difference of lnT_t, P_t is the real gasoline price, M_t represents the miles traveled per capita, $P_t \times M_t$ is the interaction term of the real gasoline price and miles traveled per capita, d_i is the seasonal dummy variable for month i,

ε_t is the error term of time t, k is a constant term, γ_i is the coefficient of the corresponding d_i, and α_1, α_2, α_3, and θ_i are scalar coefficients.

The interaction term $P_t \times M_t$ indicates that the effect on $dlnT_t$ of a unit change in one of the two variables depends on the other variable. For example, let M_t be the changing variable and hold P_t constant. Then we can get the following equation according to equation (3):

$$\frac{\Delta \mathrm{d}lnT_t}{\Delta M_t} = \alpha_2 + \alpha_3 P_t. \tag{4}$$

This means that if we increase or decrease M_t by one unit, $dlnT_t$ will increase or decrease by $\alpha_2 + \alpha_3 P_t$ in response to the change in M_t, and the magnitude of the change in $dlnT_t$ will also depend on the value of P_t.

3.2.2 Use the first differences of gasoline prices as independent variables

Since the gasoline prices has a unit root, the first difference of gasoline prices and its lags are used to construct the forecasting model for the total car sales. In this way, the model of the hybrid car sales and that of the total car sales can be parallel, and the forecasting model of the hybrid car sales can be compared with the model of the total car sales. I use an MA equation:

$$dlnT_t = \omega dP_t + \sum_{i=1}^{n} \varphi_i dP_{t-i} + \sum_{i=1}^{m} \delta_i \varepsilon_{t-i} + \mu + \varepsilon_t, \tag{5}$$

where dP_t is the first difference of the real gasoline prices at time t, ε_t is the error term at time t, μ is the constant term, n denotes the number of the lags of dP_t, m denotes the number of the prediction errors included in this MA model, and ω, φ_i and δ_i are coefficients. The values of n and m are determined according to the AIC and BIC results.

4. Data

This paper uses time series data. The data for all variables span from January 2000 to December 2013 with monthly frequency and is not seasonally adjusted. Each variable has 168 observations, of which 165 (from January 2000 to September 2013) are used for the regression analysis and three (from October 2013 to December 2013) are used to compare with forecasts. The U.S. hybrid car sales data and total car sales data are both provided by Wards Auto, and the data is measured in units.

The U.S. all grades all formulation retail gasoline prices and the U.S. consumer price index (CPI) for all urban consumers are used to construct the real gasoline prices in the study. The U.S. Energy Information Administration (EIA) collects the monthly retail gasoline prices in the U.S., and the nominal prices used in our dataset are measured in dollars per gallon. The CPI data was acquired from the database of the U.S. Bureau of Labor Statistics (BLS), and the period 1982-1984 was chosen by BLS as the base period for this CPI dataset, i.e. the CPI of the period 1982-1984 is 100. The real gasoline prices are computed by multiplying the nominal retail gasoline prices by the ratio of the base year CPI over the CPI of the current month.

The average miles traveled per capita is computed by dividing the vehicle miles traveled by the U.S. population. The monthly data on vehicle miles traveled are provided by the Federal Highway Administration via the Federal Reserve Economic Data (FRED), and the data is measured in millions of miles. The monthly U.S. population data is available also at the FRED, and the data is measured in thousands, i.e. the value of 281,083 for the population in January 2000 means that the U.S. population in that month was 281,083,000.

Figure 1 shows the monthly sales of hybrid cars in the U.S. from January 2000 to January 2014. The graph indicates that the hybrid sales data is not stationary and has a generally increasing trend over time. The sales started to fall in around June 2007 but climbed up again after around June 2011, and this phenomenon is not surprising due to the 2008 financial crisis. It is clear that in Figure 2 before 2008, the total car sales data fluctuated with an almost constant mean and variance, but after 2008, an exogenous shock (i.e. the 2008 financial crisis) happened, and caused the sales to drop to around 650,000. At around January 2009, the total car sales started to recover and continue to grow today. Note that the seasonality of the total car sales exists the whole time.

The summary statistics are listed in Table 1, which includes the mean, standard deviation and the Dickey-Fuller test result of each variable, and the first column of the table gives the variable names. The Dickey-Fuller test results indicate that both the hybrid car sales and the real gasoline prices have unit roots at the 5% level, and therefore, a test for the cointegration between the hybrid car sales and real gasoline prices is necessary.

5. Results

5.1 The effect of the change in gasoline prices on the change in hybrid car sales

The regression analysis results of equation (1) are given in Table 2. This equation is part of the VECM, and the parameters of the equation are estimated by ordinary least square (OLS). The dependent variable of the equation is the first difference of hybrid car sales at time t, and the independent variables are the lags of the first difference of hybrid car sales, the lags of the first difference of the real gasoline prices, and the lagged error correction term. The first column of Table 2 gives the corresponding variable names. The second and third column of Table 2 provide the estimate of the model with 9 lags, and the fourth and fifth column give the estimate of the model with 12 lags. The estimate of each corresponding coefficient is shown in the cell, and in the parenthesis below are the standard deviations. The 9-lag model gives the smallest BIC value, whereas the 12-lag model gives the smallest AIC model. In both models, the variables are jointly significant at the 1 percent level. However, because the 9-lag model has more significant parameters at the 5 percent level, the 9-lag model is chosen for the forecasting.

Table 2 shows that the error correction term of the equation (1) is significant at the 5 percent level. This means there exists a long-run causality between the real gasoline prices and the hybrid car sales. In Table 2, the estimated cointegration equation which represents the long-term equilibrium is

$$H_t = 40702.55 \, * P_t - 28581.73, \tag{6}$$

where the dependent variable is the hybrid car sales at time t, and the independent variable is the gasoline price of the same time period. Equation (6) implies that

$$\frac{\Delta H_{t-1}}{\Delta P_{t-1}} = 40702.55. \tag{7}$$

This means that, in the long run, if the real gasoline price increases by $1, the hybrid car sales will increase by 40702 in that month on average. The real gasoline price is significant at the 1 percent level in equation (7), and the coefficient of the real gasoline price (i.e. 40702.55) is large, considering that the mean of the hybrid car sales is 17940.81. This result suggests that the real gasoline prices have a large impact on the hybrid car sales, and the hybrid car sales and the real gasoline prices in general move in the same direction.

Equation (1) describes the short-term relationship between the changes in hybrid car sales and the changes in real gasoline prices. The short-run coefficients are not all significantly different than zero, but the test for joint significance indicates that the lags of the first difference of the real gasoline prices are jointly significant at the 1 percent level. The individual significance test results show that for the first difference of gasoline prices, its third, fifth, and eighth lags are significant at the 5 percent level, and its seventh and ninth lags are significant at the 10 percent level. Among the significant lags, all except the seventh lag have large negative coefficients, which means that these lags have a negative impact on the first difference of hybrid car sales. The lagged error term of equation (1) is significantly negative. This means that the negative feedback is necessary in the hybrid car sales to bring the real gasoline prices back to equilibrium.

5.2 Compare the change in hybrid car sales model with the growth rate of total car sales model

Table 4 gives the estimate results of equation (5). The second column of Table 4 provides the estimated coefficients of the independent variables in equation (5). The dependent variable of this equation is the log difference of the total car sales, and the independent variables are the lags of the first difference of the real gasoline prices, dummy variables that adjust for the deterministic seasonality of the total car sales, and the innovation term of the MA model. The log difference can be seen as the growth rate, and therefore the dependent variable can be interpreted as the growth rate of the total car sales of the month. The equation is estimated by OLS, and the analysis results show that only the seventh lag of the first difference of the real gasoline prices is significant at the 5 percent level, and its coefficient φ_7 is negative. To interpret the magnitude of φ_7, consider a $1 increase in the first difference of the real gasoline price in the month p. Such an increase will cause the growth rate of the total car sales of the month $p + 7$ to decrease by about 14 percent.

Table 3 reports the estimate of equation (3). The first row gives the variable names, and the second row shows the estimated coefficient of each variable with the standard deviation in parenthesis below. Because of the interaction term here, the effect of the change in real gasoline prices is uncertain, and it depends on the average miles traveled per capita. The effect on the growth rate of total car sales due to the change in real gasoline prices can be expressed by the equation:

$$\frac{\Delta \mathrm{d} lnT_t}{\Delta P_t} = 0.50 - 0.61M_t, \tag{8}$$

and the effect on the growth rate of total car sales due to the change in average miles traveled per capita is:

$$\frac{\Delta \mathrm{d} lnT_t}{\Delta M_t} = 0.78 - 0.61P_t, \tag{9}$$

To give an example to interpret equation (8), consider that the average miles traveled per capita in July 2013 is 0.833 miles. If the gasoline price of that month increases by $1, then the growth rate of the total car sales will drop by 0.8 percent in that month. By computation, we find that if the average miles traveled per capita is greater than 0.819 miles, the real gasoline price will have a negative impact on the growth rate of the total car sales, and if the average miles traveled per capita is less than 0.819 miles, then the growth rate will increase as the real gasoline prices increase. The change in the real gasoline prices will not have any effects on the total car sales growth rate if the average mile traveled per person is 0.819 miles.

In equation (9), the critical point of real gasoline prices is $1.28. This means, if real gasoline prices are larger than $1.28, then the increase in average miles traveled per capita will have a negative impact on the growth rate of total car sales; if real gasoline prices are less than $1.28, then the growth rate of total car sales will increase as average miles traveled per capita increase. For example, let the gasoline price at time t be $1. If the average miles traveled per capita increases by 1 mile, the growth rate of total car sales will increase by 0.17. In the case of $2, if the average miles traveled per capita increases by 1 mile, the growth rate of total car sales will drop by 0.44.

To compare the hybrid car sales with the total car sales, first look at Figure 1 and Figure 2. Figure 1 plots the monthly hybrid car sales against time from January 2000 to September 2013, and Figure 2 plots the monthly total car sales against time in the same time period. The graph shows clear evidence of deterministic seasonality which does not exist in the hybrid car sales. From the graph, it is obvious that the hybrid car sales have an upward trend with respect to time, and the Dickey-Fuller test indicates that the hybrid car sales have a unit root, but the total car sales do not have a unit root and is almost stationary over time.

By comparing equation (1) and equation (5), we can see that the effect of the change in the current real gasoline prices on the change in hybrid car sales is different from that on the growth rate of total car sales. Equation (6) shows that in the long run, the current real gasoline prices have a very large positive effect on the hybrid car sales of that month. For the growth rate of total car sales, the effects of the change in real gasoline prices depend on the miles traveled per capita. As seen above that 0.819 miles is a critical point of equation (8). Table 1 reports that the mean of the average miles traveled per capita is about 0.816 miles which is very close to 0.819 miles, and both the Dickey-Fuller test and Figure 4 imply that the average miles traveled per capita is stationary over time. Therefore, in the long run, the change in the real gasoline prices has very little effects on the growth rate of total car sales.

Table 2 and Table 4 provide the estimate for the short-term influence of the gasoline prices on the hybrid car sales and the total car sales, respectively. Table 2 shows that the third, fifth and eighth lags of the real gasoline prices are significant to the change in hybrid car sales at the 5 percent level, and for the growth rate of total car sales, only the seventh lag is significant at the 5 percent level in Table 4. From both tables, we can see that on average, the seventh lag of the real gasoline prices is significant to both the change in hybrid car sales and the growth rate of total car sales. This is reasonable because the decision to purchase a car is often made after a relatively long period of careful consideration. Therefore, the lagged gasoline prices tend to have a larger impact on decision-making. However, by comparison, the change in hybrid car sales are more sensitive to the gasoline prices than the growth rate of total car sales, since the hybrid car sales are also significantly affected by the more recent gasoline prices, e.g. the gasoline prices of three months before the sale.

5.3 Compare the forecasting results with the actual numbers

Table 5 lists the 1-step ahead forecasting results and the actual numbers of the hybrid car sales from October 2013 to December 2013. The first column labels the month, the second column gives the forecasting results of the hybrid car sales, the third column is the actual number of the hybrid car sales of the month, and fourth column is the forecasting error. The error is computed by dividing the absolute value of the difference between the forecasting and actual numbers by the actual sales number of the month. For instance, the hybrid car sales forecast for November 2013 is 35969, the actual number of hybrid cars that were sold in that month is 36070, and the forecasting error for that month is 0.28 percent. From Table 5, we can see that the average error of the forecasting results is about 4 percent. Figure 1 shows that a shock happened to the hybrid car sales at around the end of 2013, and this shock can partly account for the deviation of the forecasting from the actual values.

6. Conclusion

This paper investigates the relationship between hybrid car sales and real gasoline prices in the U.S. The forecasting models are based on the monthly data for sales, gasoline prices and average miles traveled per capita, and the models also adjust for non-stationarity and deterministic seasonality. I find that both monthly hybrid car sales and real gasoline prices have unit roots. This implies that if an exogenous shock, such as a financial crisis, were to affect hybrid car sales or gasoline prices, the shock would impact hybrid car sales or gasoline prices permanently. The existence of cointegration between hybrid car sales and gasoline prices indicates that there is a long-run equilibrium between hybrid car sales and gasoline prices. Therefore, even if a shock were to happen to one of the variables, e.g. hybrid car sales, the other variable gasoline prices would pull the hybrid car sales back to maintain the long-run equilibrium.

Through the comparison of the hybrid car sale model and the total car sale models, I find that the change in hybrid car sales are more sensitive to changes in gasoline prices than the growth rate of total car sales. In the short run, hybrid car sales, compared with the growth rate of total car sales, are more affected by recent changes of gasoline prices. However, on average, both the change in hybrid car sales and the growth rate in total car sales are significantly influenced by the gasoline price of the 7th month before the sale. In the long run, gasoline prices have a large positive impact on the change in hybrid car sales, but the change of gasoline prices can only modestly affect the growth rate of total car sales.

There are two major applications of my study. For policy makers, to encourage the adoption of hybrid cars, increasing the gasoline prices or taxes can effectively promote hybrid car sales. For car dealers and manufacturers, the gasoline prices of about 7 months before the sale in general can be used for forecasting sales, but when forecasting hybrid car sales, the more recent gasoline prices, such as the 3rd and 5th lagged gasoline prices also need to be taken into consideration.

One of the limitations of my study is that the time span of my dataset is restricted because hybrid cars were not introduced to the U.S. market until the late 1990s. The accuracy of my regression analysis and forecasting results, therefore, is affected. The prices of cars and government's policies regarding hybrid car sales are not incorporated in my research, but it is plausible that such changes can affect the hybrid car sales. Therefore, for further research, factors such as hybrid car prices, taxes or subsidies on hybrid cars can be included in the model. Moreover, because I did not have access to monthly data on the number of registered cars in the U.S., I used the monthly U.S. population as an alternative to compute average miles per capita. In further research, we can replace the average miles per capita with average mile per vehicle, since adding a vehicle will have a more direct effect on the fuel cost for consumers and will affect consumers' purchase decisions more directly. In addition, total car sales and gasoline prices can possibly affect each other, and we have checked that the monthly total car sales does not have a unit root. Therefore, we can apply a vector autoregression model to examine the relationship between total car sales and real gasoline prices in future research.

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Appendix

Table 1-Summary Statistics

	Mean	Standard Deviation	Dickey-Fuller Test
Panel A. Sample means and standard deviations			
Hybrid Car Sales	18305.96	13677.99	-2.495
Total Car Sales	1261569	240621.9	-5.454
Real Gasoline Prices (dollars per gallon)	1.253	0.350	-1.661
Miles Traveled Per Capita (thousand miles)	0.816	0.054	-6.861
Panel B. Means and Standard deviations of the first difference of			
Hybrid Car Sales	201.02	5126.375	-15.466
Logarithm of the Total Car Sales	-0.00037	0.158	-20.425
Real Gasoline Prices (dollars per gallon)	0.0053	0.088	-7.576

Table 2-Estimate Result of Equation (1) by OLS

	(9 lags)	(9 lags)	(12 lags)	(12 lags)
	Hybrid	Gas	Hybrid	Gas
Lag 1	-0.31**	2061.38	-0.27**	883.40
	(-0.11)	(5736.28)	(0.11)	(5542.46)
Lag 2	-0.32**	-3911.08	-0.23**	-3286.61
	(-0.11)	(6588.33)	(0.11)	(6590.19)
Lag 3	-0.10	-17116.06**	-0.05	13927.86**
	(-0.11)	(6723.19)	(0.11)	(6628.69)
Lag 4	-0.15	853.90	-0.08	-260.87
	(-0.10)	(6477.05)	(0.11)	(6695.12)
Lag 5	0.10	21571.76***	0.14	14522.81**
	(-0.10)	(6374.07)	(0.11)	(6668.78)
Lag 6	-0.18*	-382.25	0.04	-5969.14
	(-0.10)	(6666.39)	(0.10)	(6803.16)
Lag 7	-0.10	11248.04*	0.08	-10000.59
	(-0.10)	(6604.58)	(0.10)	(6462.21)
Lag 8	-0.02	-13494.35**	0.03	-10491.99
	(-0.10)	(6284.37)	(0.10)	(6476.19)
Lag 9	0.08	-11076.1*	0.08	-9227.68
	(-0.10)	(5794.68)	(0.10)	(6547.46)
Lag 10			0.01	-460.94
			(0.10)	(6574.87)
Lag 11			0.02	10350.01*
			(0.09)	(6241.12)
Lag 12			0.36***	-7336.99
			(0.09)	(5847.83)
Error Correction	-0.21**		-0.19**	
	(-0.07)		(-0.09)	
Cointegration equation				
Real Gasoline Prices	-40702.55***		-40217.28***	
	(28581.73)		(3564.26)	
Constant	28581.73		28755.72	
AIC	17.33		17.30	
BIC	18.13		18.35	

Note: ***p<0.01, **p<0.05, *p<0.1

Standard Deviations in ()

Table 3-Estimate Result of Equation (3) by OLS

Real Gasoline Prices (P)	0.50**
	(0.22)
Average Miles Traveled Per Capita (M)	0.78**
	(0.36)
Interaction Term of P and M	-0.61**
	(0.26)
January Dummy	-0.45***
	(0.04)
April Dummy	-0.25***
	(0.05)
May Dummy	-0.08**
	(0.04)
June Dummy	-0.21***
	(0.04)
July Dummy	-0.19***
	(0.03)
August Dummy	-0.12***
	(0.03)
September Dummy	-0.33***
	(0.02)
October Dummy	-0.19***
	(0.03)
November Dummy	-0.24***
	(0.04)
MA(1) Lag	-0.62***
	(0.05)

Note: ***p<0.01, **p<0.05, *p<0.1

Standard Deviations in ()

Table 4-Estimate Result of Equation (5) by OLS

L7.D(Real Gasoline Prices)	-0.14**
	(0.05)
January Dummy	-0.45***
	(0.05)
April Dummy	-0.25***
	(0.04)
May Dummy	-0.09**
	(0.04)
June Dummy	-0.220***
	(0.04)
July Dummy	-0.19***
	(0.03)
August Dummy	-0.12***
	(0.03)
September Dummy	-0.32***
	(0.02)
October Dummy	-0.18***
	(0.02)
November Dummy	-0.22***
	(0.03)
MA(1) Lag	-0.56***
	(0.06)

Note: ***p<0.01, **p<0.05, *p<0.1

Standard Deviations in ()

Table 5—1-Step Ahead Forecasting Result Report

	Forecasting Hybrid Car Sales	Actual Hybrid Car Sales	Forecasting Error (percent)
Oct-13	36843	34465	6.90
Nov-13	35969	36070	0.28
Dec-13	37502	35649	5.20

Table 6-Johansen Test Results

Maximum Rank	Trace Statistic	Maximum-eigenvalue Statistic
0	35.5669	26.3394
	(18.17)	(3.74)
1	9.2275	9.2275
	(16.87)	(3.74)

Note: 5 Percent Critical Value in ()

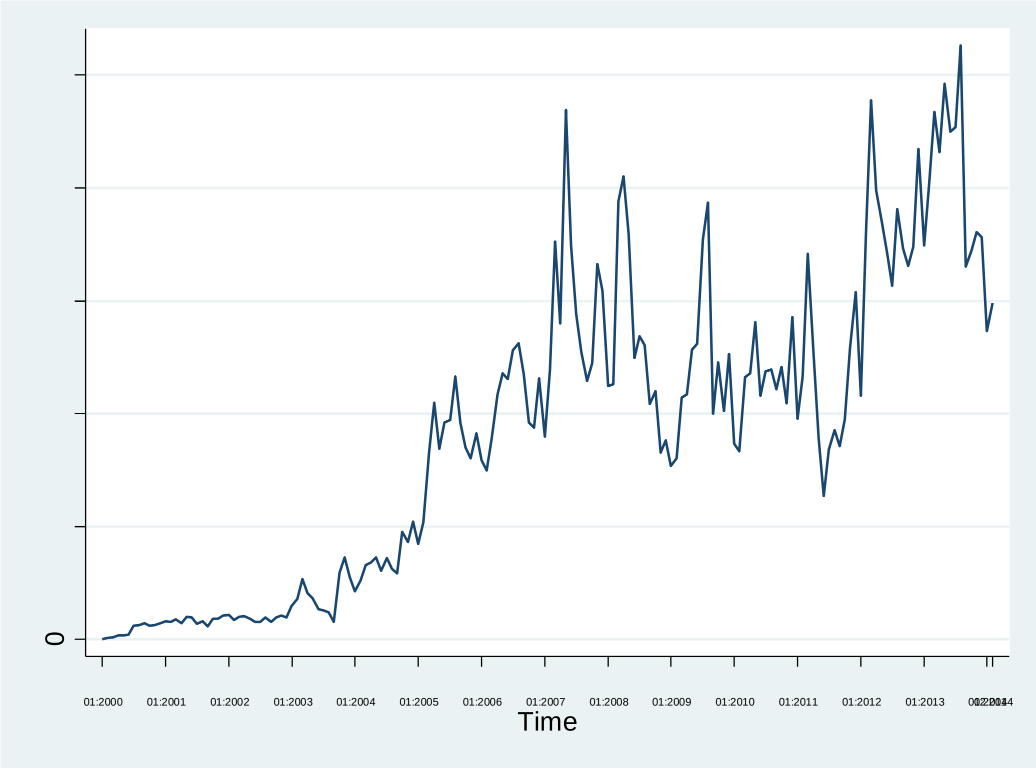

Figure 1-Monthly Hybrid Car Sales

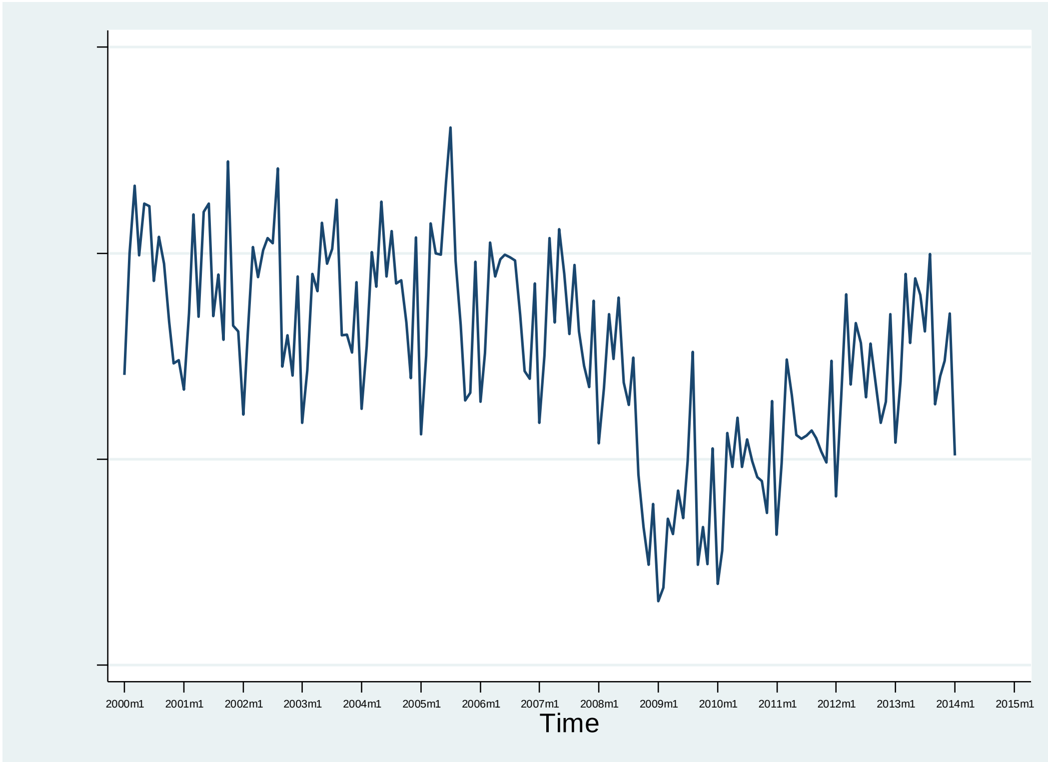

Figure 2-Monthly Total Car Sales

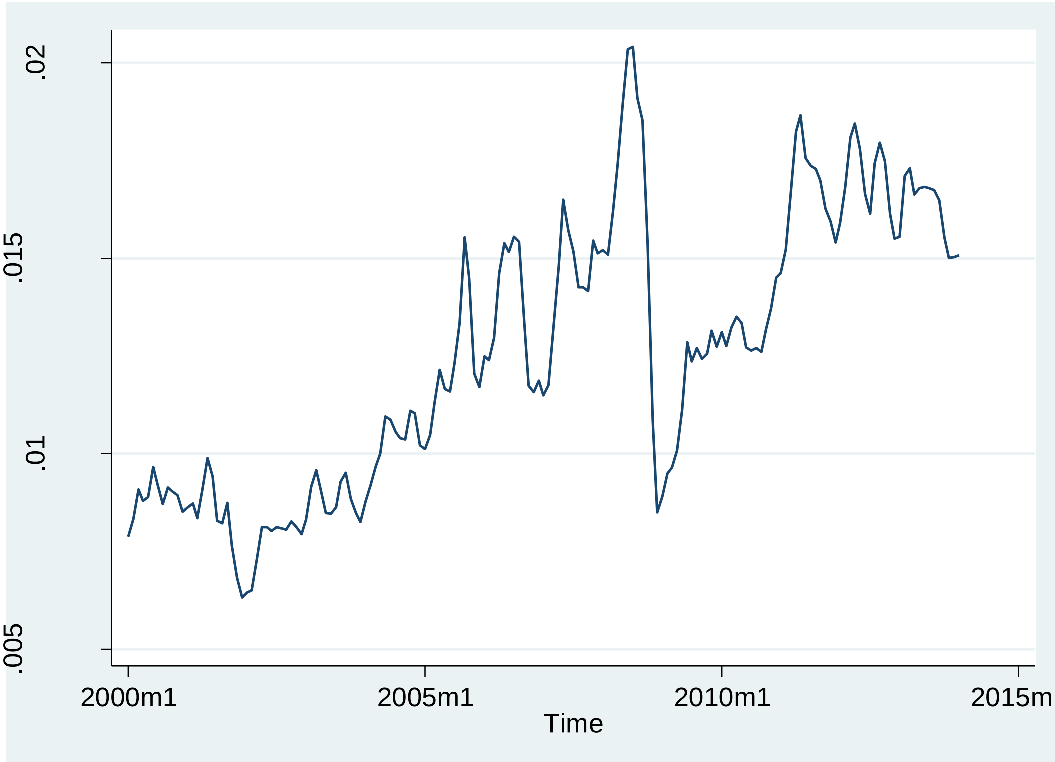

Figure 3-Monthly Real Gasoline Prices

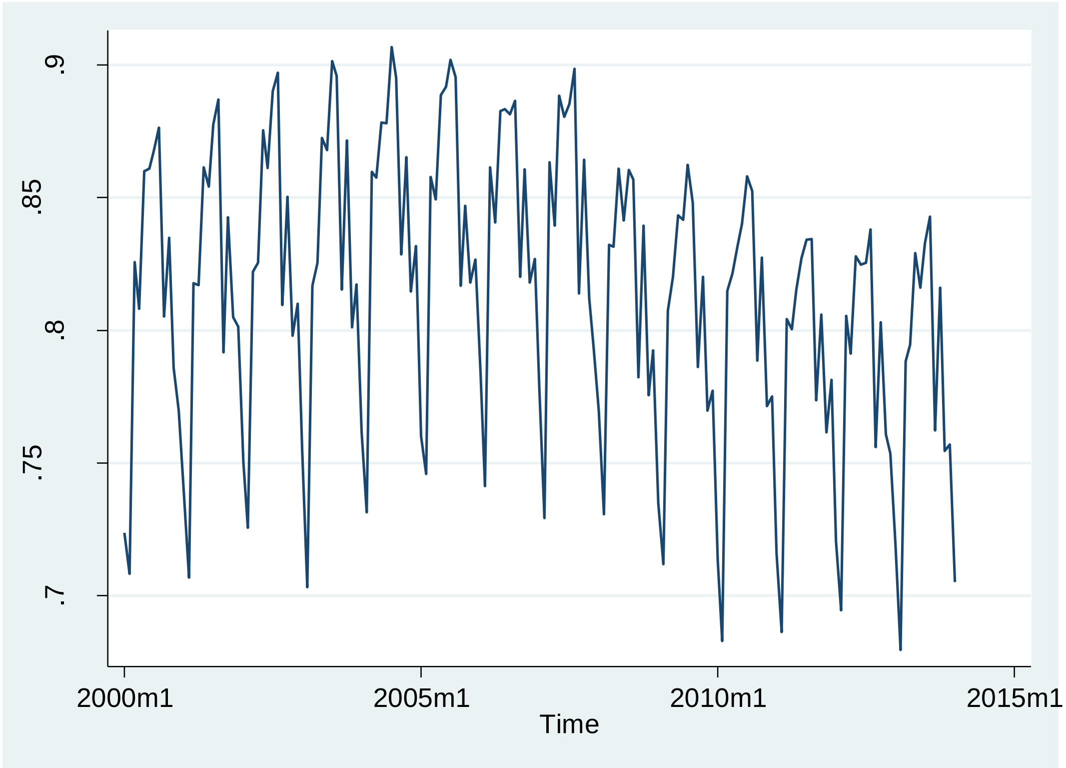

Figure 4-Monthly Average Miles Traveled Per Capita

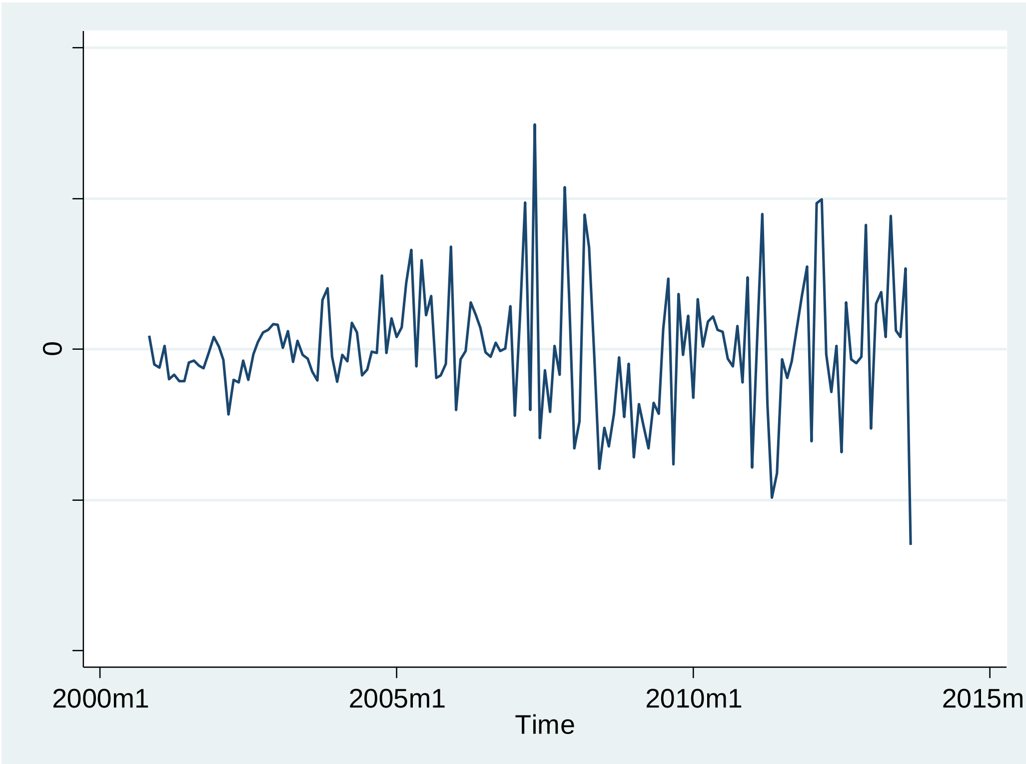

Figure 5-Forecating Residuals