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16. Abstract
This study presents an evaluation of the potential impacts on TxDOT revenues of substituting liquefied natural gas (LNG), compressed natural gas (CNG), and liquefied petroleum gas (LPG) for traditional diesel or gasoline vehicle fuels in Texas. Time series analyses are conducted for LNG, CNG, and LPG to estimate a model to forecast diesel and gasoline consumption for years 2012 to 2025. Taking into account the federal and state fuel taxes, the revenue generated from traditional fuel consumption is compared to three alternative fuel substitution scenarios. Overall, if the Federal and State excise tax rates remain at current levels the analysis suggests that substitution of LNG and LPG for traditional fuels will generate more revenue for the forecast years. However, substitution of CNG for gasoline consumption will reduce revenue if the Federal and State excise tax rates remain the same for the forecast years.

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EVALUATION OF POTENTIAL IMPACTS OF ALTERNATIVE VEHICLE FUELS ON TXDOT FUNDING

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CHAPTER 1. BACKGROUND

The transportation sector accounts for more than half of world oil consumption (Hirsch et al., 2005). In the United States, about 90% of the fuel used for on-road vehicular travel is petroleum-based, which includes gasoline and diesel (Ribeiro et al., 2007). In 2010, the transportation sector was responsible for 27% of greenhouse gas (GHG) emissions in the U.S.—the second largest source of GHG emissions, exceeded only by electrical energy generation (EPA, 2010). In addressing both the transportation sector's dependence on oil and air quality concerns, alternative fuel vehicles (AFV) offer opportunities.

Alternative fuels are derived from resources other than crude oil and they usually produce less pollution than gasoline and diesel. Some alternative fuels are produced domestically. The Energy Policy Act (EPAct) of 1992 defines alternative fuels to include ethanol (blends of 85% or more), electricity, biodiesel (B100), compressed natural gas (CNG), liquefied natural gas (LNG), liquefied petroleum gas (LPG or propane), P-Series fuels, hydrogen, methanol (blends of 85% or more), and coal-derived liquid fuels (U.S. DOE, 2009). Traditionally, the preferred fuels for motorized vehicles have been petroleum-based because of their high energy density and low cost. However, the worldwide increased demand for oil and the perceived unreliability of foreign oil supplies have resulted in fluctuating and steadily increasing petroleum fuel prices. Studies on the 1970s energy crisis indicate that the cost to the U.S. economy from a future oil price crisis could be enormous. These studies estimate the macroeconomic impacts as reducing U.S. economic activity by an average of over 2% per year for three to four years or more, which translates into gross national product (GNP) reductions in the range of $600 billion over three years, up to possibly $3 trillion over fifteen years if the lost economic growth were not subsequently made up (see NHTSA, 2002; EMF, 1992; Greene and Leiby, 1993). Therefore, substituting gasoline and diesel with alternative fuels could play a major role in reducing the vulnerability of the U.S. transportation sector to the disruption and fluctuation of the petroleum supply and significantly benefit the U.S. economy. The federal government—specifically the Department of Energy (DOE), the General Services Administration, and the Department of Agriculture—are involved in efforts to promote the use and expansion of alternative fuels and the alternative fuel infrastructure.

Vehicle characteristics and movement behavior of freight hauling trucks make them an attractive market for promoting alternative fuels. The 2007 Commodity Flow Survey reports that 70% of all shipments made via single mode were shipped by truck. Policymakers prefer trucks to promote the use of alternative fuels for a number of reasons. First, the average annual vehicle miles driven by trucks are much higher compared to household personal vehicles (FHWA, 2010). In 2010, the average annual vehicle miles traveled (VMT) per passenger vehicle (including both passenger cars and light-duty trucks) was 11,492 miles. The average VMT for trucks (all classes) was 26,604 miles (FHWA, 2010). For a class 8 truck (weight ≥ 33,001), the average annual VMT was 68,907 miles (U.S. DOE, 2012). Therefore, the potential energy and emissions benefits of alternative fueling are greater per converted truck than per converted passenger vehicle. Second, while trucks made up only 4.3% of the vehicles on the road in 2010, they accounted for more than 26% of the fuel consumed in the U.S. (FHWA, 2010). Per-vehicle fuel consumption and fuel cost are key drivers for adopting new technology for heavy trucks. Third, government agencies or regulated companies purchase a significant number of fleet vehicles. For example, in 2011, more than 17% of the federal fleet vehicles were medium and heavy trucks (U.S. DOE, 2011). These organizations are more familiar with government rules and regulations and are more likely to play a key leadership role by demonstrating practical applications for alternative fuel vehicles (AFVs) (Nesbitt and Sperling, 1998). As a result, a variety of alternative fuels and advanced propulsion technologies have been explored for heavy trucks, including battery electric, hybrid electric, biodiesel, ethanol, propane, dimethyl ether (DME), LNG, CNG, and both liquefied and gaseous hydrogen (Myers et al., 2012).

The use of natural gas as an alternative fuel for motor vehicles began in Italy as early as the 1930s (Yeh, 2007). Since the petroleum crisis in 1970s, natural gas has been promoted by governments in both developed and developing countries as a clean alternative to crude-oil-based transportation fuels, and also to reduce dependence on imported oil. The use of natural gas as an alternative fuel is advantageous for a number of reasons. First, 94% of U.S. natural gas is produced domestically; second, natural gas produces 5% to 9% fewer GHG emissions than petroleum-based fuels; third, it generates about 20% to 45% less smog-producing products; and finally, it is less expensive than gasoline (U.S. DOE, 2013). Natural gas is one of the cleanest burning fuels and can be used in vehicles in the form of either CNG or LNG. LNG is more suitable for heavy-duty vehicles because it has much higher energy density than CNG and can provide a safe traveling distance of up to 600 miles between refueling stops (Myers et al., 2012).

The State of Texas also promotes the use of natural gas as an alternative fuel. As a part of the Texas Emissions Reduction Plan, the Texas Commission on Environmental Quality (TCEQ) administers the Natural Gas Vehicle (NGV) Grant Program, Clean Transportation Triangle Program, and the Texas clean fleet program. The NGV grant program provides grants to replace existing medium- and heavy-duty vehicles with new, converted, or repowered NGVs. Through the Clean Transportation Triangle program, TCEQ may also award grants to support the development of a network of natural gas fueling stations along the interstate highways connecting Houston, San Antonio, Dallas, and Forth Worth. The Texas Clean Fleet Program, part of the Texas Emissions Reduction Plan, encourages owners of fleets containing diesel vehicles to permanently remove the vehicles from the road and replace them with AFVs or hybrid electric vehicles (HEVs). The Alternative Energy Division of the Railroad Commission of Texas administers a Low Emissions Alternative Fuels Equipment Initiative Program, which offers grants to buyers who wish to replace aging medium- or heavy-duty diesel school buses or delivery vehicles with qualified propane or natural gas vehicles that meet or exceed current U.S. Environmental Protection Agency (EPA) emissions standards (AFDC, 2013).

To budget effectively, states must be able to predict revenue generated from different sources. Fuel tax revenues represent a significant portion of state transportation revenue collected and provide matching funds for federal sources. Most states use statistical and/or econometric modeling methods to estimate revenue (Berwick and Malchose, 2012). The objectives of this study are to estimate forecasting models for annual diesel and gasoline consumption in the state of Texas and to investigate the effects on the state transportation revenue of using LNG, CNG, and LPG alternative fuels. To achieve these objectives, different statistical/econometric modeling techniques were examined to estimate fuel consumption. Time series data and information from multiple sources were used for the analysis. Econometric models were developed to estimate annual diesel consumption, based on historical data from 1981 to 2011 for annual fuel sales, VMT, fuel price, per capita personal income, and population.

Report Summary

This study presents an evaluation of the potential impacts on TxDOT revenues of substituting liquefied natural gas (LNG), compressed natural gas (CNG) and liquefied petroleum gas (LPG) for diesel fuel in heavy-duty vehicles in Texas. Time series analysis is conducted to estimate a model to forecast diesel and gasoline consumption for years 2012 to 2025. Taking into account the federal and state fuel taxes, the revenue generated from diesel and gasoline consumption is compared to revenue that could be generated for LNG, CNG and LPG substitution scenarios. Overall, the result of the analysis suggests that substitution of LNG and LPG for diesel consumption will generate more revenue if the federal and state excise tax rates remain the same for the forecast years. Substitution of CNG for gasoline will decrease state revenue unless the CNG gas tax is raised.

The following points highlight the results:

Regarding LNG substitution for Diesel Fuel

- Due to cost of fuel conversion and physical size of LNG on-board vehicle fuel tanks, trucks rather than passenger cars are the most suitable vehicle type for LNG fueling.

- Since the truck fleet is largely fueled by diesel, this report forecasts diesel consumption through 2025 and then considers the impacts of converting from diesel to LNG at the rates of 10, 20, and 50%.

- Current tax rates for diesel and LNG fuel are \$0.44 and \$0.269 per liquid gallon, including both Texas state and federal excise taxes. However, Texas receives approximately 87.9% of the federal tax collected in Texas for both fuels, yielding the effective tax rates of \$0.4145 and \$0.2546 for diesel and LNG, respectively.

- LNG provides only about 60% of the energy of an equivalent volume of diesel, meaning the user must purchase 1.67 gallons of LNG to travel the same distance as on 1 gallon of diesel.

- Because users must buy more LNG to go the same distance, after adjusting for the fraction of federal tax received by Texas, the effective tax rates are \$0.414 per gallon of diesel and \$0.424 per energy equivalent gallon for LNG.

- Although the trucking community has some interest in LNG, this interest seems to be based primarily on LNG prices being less than diesel fuel. Current pump prices at Texas retail outlets selling LNG fuel are approximately \$2.75 per gallon compared to about \$3.90 per gallon for diesel. However, the LNG energy equivalent price (computed by dividing \$2.75 by 0.6) is \$4.58 per gallon.

- Current federal law (through December 31, 2013) provides a \$0.50 per gallon tax rebate for LNG purchases. This rebate is paid from general revenue, not the Highway Trust Fund.

Regarding CNG Substitution for Gasoline

- Light-duty vehicles, including passenger cars and light-duty trucks, are the most suitable vehicles for CNG fueling because the driving ranges of CNG-fueled vehicles are limited. CNG has only 25% of the energy density of diesel fuel.

- Since the light-duty vehicle fleet is largely fueled by gasoline, this report forecasts gasoline consumption through 2025 and then considers the impacts of converting from gasoline to CNG at the rates of 10, 20, and 50%.

- The tax rates and consumer "pump" prices are based on "gasoline gallon equivalents" (GGE) because CNG is sold in a gaseous form—not as a liquid. In other words, CNG is sold in a quantity containing approximately the same energy as one gallon of gasoline.

- The current tax rate for gasoline is $0.384 per liquid gallon and for CNG fuel is $0.333 per GGE (this figure includes both Texas state and federal excise taxes). However, Texas receives approximately 83.9% of the federal tax collected in Texas for gasoline and approximately 93.3% of the federal CNG tax collected in Texas. Applying these adjustments, the effective tax rates are $0.354 and $0.321 for gasoline and CNG, respectively.

- Given the current effective excise tax rates for gasoline versus CNG, TxDOT will lose revenue as CNG replaces gasoline as a vehicle fuel. Based upon current federal and state tax rates and percentages of federal taxes returned to Texas, ***increasing the current $0.15 per GGE CNG state tax rate to $0.1836 per GGE*** will provide equivalent effective tax rates for gasoline and CNG.

- Interest in CNG within the light-duty vehicle community seems to be based primarily on CNG *reducing* consumer costs.

    - Current pump prices are favorable. Texas retail outlets are selling CNG fuel for $2.10 per GGE compared to about $3.50 per gallon for gasoline. In Texas, the state excise tax is not collected at the pump, so adding $0.15 per gallon brings the actual price to about $2.25 per GGE.

    - Additionally, current federal law (through December 31, 2013) provides a $0.50 per GGE Alternative Fuel Excise Tax Credit for CNG purchases. This rebate is paid from general revenue, not the Highway Trust Fund.

    - The cost to convert a currently owned or newly purchased light-duty vehicle to CNG is approximately $10,000 or more. If an LNG user drives 12,000 miles per year, has an overall fuel economy of 28 miles per gallon, saves $1.25 per gallon using CNG instead of gasoline, and receives the $0.50 per GGE federal tax credit, then (ignoring inflation) almost seven years will be required to amortize the CNG conversion cost.

Regarding LPG Substitution for Diesel

- The driving range and performance of LPG-fueled vehicles is similar to gasoline fueled vehicles. Although the primary market for LPG has traditionally been residential heating, it is a viable fuel for light and medium duty vehicles including passenger cars, as well as, light-and-medium duty trucks since the energy content of LPG is generally about 73% that of gasoline or 64% of diesel fuel.

- Since the light duty vehicle fleet is largely fueled by gasoline, this report forecasts gasoline consumption through 2025 and LPG use as 10, 20, or 50 percent conversions from gasoline to LPG.

- Current nominal tax rates for gasoline and LPG fuel are $0.384 and $0.286 per liquid gallon including both Texas State and federal excise taxes. However, Texas receives approximately 83.9 percent of the federal gasoline tax collected in Texas and approximately 88.4 percent of the federal LPG tax collected in Texas. Adjusting the nominal rates for the fractions of federal taxes returned to Texas and adjusting for the fact that LPG contains about 73 percent of the energy of gasoline per unit volume the effective tax rates are $0.354 and $0.370 for gasoline and LPG, respectively.

- Interest within the light- and medium-duty vehicle community in LPG seems to be based primarily on LPG *reducing* consumer costs.
  - Current pump prices are slightly favorable. Gulf coast retail outlets are selling LPG fuel for $2.17 per gallon. In Texas, the State excise tax is not collected at the pump for LPG so adding $0.15 per gallon brings the actual price to about $2.32 per gallon. The federal tax credit of $0.50 per gallon of LPG fuel reduces the price per gallon to $1.82. Taking into account the energy density of LPG fuel the gasoline gallon equivalent price of LPG fuel is $2.49 compared to about $3.11 per gallon for gasoline.
  - Additionally, the federal tax credit (through 31 December 2013) of $0.50 per gallon of LPG is paid from general revenue not the Highway Trust Fund.
  - Conversion costs for either currently owned or newly purchased light duty vehicles are not so favorable at approximately $4,000 or more. If one drives 12,000 miles per year, has overall fuel economy of 28 miles per gallon, saves $0.62 per gallon using LPG instead of gasoline (this includes the $0.50 per GGE federal tax credit) ignoring inflation, almost fifteen years will be required to amortize the LPG conversion cost.

CHAPTER 2. LIQUEFIED NATURAL GAS (LNG)

1. INTRODUCTION TO LNG

LNG is an odorless, colorless, noncorrosive, and nontoxic fuel. LNG is composed of almost 100% methane derived from natural gas after extraction from underground shale reserves. During the liquefaction process, oxygen, carbon dioxide, sulfur compounds, and water are removed, purifying the fuel. As a result, LNG-fueled vehicles can offer significant emissions benefits compared with diesel-powered vehicles, and can significantly reduce carbon monoxide and particulate emissions as well as nitrogen oxide emissions (EPA 2002). Moreover, LNG is domestically produced in the U.S., while diesel is manufactured using oil, of which nearly two-thirds is imported (AFDC, 2012). Advances in horizontal drilling and fracturing technology that facilitate the extraction of natural gas have resulted in an abundance of domestic natural gas, such that its price has decoupled from petroleum (Myers et al., 2012) and is currently significantly lower than the diesel price (Silverstein, 2013; Sutherland, 2011). However, LNG is a cryogenic fuel that will gradually degrade; as a perishable product in storage, it must be consumed in a timely manner (Myers et al., 2012). As LNG must be stored at extremely low temperatures, the tanks required to maintain these temperatures on vehicles are large. On average, LNG tanks require 70% more volume than diesel tanks for the same energy storage (TIAX, 2013).

Early research regarding the viability of LNG for heavy trucks was conducted based on a fleet of LNG-fueled refuse trucks operated in 1997 in Pittsburg, Pennsylvania, by a private company, Waste Management, Inc. The driver responses regarding the LNG fuel were very positive, in part because LNG-fueled engines generate less noise than diesel-powered engines. The use of cleaner fuel also helped the company when bidding on waste hauling contracts in cities trying to improve air quality (EPA, 2002). Recent research on alternative fuel suggests the use of LNG as a feasible alternative fuel for long-haul commercial trucks (Myers et al., 2012).

In recent years, oil prices have fluctuated while the price of natural gas has remained steady and lower in comparison. Increasing diesel prices have motivated trucking companies to operate trucks that run on natural gas and buy new trucks that are powered by natural gas—even though LNG-fueled trucks can cost as much as $30,000 more than diesel-fueled trucks (The Wall Street Journal, 2012). Additionally, LNG gas use is also encouraged by a tax incentive. A tax credit of $0.50 per gallon is available for LNG users between January 1, 2005, and December 31, 2013 (U.S. DOE). From the trucking company perspective, this tax incentive can be used to offset higher initial vehicle purchase or conversion costs. Diesel-fueled trucks can be converted to use LNG through a process available from several vendors; currently approximate costs run from $10,000 to $18,000 depending on the engine size and desired vehicle range (which affects the size of the LNG fuel tanks). At least two vendors, EcoDual LLC and Peake Fuel Solutions LLC, have conversions kits available that allow diesel trucks to run on a mixture of diesel and up to 85% or 70% natural gas but retain the ability to run on 100% diesel when natural gas fuels are not available. Due to the current lack of LNG or CNG fueling stations, the dual fuel capability offered by these kits seems to be very desirable. The Peake kit has only recently been approved by the EPA and is becoming commercially available during spring 2013.

The likelihood of LNG consuming a significant fraction of the diesel motor fuel market is, of course, dependent upon the market prices of the two competing products. A check of LNG prices at the pump in the Houston area in mid-March 2013 indicates that the prices were approximately $2.75 per liquid gallon. Diesel fuel at the same outlets was priced around $3.90 per gallon. While this might appear to be a significant LNG price advantage, if we adjust for the energy density of the two fuels (dividing the LNG price by 0.60 to reach the energy density of diesel), the LNG price becomes $4.58 per equivalent gallon. Applying the $0.50 per gallon federal tax credit, the LNG price becomes $4.08 per gallon—or very close to that of diesel fuel. (By the way, under current law, the $0.50 per gallon tax credit is being paid from the federal general fund, not the Highway Trust Fund, so it does not currently affect the transportation revenue available to Texas.) We can reasonably expect that retail outlets will price LNG near the price they charge for diesel fuel since it is the competing product and they have little incentive to reduce their potential profit margins. Wholesale prices for LNG—the prices paid by retail vendors and very large consumers—are rumored to be approximately half the Houston pump prices. If that is true, we might expect pump prices to moderate as more vendors enter the market and more consumers seek LNG fuel.

2. METHODOLOGY

Forecasting plays a key role for state government agencies to predict revenues and estimate cash flow. A sound forecasting method can help improve future investment planning and maximize investment returns. Most states employ statistical and/or econometric models to estimate and forecast fuel consumption. In most cases, observed historical data is used to find the parameters of a specified relationship that fit the observed data most closely. The parameters obtained using observations from the past are used to forecast future estimates. In this study we employ time series analysis to estimate annual diesel consumption model parameters that can be used for forecasting. A brief description of the model is presented in the following sub-section.

Time Series Analysis

Model Structure. A traditional time series model was used to model annual diesel sales. Let t be the index for annual time period, y_t is the diesel consumption at time t, β is a corresponding vector of coefficients to be estimated (including a constant), u_t denotes the sequence of errors or disturbances, $\mathbf{x_t} = (x_{t1}, x_{t2}, x_{t3}, ..., x_{tk})$ denotes the set of all independent variables in the equation at time t, and further X denotes the collection of all independent variables in the equation at time t.

$$y_t = \beta' \mathbf{x_t} + u_t$$

The following assumptions are required for the time series model.

Assumptions

1. The time series process follows a model that is linear in parameters.
2. In the sample (and therefore in the underlying time series process), no independent variable is constant and no independent variable is a perfect linear combination of the others.

3. For each *t*, the expected value of the errors u_t, given the explanatory variables for all time periods, is zero.

$$\mathrm{E}(u_t \mid \mathbf{X}) = 0, t = 1,2,...T.$$

4. Conditional on **X,** the variance of u_t is the same for all *t*.

$$\mathrm{Var}(u_t \mid \mathbf{X}) = \mathrm{Var}(u_t) = \sigma^2, t = 1,2,...T.$$

5. Conditional on **X,** the errors in two different time periods are uncorrelated.

$$\mathrm{Corr}(u_t u_s) = 0, \text{for all } t \neq s$$

Many economic time series have a common tendency to grow over time. We must recognize that some series contain a time trend in order to draw causal inference using time series data. Ignoring the fact that two sequences are trending in the same or opposite directions can lead us to falsely conclude that changes in one variable are actually caused by changes in another variable (Wooldridge, 2006). One popular formulation of a time series model incorporating a trending variable is the following:

$$y_t = \beta_0 + \beta_1 t + u_t$$

The above formulation is known as a *trend-stationary process*. Interpretation of β_1 is very simple for such a model. β_1 measures the change in y_t from one period to the next due to the passage of time, holding all other unobserved factors constant. Explanatory variables can also be incorporated along with the trending variable. Using the time trend variable along with other explanatory variables, the model takes the following form:

$$y_t = \beta_0 + \beta_1 t + \beta_2 x_{t1} + \beta_3 x_{t2} + u_t$$

Allowing for the trend in the time series regression explicitly recognizes that y_t may be growing ($\beta_1 > 0$) or shrinking ($\beta_1 < 0$) over time for reasons essentially unrelated to other explanatory variables (here x_{t1} and x_{t2}). An assumption of weak dependence along with the stationary assumption should be made.

In the time series data, if the error terms are correlated over time (i.e., violation of the fifth assumption stated above), then the serial correlation should be taken care of in the model. A first-order autoregressive model that takes into account the correlation of the error term at time period *t* with the error term at time period *t*-1 takes the following form:

$$y_t = \beta' \mathbf{x_t} + u_t \qquad \text{where} \quad u_t = \rho u_{t-1} + \varepsilon_t$$

u_t is the error term during time period *t*, which is a function of the previous error term plus a new disturbance term ε_t that is assumed to be normally distributed; ρ ($-1 \leq \rho \leq 1$) is the autocorrelation parameter.

Model Performance Evaluation

In order to evaluate the performance of the estimated models to forecast diesel consumption, we need to compare the model prediction performance between the estimated models. To quantify the prediction performance of the models under consideration, we have adopted two measures based on the residual, i.e., the difference between the actual and the predicted diesel consumption. Lower values of the measures indicate better performance of the model in forecasting future share prices. The first measure is the sum of the absolute residual for the two-year time period, which can be expressed as

$$\sum_{t=2010}^{T=2011} | y_t - y_{t,Forecast} |$$

The next performance measure is the sum of the square of the residual for the forecasted two years and can be expressed as

$$\sum_{t=2010}^{T=2011} (y_t - y_{t,Forecast})^2$$

3. ANALYSIS AND RESULTS

To estimate the diesel consumption model, we reviewed various combinations of independent variables and two different functional forms of time series analysis to arrive at the best alternative annual forecast model. The study examines data issues, model specifications, critical assumptions, and forecast performance. Two different forms of dependent variables are analyzed. The first one is the diesel consumption in million gallons and the second one is the $\log_e$ of diesel consumption in gallons. The second model gives a better R-squared value for all the models and is presented in the report. Time series data for the dependent and explanatory variables are collected from 1984 to 2011. The diesel consumption model is estimated using data from 1984 to 2009. Two years of data (year 2010 and 2011) are used to validate the model results and to evaluate model performance. The data used in the analysis is shown in the Appendix A.

Explanatory Variables

Different explanatory variables are considered for estimating the diesel consumption model. The fuel demand (gasoline and/or diesel) models used by other state DOTs and state agencies are reviewed to get a clear picture about the state of practice. Explanatory variables used to estimate the fuel consumption model include fuel efficiency, real per-capita personal income, population, population growth, wages, salary growth, VMT, real gasoline price, real disposable income, vehicle fleet size, and employment data (Berwick and Malchose, 2012, WSDOT, 2010). Fuel price and VMT variables appear very tempting to use as explanatory variables for estimating fuel demand. However, estimating future gas prices and VMT are very difficult tasks. Moreover, these variables are more likely to be endogenous to the response variable diesel consumption. The variables tested to obtain the final model specification include population, per capita personal income, and gross domestic product (GDP).

Data Sources

Multiple sources of data and information are used to support the analyses and conclusions in this report. The dependent variable of this study is the annual diesel sales to on-highway consumers in Texas. The diesel consumption data from 1984 to 2011 is collected from the U.S. Energy Information Administration (EIA). Yearly population data is obtained from the Texas Department of State Health Services. Per capita personal income and GDP data are collected from the Bureau of Economic Analysis (BEA). Federal and state tax data are collected from the FHWA website to estimate revenue generated from diesel consumption.

The estimated model specification and results are presented in the following section.

Model Estimation

Model 1: Trend Stationary Model

The first model we estimate is a trend-stationary model where time is the only explanatory variable used in the analysis. We assume there is no serial correlation between the error terms. The parameter estimates of the trend-stationary model are presented in Table 1.

Table 1. Trend-Stationary Model Results.

Dependent Variable: $\log_e$(Diesel Consumption in Gallons)			
Variable	*Parameter Estimate*	*t-Value*	*Pr > |t|*
Intercept	-80.143	-14.98	<0.0001
Year	0.051	19.01	<0.0001
R-square value	0.938		

The coefficient of the trend variable (year) is statistically significant (p-value <0.0001). The year variable can be interpreted as the average per year growth rate in diesel consumption. That means the diesel consumption grows about 5.1% per year on average, holding all other factors fixed. The incorporation of time as an independent variable to explain the variation in diesel consumption performs very well with an R-square value of 0.9377 and root mean square error of 0.10244.

Model 2: Time Series Model with Explanatory Variables

We incorporated three exogenous variables in addition to the trend variable in the regression equation. The variables considered are $\log_e$(population), $\log_e$(per capita personal income), and $\log_e$(GDP). The parameter estimate of the ln (GDP) variable is found to have a negative sign, which is very counterintuitive. The variable is also not statistically significant at a 0.05 significance level and was removed from the model. The model specification with statistically significant parameter estimates is presented in Table 2.

Table 2. Time Series Model Results, Including Explanatory Variables.

Dependent Variable: $\log_e$(Diesel Consumption in gallons)			
Variable	Parameter Estimate	t-Value	Pr > |t|
Intercept	209.034	6.49	<0.0001
Year	-0.109	6.09	<0.0001
ln (Per Capita Personal Income $)	1.599	5.18	<0.0001
ln (Population in millions)	4.865	7.91	<0.0001
R-square value	0.988		

After incorporating exogenous variables, the model is able to explain most of the timewise variation in diesel consumption. The R-squared value of this model is 0.988 and the root mean square is 0.0479. As expected, per capita personal income and population are positively correlated with the diesel consumption. The estimated parameter for the ln(per capita personal income) variable is 1.599, which in a log-log model is also the income elasticity for diesel consumption. The estimated parameter of the ln(population) variable is 4.865, which in the log-log model is the population elasticity for diesel consumption. After accommodating the explanatory variables in the model, the trend variable exhibits a shrinking nature. That means the diesel consumption shrinks about 10.9% per year on average, holding all other factors fixed.

Model 3: First-Order Autoregressive Model

The Yule-Walker procedure is used to estimate a first-order autoregressive model with the natural log of three exogenous variables: per capita personal income, population, and GDP. In this model, the parameter estimate of the ln (per capita personal income) variable is also found to be insignificant at a 0.05 significance level. However, we kept this variable at a significance level of 0.09 in the model since the literature strongly suggests incorporating this variable in a diesel consumption model (WSDOT, 2010). Again, the parameter estimate of the ln (GDP) variable has negative sign, which is very counterintuitive. Parameter estimates of this model that include all three variables and an autoregressive term are shown in Table 3.

Table 3. First-Order Autoregressive Model Results.

Dependent Variable: log_e(Diesel Consumption in gallons)			
Variable	Parameter Estimate	t-Value	Pr > |t|
Intercept	4.806	1.66	0.1114
ln (Per Capita Personal Income $)	0.544	1.79	0.0877
ln (Population in millions)	4.223	4.07	0.0006
ln (GDP)	-0.855	-2.80	0.0106
Auto Regressive Parameter (ρ)	-0.266	-1.27	0.2179
R-square value	0.981		

The first-order autoregressive model explains most of the timewise variation in diesel consumption. The R-squared value of this model is 0.981 and the root mean square is 0.0602. As expected, per capita personal income and population are positively correlated with the diesel consumption. However, the negative sign of the GDP variable is counterintuitive. The parameter estimates of this log-log model also represent the elasticity of the corresponding variables. The parameter estimate for the ln(per capita personal income) variable is 0.544, which in a log-log model is also the income elasticity for diesel consumption. The parameter estimate of the ln(population) variable is 4.223, which in the log-log model is the population elasticity for diesel consumption. The parameter estimate for the ln(per capita personal income) variable is -0.855, which in a log-log model is also the income elasticity for diesel consumption. The first-order autoregressive parameter is negative and not significant at a 0.05 significance level.

Validation/Model Performance Evaluation

The model evaluation process included examination of residuals (difference between estimated diesel consumption and actual diesel consumption) and comparison of the abilities of the three candidate models to reproduce a selected portion of the observed data set. The process is described in Appendix B.

The sum of the absolute residuals for the two-year model-testing period is much lower for the second model compared to the first model. The sum of the squares of the residuals for the forecasted two years is also smaller for Model 2 compared to Model 1 and Model 3. Both of the measures show that Model 2 (the model with explanatory variables) performs better in forecasting diesel consumption compared to the other two models.

Forecasting

Using the estimated parameters for the trend stationary model, the diesel consumption is forecasted for year 2012 to 2025. For the second and third models, the population and the per capita personal income variables must be estimated using separate models. We use a time stationary model to estimate and consequently forecast those exogenous variables. For population, a linear time trend model gives the best model fit. For per capita personal income, a quadratic time trend model gives the best fit. For GDP, an exponential time trend model gives the best model fit. Figures 1, 2, and 3 show the diesel consumption model for the estimation years (labeled *1* in the circle), validation years (labeled *2* in the circle), and forecast year (labeled *3* in the circle) for the three models under consideration. The first model seems to over-estimate the diesel consumption, especially during the periods of economic recession. The second model and third models follow the actual diesel consumption data for the estimation and validation periods very well and therefore are more likely to forecast the diesel consumption better than the trend stationary model. However, the second model is preferred for the revenue estimation based on the model performance measures, the intuitive parameter estimates, and the R-squared statistic. Since statistical models are simplified representations of reality based upon observed data, economic shocks of recession or spiking oil/fuel prices may render usually reliable forecasts worthless. Therefore, the expected variation of the diesel consumptions are calculated for all the models at 95% confidence and shown in the figures with small dashed lines for the forecast periods.

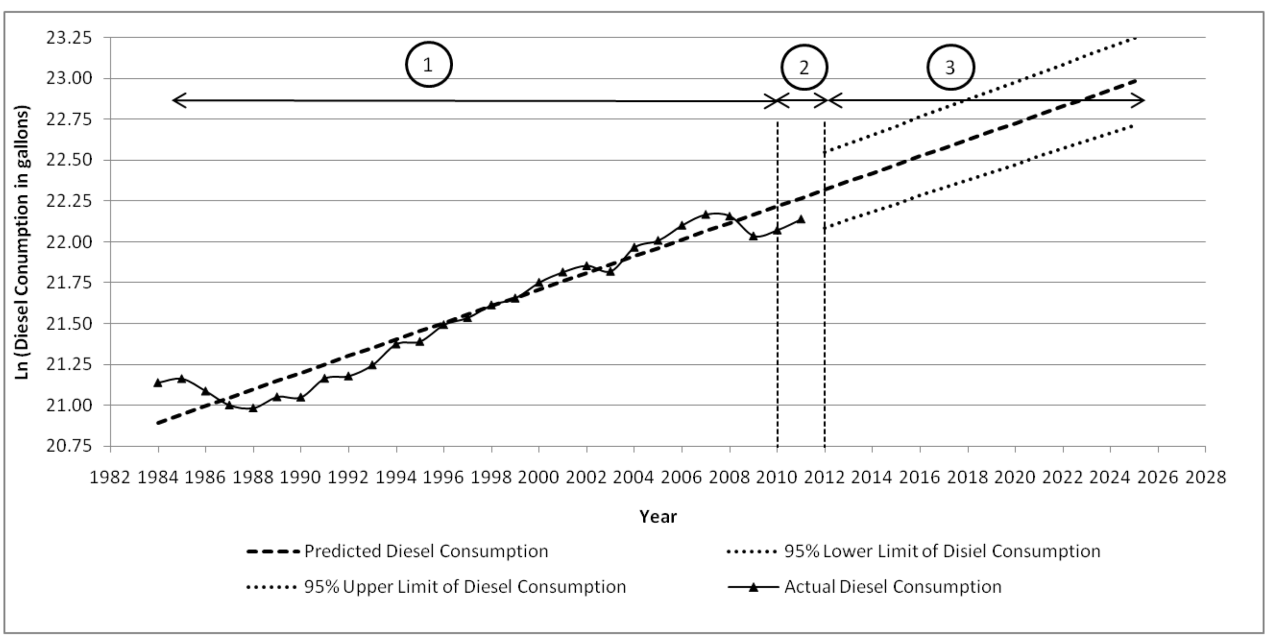

Figure 1. Annual Diesel Consumption Model and Forecast (Trend Stationary Process).

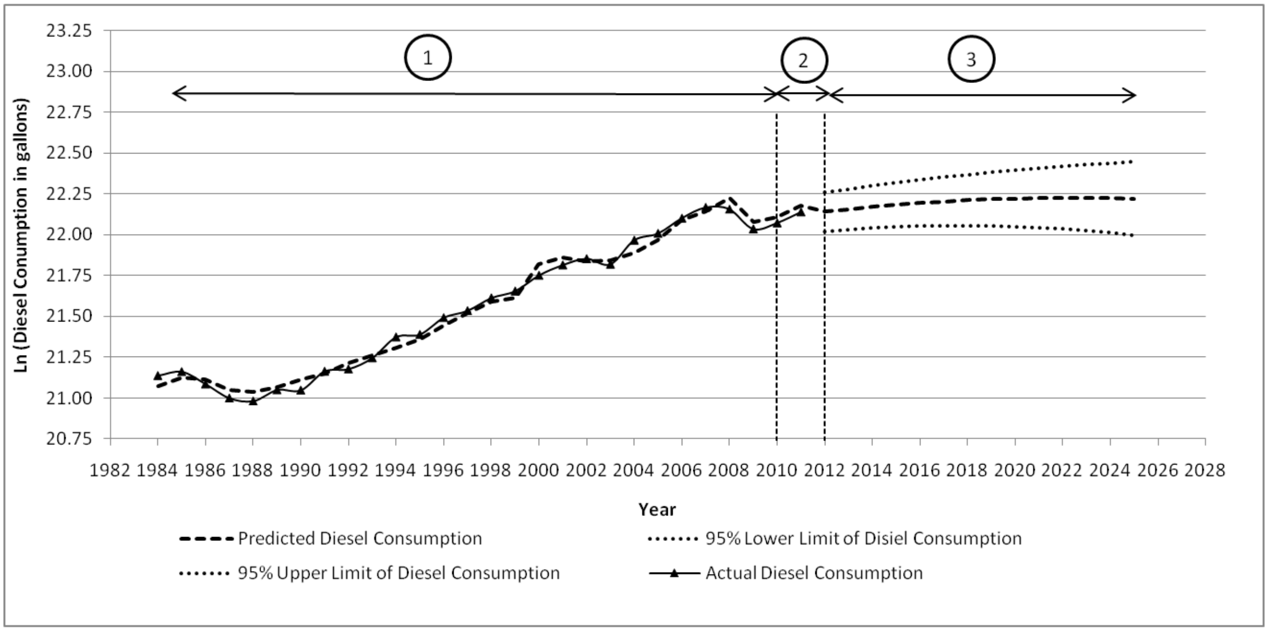

Figure 2. Annual Diesel Consumption Model and Forecast (Time Series Model Including Exogenous Variables).

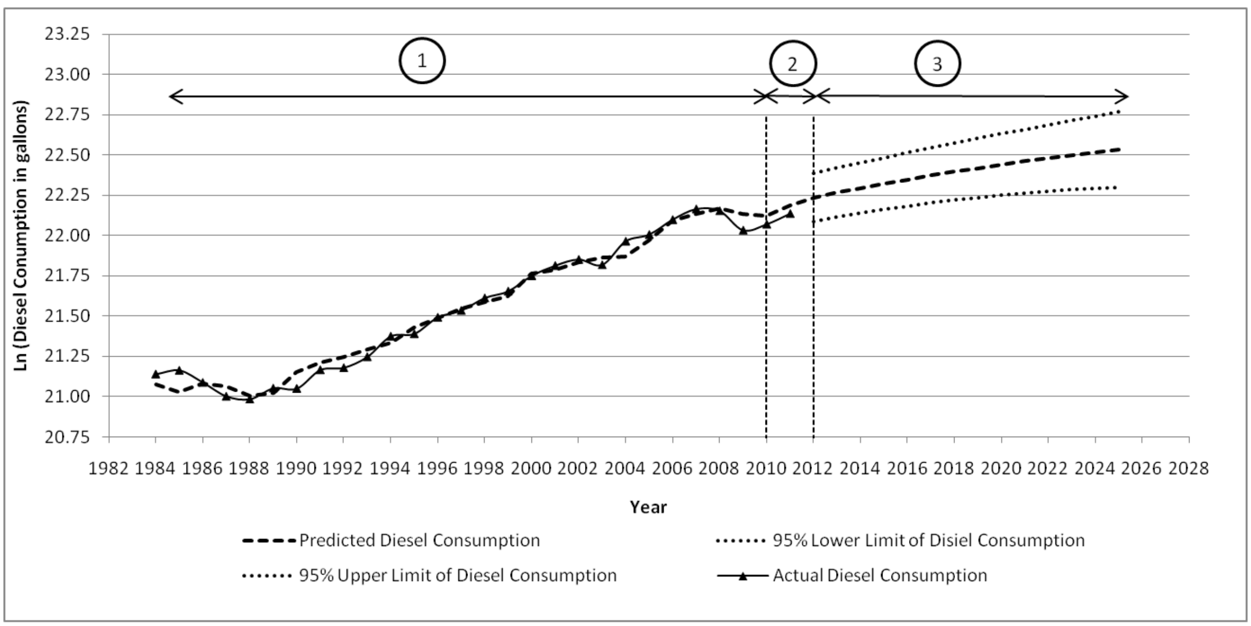

Figure 3. Annual Diesel Consumption Model and Forecast (First-Order Autoregressive Time Series Model).

4. REVENUE CALCULATION

Current federal and Texas state tax rates and the time series model with explanatory variables (Model 2) are used to estimate the revenue generated from diesel consumption. The tax rates used in revenue calculation are presented in Table 4.

Table 4. Tax Rates Used in Revenue Calculation.

Texas and Federal Motor Fuel Excise Taxes		
Current Nominal Rates		
	Diesel	LNG
	$/gallon	$/gallon
Federal	0.244	0.119
State	0.2	0.15
Adjusting for Taxes Received by Texas [Texas receives 87.9% of federal tax.]		
Federal	0.2145	0.1046
State	0.2	0.15
Adjusting for Energy Equivalent Volumes [LNG contains 60% of the energy per diesel gallon]		
Federal	0.2145	0.1743
State	0.2	0.25
Effective Texas Rate Per Liquid Gallon		
Total $/gallon	**0.4145**	**0.4243**

Table 4 shows that the current nominal excise tax rates are adjusted to account for the 87.9% of federal taxes that actually return to Texas. Because diesel and LNG excise taxes are based upon liquid gallons, the LNG rate must be adjusted to account for the fact that LNG contains approximately 60% of the energy in a gallon of diesel. Therefore, roughly speaking, a vehicle will use 1.667 gallons of LNG to travel the same distance as it could travel on 1 gallon of diesel. Therefore, the effective tax rates show that almost 1¢ more tax would be collected for each *diesel equivalent gallon* of LNG compared to each gallon of diesel fuel.

Based on the estimated diesel consumption and the revenue generated from diesel consumption, we estimate the revenue for three scenarios where 10%, 20%, and 50% of diesel consumption would be replaced by LNG consumption. The revenue calculation takes into account the diesel gallon equivalents (DGE) energy of LNG fuel and the current state and federal tax rates. The revenue calculation assumes that Texas receives about $0.879 per dollar of collected federal tax (FHWA, 2010). Inflation rates are not considered in the revenue calculation. In this study, we assume the tax rates will remain the same for the forecast periods. We also assume the price of LNG will be competitive with the diesel price. Figure 4 shows the estimated average revenue for four scenarios from 1984 to 2025.

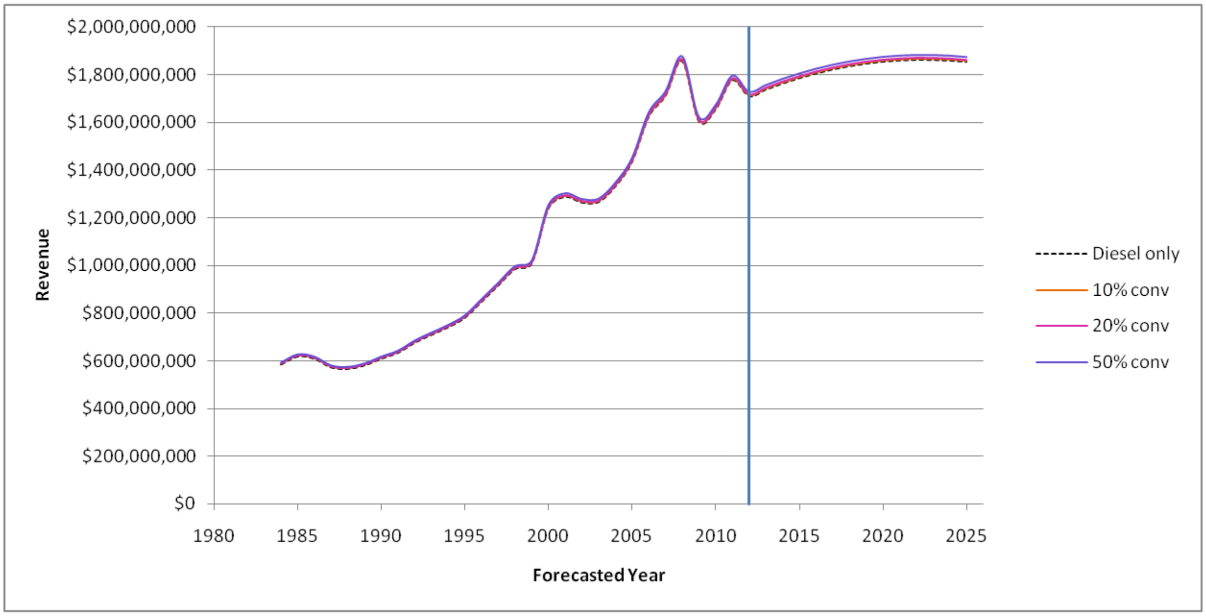

Figure 4. Estimated Average Revenue.

Figure 5 shows the revenue comparison only for the forecast years. The forecast shows the LNG conversion results in an increase in Texas state revenues. The magnitude of increased revenue increases as more LNG replaces diesel consumption. The added benefit arises because 1.67 gallons of LNG are required to get the same energy as 1 gallon of diesel.

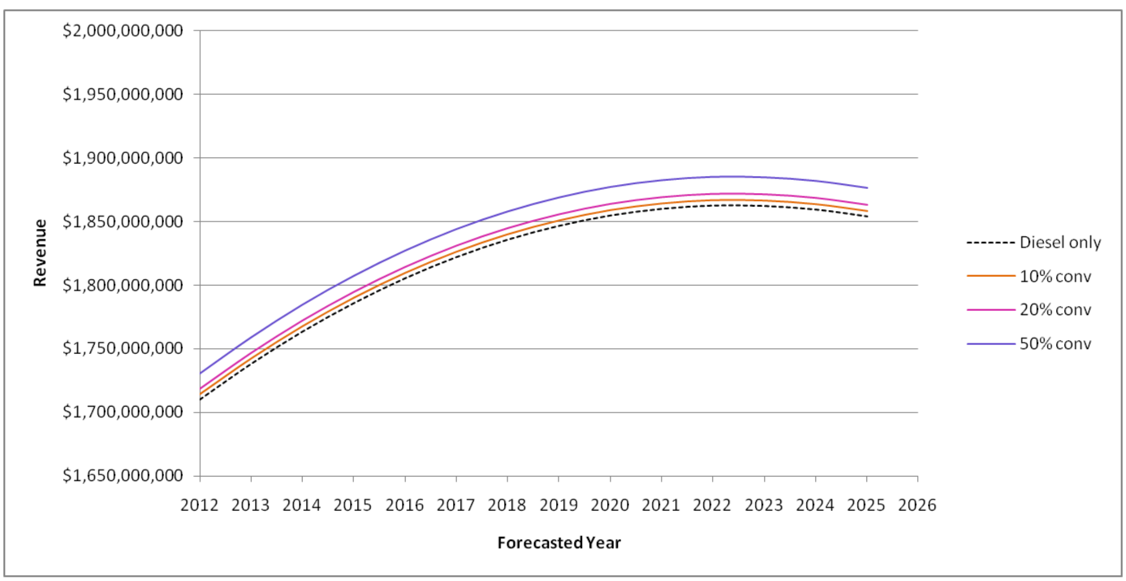

Figure 5. Added Revenue from LNG Conversion.

The added revenue generated after conversion is calculated for all three scenarios and presented in Table 5. The LNG conversion can potentially increase the revenues more than $4 million if the LNG substitutes for 10% of diesel consumption in 2013. For the same year, a 20% substitution yields added revenue of slightly more than $8 million and a 50% substitution results in added revenue of more than $20 million. The forecast also shows the revenue steadily increasing from year 2012 to 2022 and then slightly decreasing afterwards.

Table 5. Estimated Revenue from LNG Conversion.

Forecast year	Only Diesel	10% LNG + 90% Diesel	20% LNG + 80% Diesel	50%LNG + 50%Diesel	Revenue Generated from LNG use		
					10% LNG	20% LNG	50% LNG
2012	$1,710,172,010	$1,714,239,938	$1,718,307,866	$1,730,511,650	$4,067,928	$8,135,856	$20,339,641
2013	$1,738,276,241	$1,742,411,019	$1,746,545,798	$1,758,950,134	$4,134,779	$8,269,557	$20,673,894
2014	$1,763,664,869	$1,767,860,039	$1,772,055,208	$1,784,640,718	$4,195,170	$8,390,340	$20,975,849
2015	$1,786,027,636	$1,790,275,999	$1,794,524,362	$1,807,269,452	$4,248,363	$8,496,727	$21,241,817
2016	$1,805,601,823	$1,809,896,746	$1,814,191,670	$1,827,076,442	$4,294,924	$8,589,848	$21,474,619
2017	$1,822,290,007	$1,826,624,627	$1,830,959,246	$1,843,963,104	$4,334,619	$8,669,239	$21,673,097
2018	$1,836,008,563	$1,840,375,814	$1,844,743,065	$1,857,844,819	$4,367,251	$8,734,503	$21,836,256
2019	$1,846,873,032	$1,851,266,126	$1,855,659,220	$1,868,838,503	$4,393,094	$8,786,188	$21,965,471
2020	$1,855,017,177	$1,859,429,643	$1,863,842,110	$1,877,079,509	$4,412,466	$8,824,933	$22,062,332
2021	$1,860,218,504	$1,864,643,342	$1,869,068,181	$1,882,342,697	$4,424,839	$8,849,677	$22,124,193
2022	$1,862,824,633	$1,867,255,671	$1,871,686,709	$1,884,979,822	$4,431,038	$8,862,076	$22,155,189
2023	$1,862,452,106	$1,866,882,257	$1,871,312,409	$1,884,602,864	$4,430,152	$8,860,303	$22,150,758
2024	$1,859,660,522	$1,864,084,033	$1,868,507,545	$1,881,778,079	$4,423,511	$8,847,023	$22,117,557
2025	$1,854,275,319	$1,858,686,020	$1,863,096,722	$1,876,328,828	$4,410,702	$8,821,404	$22,053,509

5. CONCLUSIONS

The abundance of shale natural gas resources and advancement in drilling technology have produced a sound supply of natural gas in the U.S. The environmental benefit of LNG over diesel makes LNG a cleaner fuel choice. The energy density of LNG, price fluctuations of crude-oil-based fuels, and comparatively low price of LNG presents an attractive alternative for the trucking companies. The conversion of vehicles from diesel to LNG or the purchase of new LNG-powered trucks will affect the state revenue that is generated from fuel consumption. In this study, we estimated a diesel consumption model based on historical data to evaluate the impact of such substitution.

Three different forms of time series models were developed using data from 1984 to 2009. The first model is a time stationary model that includes only time as the explanatory variable. The second model incorporates per capita personal income and population in addition to time as independent variables. We estimate a third model that exclusively considers serial correlation between the error terms.

Model validation showed that the second model performs better compared to the first and third models. The second model was selected to forecast diesel consumption for 2012 to 2025. The estimated diesel consumption was used to calculate the state revenue generated from diesel consumption. Then we estimated the revenue for three scenarios where 10%, 20%, and 50% of diesel consumption would be replaced by LNG consumption. All these cases show that substituting LNG for diesel would result in greater revenue for the state of Texas (contingent upon the present tax rates remaining the same for the forecast years).

CHAPTER 3. COMPRESSED NATURAL GAS (CNG)

1. INTRODUCTION TO CNG

Compressed natural gas (CNG) is an alternative fuel derived from natural gas and contains about 95% methane. CNG has become a viable alternative fuel in many countries around the globe in response to higher gasoline prices and concerns over the environmental impact of petroleum consumption for transportation. The U.S. Department of Energy (U.S. DOE) reports that CNG vehicles produce 60% to 90% less smog-producing pollutants and reduce greenhouse gas emissions by 30% to 40%. In the United States, the price of CNG is less volatile compared with gasoline because 94% of U.S. natural gas is produced domestically (U.S. DOE). In 2011, about 45% of the petroleum consumed was imported from foreign countries (U.S. EIA). The U.S. Congress strongly supports reducing petroleum use and has passed laws to provide incentives for natural gas users.

The State of Texas also promotes the use of CNG as an alternative to gasoline. As a part of the Texas Emissions Reduction Plan, the Texas Commission on Environmental Quality (TCEQ) administers the Clean Transportation Triangle Program, which awards grants to support the development of a network of natural gas fueling stations along the interstate highways connecting Houston, San Antonio, Dallas, and Forth Worth (U.S. DOE). The Texas Gas Service Conservation Program offers commercial and residential customers in the Austin and Sunset Valley area a $2,000 rebate for the purchase of a natural gas vehicle or $3,000 for conversion of a gasoline-powered vehicle to operate on natural gas, and a $1,000 rebate for the purchase of a natural gas forklift. The program also offers a $2,000 incentive for the installation of a vehicle-refueling unit (Texas gas service). CNG gas use is further encouraged by a tax incentive. A tax credit of $0.50 per gasoline gallon equivalent (GGE) is available for CNG users between January 1, 2005, and December 31, 2013 (U.S. DOE).

CNG vehicles may be safer than traditional vehicles for a number of reasons. The cylinders that hold the compress natural gas are significantly stronger than gasoline tanks, making them less likely to ignite after a collision. They have withstood impact and bonfire testing and meet U.S. Department of Transportation safety standards. Additionally, natural gas is lighter than air and will dissipate upward rapidly in the unlikely event of a leak (Bakar, 2008; Texas Gas Service). The long term engine performance of CNG-powered vehicles may also be better compared with the performance of gasoline-powered vehicles because natural gas does not produce sludge, acids, and residue, as gasoline does (CNG California).

In the U.S., the price of CNG fuel has remained steady and significantly lower than gasoline. However, the purchase prices for new CNG-powered vehicles are currently higher compared with those of gasoline-powered vehicles, although the fuel cost savings of CNG vehicles can make up the incremental cost over the life of CNG vehicles (Yacobucci, 2011). Honda manufactures dedicated CNG-powered sedans that are comparable to its gasoline-powered sedans. The purchase price difference between a conventional Honda Civic EX and a dedicated CNG-powered Honda Civic GX is roughly $6,000. Gasoline-fueled vehicles can be converted to use CNG through conversion processes that currently cost approximately $10,000 to $18,000 and include the retrofit system, fuel tanks and related tubing/brackets, and installation (NGV America, 2012).

The likelihood of CNG consuming a significant fraction of the gasoline motor fuel market is, of course, dependent upon the market prices of the two competing products. A check on CNG prices at the pump in the Austin area in early April 2013 indicates that the prices were approximately $2.10 per GGE plus $0.15 state fuel tax. (In Texas, CNG users buy an annual prepaid tax label based on vehicle weight and miles traveled; this label's cost is based on $0.15 per GGE state tax). Gasoline fuel at the same time was priced around $3.50 per gallon. Applying the $0.50 per gallon federal tax credit, the CNG price becomes $1.75 per gallon, which is half the gasoline price. As already mentioned, under current law, the $0.50 per gallon tax credit is being paid from the federal general fund, not the Highway Trust Fund, so it does not currently affect the transportation revenue available to Texas. Assuming the average retail price of gasoline remains between $1 to $1.75 per gallon greater than CNG, the annual fuel cost savings of a vehicle using CNG with energy efficiency of 28 miles per gallon and usage of 12,000 miles per year would be roughly $429 to $750 (U.S. DOE).

Although CNG-fueled vehicles have been in the U.S. market for a long time, their number is quite small compared to gasoline-fueled vehicles. In 2009, the U.S. had about 114,270 CNG vehicles and 69,018 of them (slightly more than 60%) were light-duty vehicles (U.S. EIA, 2011). This compares with roughly 240 million conventional (mostly gasoline) light-duty vehicles (Davis et al., 2011). Currently, 574 public CNG stations in the U.S. compete with more than 120,000 retail gasoline stations (U.S. DOE, Statistics Brain). The market share of CNG vehicles is not significant because of the higher price of new CNG vehicles, conversion cost, concerns about vehicle performance, and limited fuel infrastructure (Yacobucci, 2011). However, the abundance of natural gas in the U.S., the volatile price of gasoline, substantial price differences between CNG and gasoline, automobile manufacturer interest in CNG light-duty vehicles, federal and state incentives for CNG infrastructure, and observed environmental benefits are likely to increase the market share of CNG vehicles. Thus, evaluating the potential impact on the state economy is crucial.

2. ANALYSIS AND RESULTS

Because CNG energy density is roughly 25% compared to gasoline, CNG-fueled vehicles need large on-board storage tanks but still have limited mileage ranges. Range is a significant issue for heavy-duty long-haul trucks, but it is much less important for light-duty passenger cars and trucks. Therefore, CNG is generally considered primarily as an alternative fuel for light-duty gasoline-powered vehicles. If CNG primarily competes with gasoline in the vehicle fuel market, estimates of its market intrusion might be related to the overall gasoline fuel market.

A gasoline fuel usage prediction model for Texas was developed. To estimate the gasoline consumption model, combinations of independent variables and three different functional forms of time series analysis were examined to arrive at the best alternative annual forecast model. Data issues, model specifications, critical assumptions, and forecast performance are described. Two different forms of dependent variables were considered: gasoline consumption in millions of gallons and the $\log_e$ of gasoline consumption in gallons. The second model gives a better R-squared value for all the models considered. Time series data for the dependent and explanatory variables were collected from 1981 to 2011. The gasoline consumption model is estimated using data from 1981 to 2009. Two years of data (2010 and 2011) are used to validate the model results and to evaluate model performance. Appendix C provides the data used in the analysis.

Explanatory Variables

The gasoline consumption model development process included a review of the fuel demand (gasoline and/or diesel) models used by other state DOTs and agencies to get a clear picture of the state of practice. Explanatory variables were considered to estimate the fuel consumption model include fuel efficiency, real per-capita personal income, population, population growth, wages, salary growth, vehicle miles traveled (VMT), real gasoline price, real disposable income, vehicle fleet size, and employment data (Berwick and Malchose, 2012, WSDOT, 2010). Fuel price and VMT variables are excluded in order to avoid the complexity of their estimation for future periods. Moreover, these variables are more likely to be endogenous to the response variable for gasoline consumption. The variables tested to obtain the final model specification include population, per capita personal income, and gross domestic product (GDP).

Data Sources

Multiple sources of data and information are used to support the analyses and conclusions in this report. The dependent variable of this study is the annual gasoline sales to on-highway consumers in Texas. The gasoline consumption data from year 1981 to 2011 is collected from the U.S. Energy Information Administration (EIA). Yearly population data is obtained from the Texas Department of State Health Services. Per capita personal income and GDP data are collected from the Bureau of Economic Analysis (BEA). Federal and state tax data are collected from the FHWA website to estimate revenue generated from gasoline consumption.The estimated model specification and results are presented in the following section.

Model Estimation

Model 1: Trend Stationary Model

The first model we estimate is a trend-stationary model where time is the only explanatory variable used in the analysis. We assume there is no serial correlation between the error terms. The parameter estimates of the trend-stationary model are presented in Table 6.

Table 6. Trend-Stationary Model Results.

Dependent Variable: log_e(Gasoline Consumption in Gallons)			
Variable	*Parameter Estimate*	*t-Value*	*Pr > |t|*
Intercept	-10.6845	-5.59	<0.0001
Year	0.0169	17.60	<0.0001
R-square value	0.9198		

The coefficient of the trend variable (year) is statistically significant (p-value <0.0001). The year variable can be interpreted as the average per year growth rate in gasoline consumption. That means the gasoline consumption grows about 1.7% per year on average, holding all other factors fixed. The incorporation of time as an independent variable to explain the variation in gasoline consumption performs very well with an R-squared value of 0.9198 and root mean square error of 0.04318.

Model 2: Time Series Model with Explanatory Variables

We incorporated three exogenous variables in addition to the trend variable in the regression equation. The variables considered are $\log_e$(population), $\log_e$(per capita personal income), and $\log_e$(GDP). The per capita personal income variable was not significant and was removed from the model. The parameter estimates of ln(GDP) and ln(Population) are positive as expected. Although the GDP variable is not significant at a 0.05 level, we kept it as a proxy of economic growth over time. The model specification is presented in Table 7.

Table 7. Time Series Model Results, Including Explanatory Variables.

Dependent Variable: $\log_e$(Gasoline Consumption in gallons)			
Variable	Parameter Estimate	t-Value	Pr > |t|
Intercept	71.0300	6.84	<0.0001
Year	-0.0281	-4.86	<0.0001
ln (GDP in million $)	0.1751	1.73	0.0963
ln (Population in millions)	1.9268	6.90	<0.0001
R-square value	0.9808		

After incorporating exogenous variables, the model is able to explain most of the timewise variation in gasoline consumption. The R-squared value of this model is 0.9808 and the root mean square is 0.02199. As expected, GDP and population are positively correlated with gasoline consumption. The estimated parameter for the ln (GDP in million $) variable is 0.1751, which in a log-log model is also the GDP elasticity for gasoline consumption. Similarly, the estimated parameter of the ln(population) variable is 1.9268 and in the log-log model is the population elasticity for gasoline consumption. After accommodating the explanatory variables in the model, the trend variable exhibits a shrinking nature. That means the gasoline consumption shrinks about 2.81% per year on average, holding all other factors fixed.

Model 3: First-Order Autoregressive Error Model

The Yule-Walker procedure is used to estimate a first-order autoregressive error model with the natural log of three exogenous variables: per capita personal income, population, and GDP. In this model, the population and the auto regressive parameters are found to be statistically significant at a 0.05 level.

Table 8. First-Order Autoregressive Error Model Results.

Dependent Variable: log_e(Gasoline Consumption in gallons)			
Variable	Parameter Estimate	t-Value	Pr > |t|
Intercept	20.2627	103.04	<0.0001
ln (Population in millions)	0.9190	13.79	<0.0001
Auto Regressive Parameter (ρ)	-0.6631	-4.52	<0.0001
R-square value	0.9793		

The first-order autoregressive model explains most of the timewise variation in gasoline consumption. The R-squared value of this model is 0.9793 and the root mean square is 0.02235. As expected, population is positively correlated with the gasoline consumption. However, the GDP variable is found statistically not significant for the first-order auto-regressive error model. The parameter estimates of this log-log model also represent the elasticities of the corresponding variables. The parameter estimate of the ln(population) variable is 0.9190, which in the log-log model is the population elasticity for gasoline consumption. The first-order autoregressive parameter is negative and significant at the 0.05 significance level.

Validation/Model Performance Evaluation

We first plot the residuals (difference between the estimated gasoline consumption and the actual gasoline consumption) of the estimated models to visually examine the residuals' distribution. The residual plot for the first model (Figure 6) shows that the residuals of the adjacent periods have the same sign and also exhibit stickiness between the adjacent periods, indicating the presence of serial correlation between the error terms of this model. On the other hand, the residual distribution for Model 2 and Model 3 (Figures 7 and 8) show a fairly random scatter plot around zero. Very few adjacent residuals are observed to have similar values and display less stickiness compared to the first model, indicating that the explanatory variables remove most of the serial correlation. The magnitudes of the residuals are also smaller for both Model 2 and Model 3 compared to the first model's residuals.

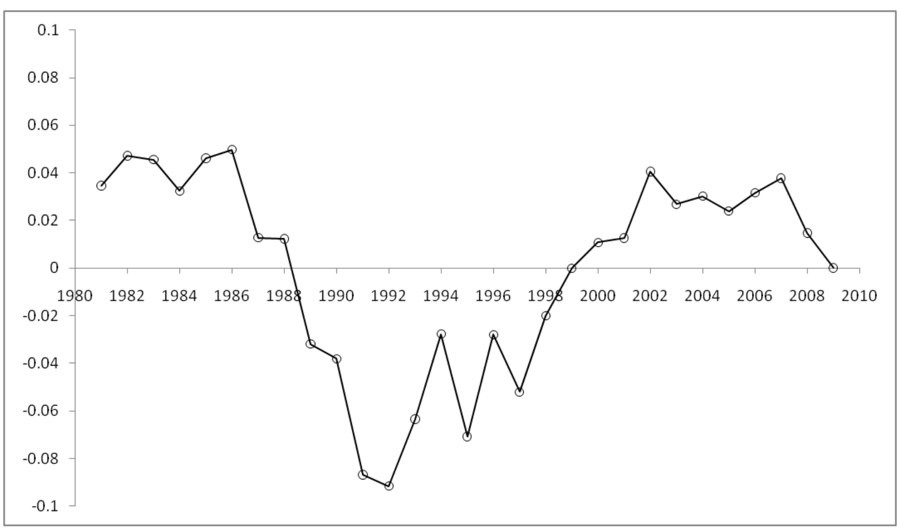

Figure 6. Residual Plot for Trend Stationary Model (Model 1).

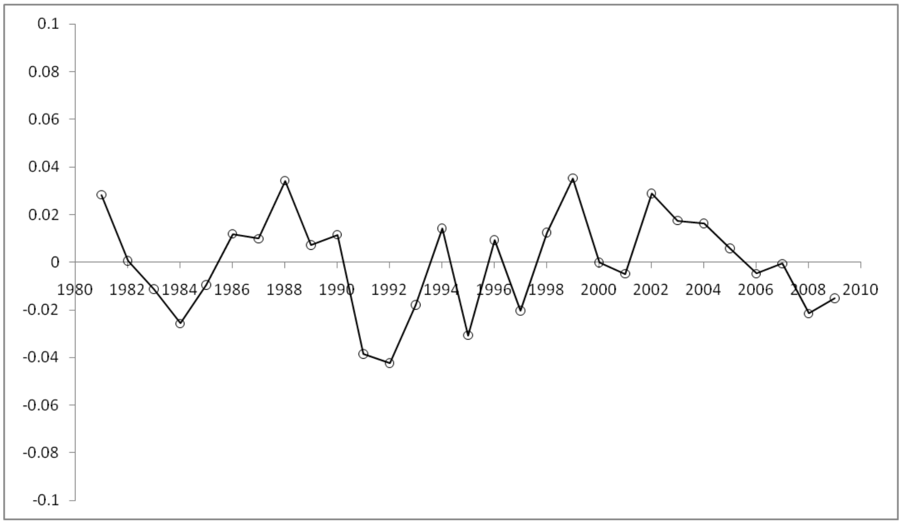

Figure 7. Residual Plot for Time Series Model with Explanatory Variables (Model 2).

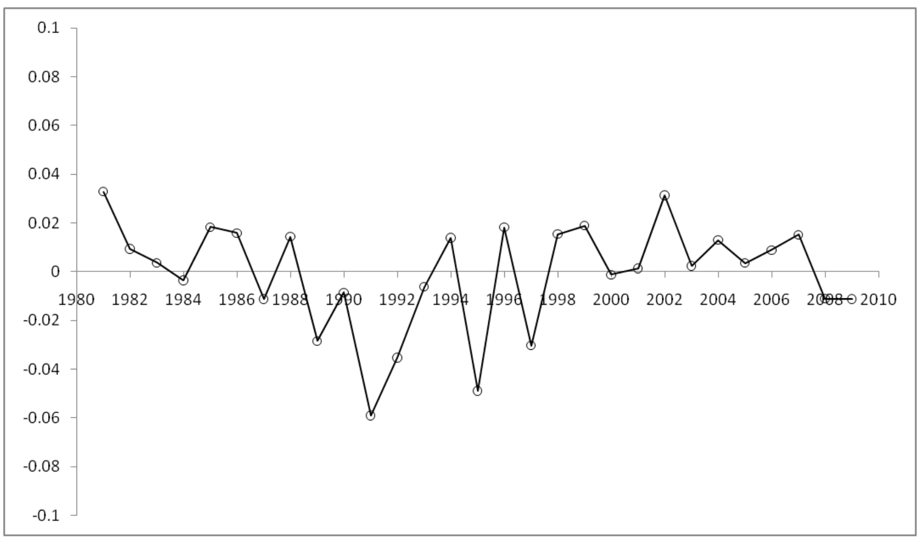

Figure 8. Residual Plot for First-Order Autoregressive Error Model (Model 3).

The estimated coefficients for the models are used to forecast the gasoline consumption for year 2010 and 2011. The forecasted values are compared with the actual gasoline consumption data to calculate the performance measures. The calculated performance measures for the models are presented in Tables 9-11.

Table 9. Model 1 Performance Measures.

Model 1: Trend-Stationary Model			
ln (Gasoline Consumption)		$\sum_{t=2010}^{T=2011} \lvert y_t - y_{t,Forecast} \rvert$	$\sum_{t=2010}^{n=2011} (y_t - y_{t,Forecast})^2$
Forecasted	Actual		
23.2208	23.2217	0.000905008	0.00000819
23.2377	23.1988	0.038903329	0.00151347
		0.039808337	0.00151428

Table 10. Model 2 Performance Measures.

Model 2: Time Series Model with Exogenous Variable			
ln (Gasoline Consumption)		$\sum_{t=2010}^{T=2011} \lvert y_t - y_{t,Forecast} \rvert$	$\sum_{t=2010}^{n=2011} (y_t - y_{t,Forecast})^2$
Forecasted	Actual		
23.2329	23.2217	0.011195	0.000125
23.2568	23.1988	0.058003	0.003364
		0.069198	0.003490

Table 11. Model 3 Performance Measures.

Model 3: First-Order Autoregressive Time Series Model			
ln (Gasoline Consumption)		$\sum_{t=2010}^{T=2011} \lvert y_t - y_{t,Forecast} \rvert$	$\sum_{t=2010}^{n=2011} (y_t - y_{t,Forecast})^2$
Forecasted	Actual		
23.2224	23.2217	0.000695	0.0000048
23.2442	23.1988	0.045403	0.002061
		0.046098	0.002062

The sum of the absolute residuals for the two-year model-testing period is the lowest for the first model. The sum of the squares of the residuals for the forecasted two-year period is also smaller for Model 1 compared to Model 2 and Model 3. However, serial autocorrelation is more likely to be present in the first model compared to the other models. Moreover, a two-year time period provides a small number of observations for validating the models. However, the sum of the absolute residuals and the sum of the squares of the residuals for the two-year validation periods show a better performance of Model 3 compared to Model 2.

Forecasting

Using the estimated parameters for the trend stationary model and the time series model with exogenous variables, gasoline consumption is forecasted for years 2012 to 2025. For the second and third models, the population and GDP variables must be estimated using separate models. We use a trend stationary model to estimate and consequently forecast those exogenous variables. For population and also for GDP, the exponential trend stationary model gives the best model fits. Figures 9, 10, and 11 show the gasoline consumption model for the estimation years (labeled *1* in the circle), validation years (labeled *2* in the circle), and forecast years (labeled *3* in the circle) for the three models under consideration. The first model seems to over-estimate gasoline consumption, especially during the periods of economic recession. The second and third models follow the actual gasoline consumption data for the estimation periods very well, but the third model performs better for the validation periods and therefore is more likely to forecast future gasoline consumption better than Model 1 or Model 2. Therefore, the third model is preferred for revenue estimation based on the model performance measures, the intuitive parameter estimates, and a good R-squared statistic. Since statistical models are simplified representations of reality using observed data, economic shocks of recession or spiking oil/fuel prices may render usually reliable forecasts worthless. The expected variations of gasoline consumption are calculated for all the models at a 95% confidence level and are shown in the figure as small dotted line bands about the model forecast.

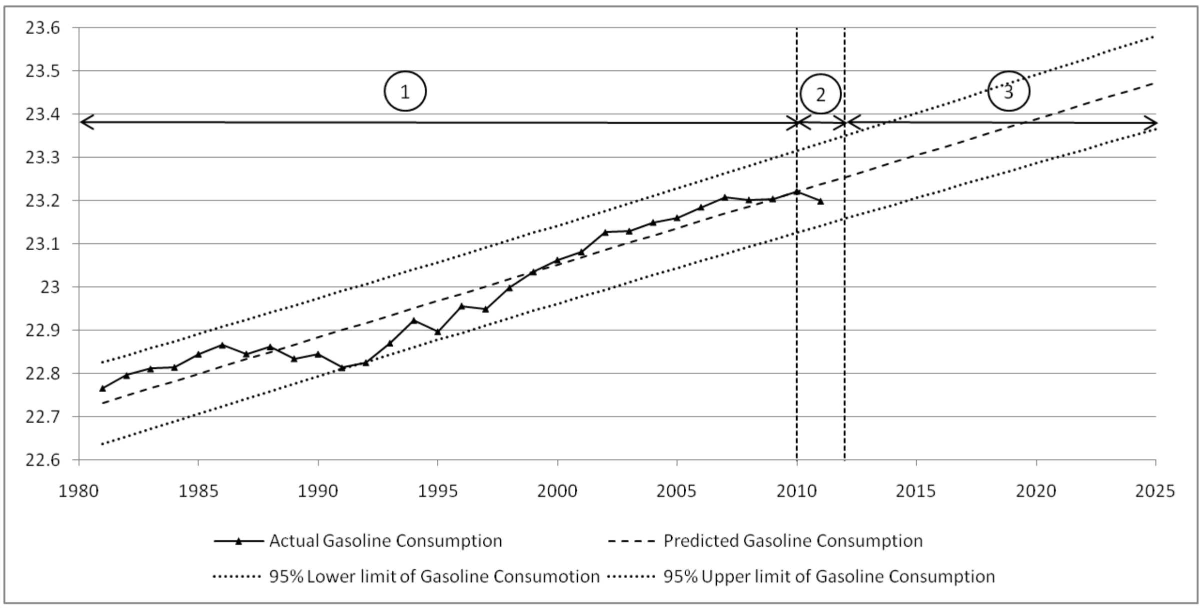

Figure 9. Annual Gasoline Consumption Model and Forecast (Trend Stationary Process, Model 1).

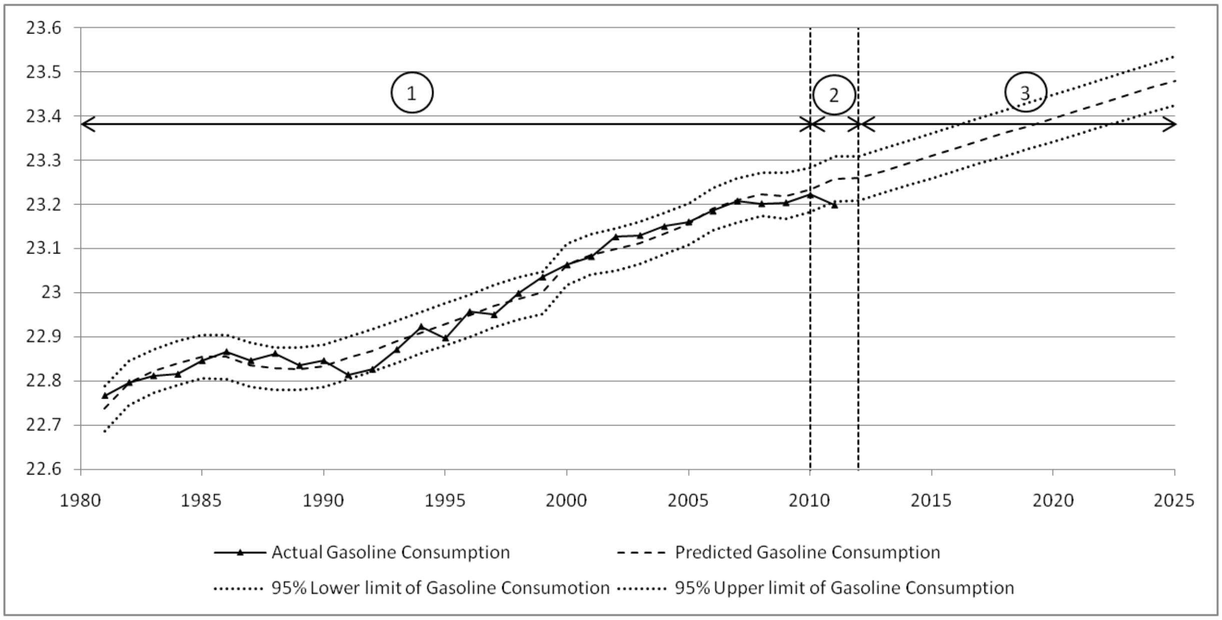

Figure 10. Annual Gasoline Consumption Model and Forecast (Time Series Model including Exogenous Variables, Model 2).

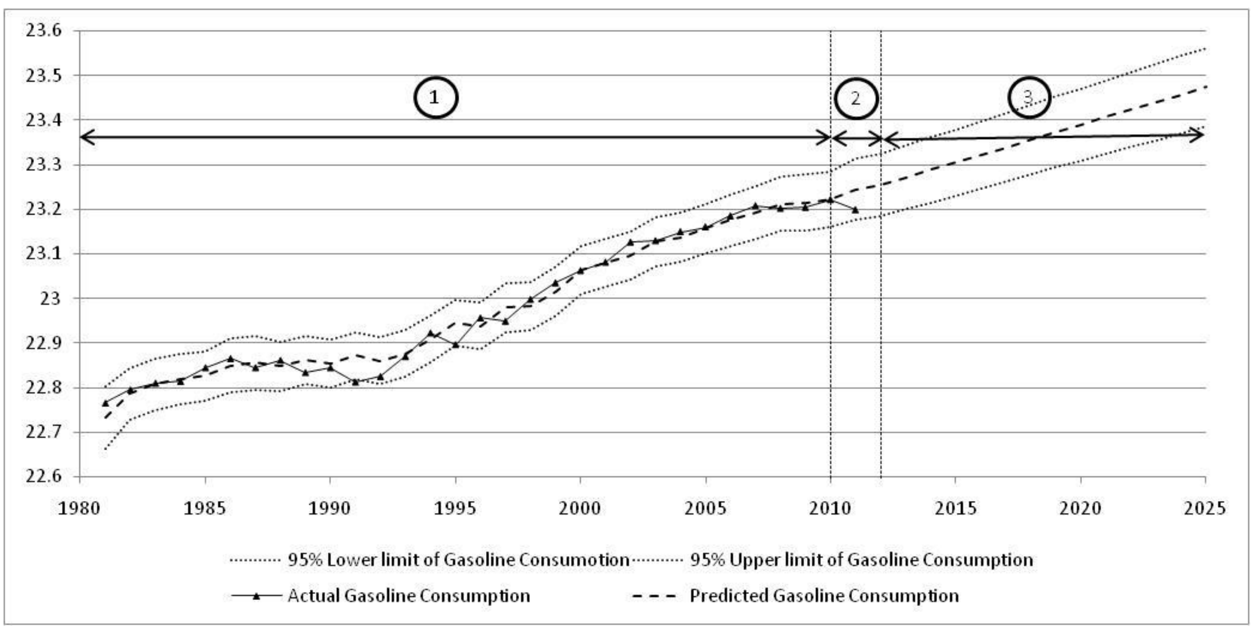

Figure 11. Annual Gasoline Consumption Model and Forecast (First-Order Autoregressive Error Model, Model 3).

Revenue Calculation

The models use current federal and Texas state tax rates and the time series model with explanatory variables (Model 3) to estimate the revenue generated from gasoline consumption. The tax rates used in revenue calculation are presented in Table 12.

Table 12. Tax Rates Used in Revenue Calculation.

Texas and Federal Motor Fuel Excise Taxes		
Current Nominal Rates		
	Gasoline	CNG
	$/gallon	$/GGE
Federal	0.184	0.183
State	0.200	0.150
	Adjusting for Taxes Received by Texas	
	Texas receives 83.9% of federal tax for gasoline.	Texas receives 93.3% of federal tax for CNG.
Federal	0.154	0.171
State	0.200	0.150
Effective Texas Rate Per Gallon		
Total $/gallon	**0.354**	**0.321**

Table 12 shows that the current nominal excise tax rates are adjusted to account for the 83.9% of federal tax for gasoline and 93.3% of federal tax for CNG that is actually returned to Texas. The effective tax rates show that almost 3.36¢ more tax would be collected for each gallon of *gasoline* compared to each GGE of CNG fuel. Additionally, although current federal law (through December 31, 2013) provides a $0.50 per GGE Alternative Fuel Excise Tax Credit for CNG purchases, this rebate is paid from general revenue, not the Highway Trust Fund. Therefore, the Alternative Fuel Excise Tax Credit for CNG is excluded from the transportation revenue calculations.

Based on the estimated gasoline consumption and the revenue generated from gasoline consumption, we estimate the revenue for three scenarios where 10%, 20%, and 50% of gasoline consumption would be replaced by CNG consumption. The revenue calculation takes into account the current state and federal tax rates. The revenue calculation for Texas assumes that Texas receives about $0.839 per dollar of collected federal tax from gasoline consumption and $0.933 per dollar of collected federal tax from CNG consumption. Inflation rates are not considered in the revenue calculation. In this study, we assume the tax rates will remain the same for the forecast periods. Figure 12 shows the estimated average revenue for four scenarios from 1981 to 2025.

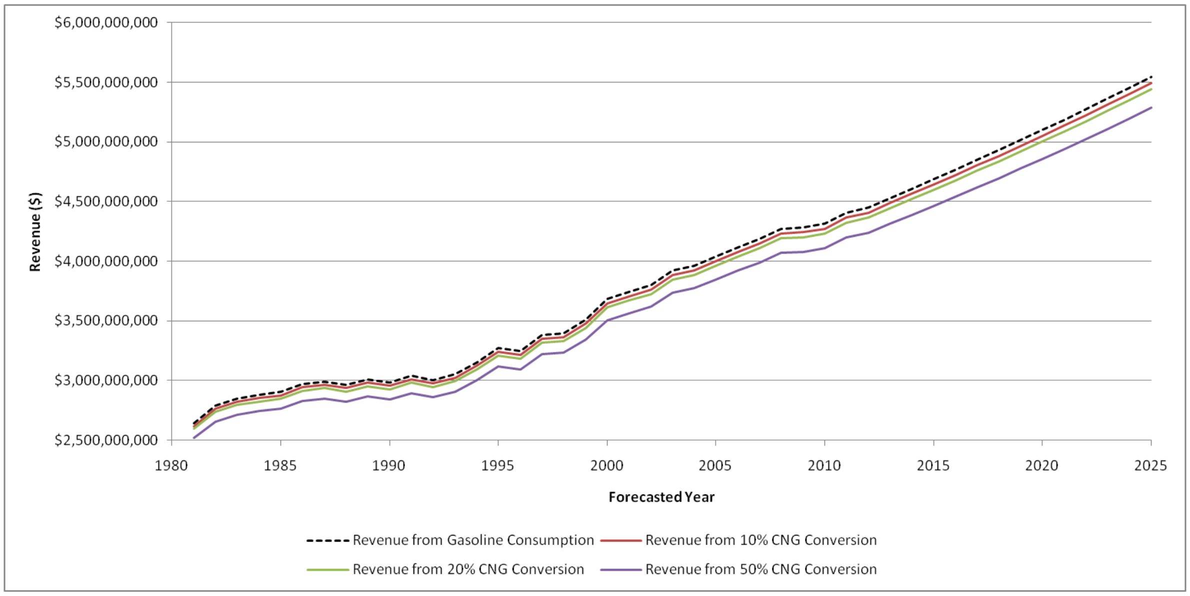

Figure 12. Estimated Annual Revenue.

Figure 13 shows the revenue comparison only for the forecast years. The forecast shows the CNG conversion results in a decrease in Texas state revenues compared to the base case (for the base case, revenue is calculated assuming only gasoline is consumed and no CNG conversions are performed). The magnitude of reduced revenue increases as more CNG replaces gasoline consumption. The reduction in revenue occurs because each time a GGE of CNG replaces a gallon of gasoline, the state revenue fund incurs a loss of 3.36¢. This loss results because the state tax rate for CNG is very low compared to gasoline. Table 37 in Appendix D presents the state tax rates for CNG in various U.S. states (IFTA, 2012). As we can see, most states have a higher tax rate for CNG fuel. A moderate increase in state tax for CNG can help Texas not only overcome this reduction in state revenue but also generate revenue from CNG consumption.

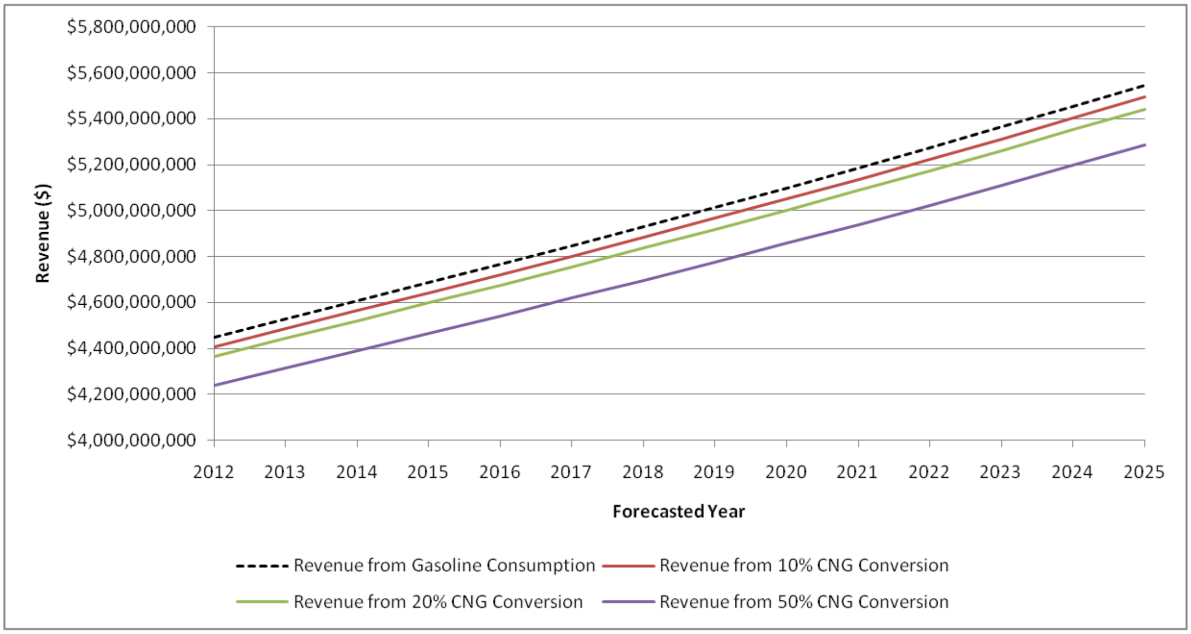

Figure 13. Forecast Years Annual Revenue Estimates.

Figure 14 shows the revenue comparison for the forecast year 2015 for various state tax rate scenarios. As we can see, if the state tax rate increased from 15¢ to 18.4¢ per GGE (actually 18.36¢ per GGE), the revenue earned from CNG conversion breaks even with the gasoline tax revenue, producing no revenue impact. If the tax rate increased from 15¢ to 20¢ per GGE, which is the current tax rate for gasoline, more revenue can be generated compared to the base case. The differences in revenue for different tax rate scenarios are presented in Figure 15.

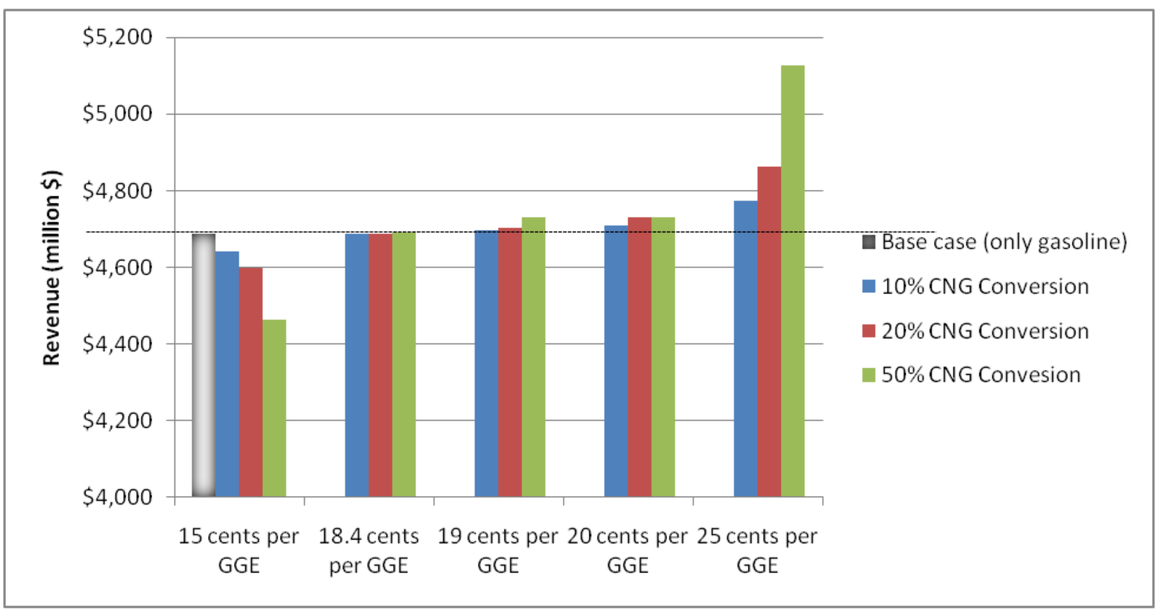

Figure 14. Total revenue for different state tax on CNG.

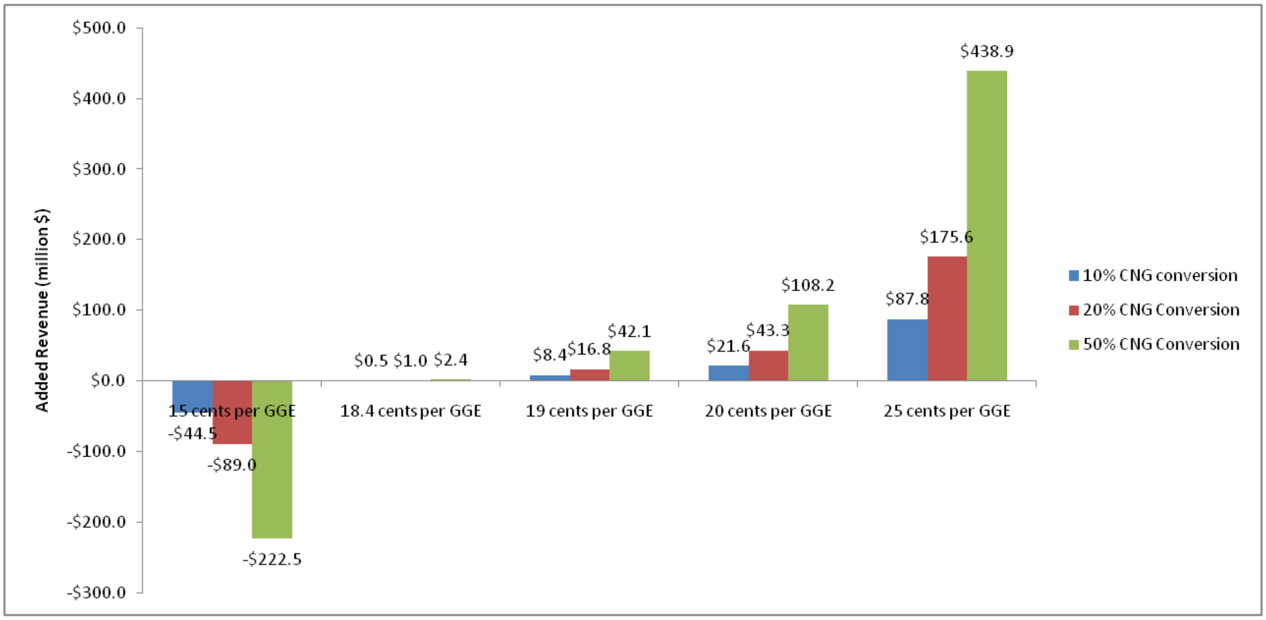

Figure 15. Differences in revenue for different state tax rates on CNG for year 2015.

As we can see from Figure 10, if the current tax rate prevails, then conversion of 10% of gasoline consumption to CNG consumption could cost Texas about $44.5 million in reduced revenue from light-duty vehicle fuel excise taxes in 2015. However, if the state's CNG tax rate increased from 15¢ to 18.4¢, $0.5 million of increased revenue can be generated at that 10% conversion rate. If the state tax rates for gasoline and CNG became the same, which is 20¢ per GGE, then Texas could generate about $21.6, $43.3, and $108.2 million in increased revenue at the 10%, 20%, and 50% conversion rates.

3. CONCLUSION

The environmental benefit of CNG over gasoline makes CNG a cleaner fuel choice. The difference in fuel price between CNG and gasoline, coupled with the price fluctuations of gasoline, can potentially induce consumers to buy more CNG vehicles. However, presently the cost of conversion of old gasoline vehicles to CNG vehicles is expensive. The conversion of gasoline-powered vehicles to CNG-powered vehicles or the purchase of new light-duty CNG-powered vehicles will affect the state revenue that is generated from fuel consumption. In this study, we estimated a gasoline consumption model based on historical data to evaluate the impact of such a fuel substitution.

Three different forms of time series models were developed using data from 1981 to 2009. The first model is a time stationary model that includes only time as the explanatory variable. The second model incorporates GDP and population in addition to time as independent variables. We estimate a third model that includes population as an explanatory variable and exclusively considers serial correlation between the time-dependent error terms.

Model validation showed that the third model performs better compared to the other models. The third model was selected to forecast gasoline consumption for 2012 to 2025. The estimated gasoline consumption was used to calculate the state revenue generated from gasoline consumption. Then we estimated the revenue for three scenarios where 10%, 20%, and 50% of gasoline consumption would be replaced by CNG consumption. All these cases show that substituting gasoline consumption with CNG would result in lower revenue for the state of Texas if the current tax rates remain the same for the forecast years. A moderate increase in the Texas state tax rate for CNG fuel has the potential to overcome the loss in revenue. Applying the same state tax rate to both CNG and gasoline would result in added Texas excise tax revenue from light-duty vehicles because Texas receives a slightly higher percentage of collected federal excise taxes for CNG compared to gasoline.

CHAPTER 4. LIQUEFIED PETROLEUM GAS (LPG)

1. INTRODUCTION TO LPG

Liquefied petroleum gas (LPG), also known as propane, or butane is another alternative fuel derived as a bi-product of natural gas production and the oil refining process. LPG is composed of mostly propane and butane. Natural gas purification produces about 55 percent of all LPG, while crude oil refining produces about 45 percent (Texas Comptroller of Public Accounts, 2008). Like other alternative fuels, LPG is a cleaner-burning fuel than diesel and gasoline and 90% of propane used in the U.S. comes from domestic sources (U.S. Department of Energy, 2013). LPG-fueled vehicles produce significantly lower greenhouse gas (GHG) emission compared to conventional gasoline powered vehicles; of course, the emission reduction benefit varies with the engine design.

The state of Texas is a proponent of the use of LPG as an alternative to gasoline. As a part of Texas Emissions Reduction Plan, the Texas Commission on Environmental Quality (TCEQ) administers programs that provide grants to the owners of vehicle fleets to permanently remove diesel vehicles from the road and replace them with alternative fuel vehicles (AFVs) or hybrid electric vehicles (HEVs). TCEQ programs include the “Alternative Fueling Facilities Program” that provides grants for alternative fueling infrastructure and the “Emissions Reduction Incentive Grants (ERIG) Program” that allows grants for clean vehicles and infrastructure, and the “Texas Clean Fleet Program.” The Railroad Commission of Texas Alternative Energy Division's “Low Emissions Alternative Fuels Equipment Initiative Program” also offers grants to buyers who wish to replace aging medium- or heavy-duty diesel school buses or delivery vehicles with qualified propane or natural gas vehicles that meet or exceed current U.S. Environmental Protection Agency (EPA) emissions standards (AFDC, 2013). Additionally, LPG gas use is encouraged by a federal tax incentive. A tax credit of $0.50 per gallon is available for LPG users between January 1, 2005, and December 31, 2013 (U.S. DOE).

LPG is used as a fuel in the residential, commercial, industrial, and transportation sectors. The state of Texas is the nation’s largest producer and consumer of LPG. In year 2011, Texas consumed 500.98 million barrels of LPG for fuel, 60.4 percent of all LPG consumed in the U.S. (U.S. Energy Information Administration, 2011). Although the transportation sector accounts for only 0.115 percent of LPG consumption in Texas, LPG is one of the most commonly used alternative fuels in the U.S. (EIA, 2012; NHTSA, 2002). Texas is a strong proponent of alternative fuels and alternative fuel vehicles and mandates state agencies to purchase alternative fuel vehicles (U.S. Department of Energy, 1999). Texas is among the three states in the U.S. that consume the most LPG as transportation fuel and has the highest number (457) of LPG fuel stations in the nation (AFDC, 2013). Motivated in part by the state law, the largest fleet in Texas, operated by Texas Department of Transportation (TxDOT), has been using hundreds of LPG-fueled and bi-fuel (LPG and gasoline) vehicles for their fleet since 1992 (U.S. DOE, 1999; Huang *et al.*, 1999; Werpy *et al.*, 2010; TxDOT, 2012). However, the number of the LPG vehicles in TxDOT’s fleet has fallen sharply from year 2001 to 2010. In fiscal year 2001, TxDOT’s fleet included 4,677 LPG vehicles, which remained relatively stable until 2004. The number of LPG vehicles started to drop in year 2005 (3869 LPG vehicles) and by fiscal 2010, this portion of the fleet had dropped by 77.6 percent from 3,269 to 1,048 vehicles (Texas Comptroller of Public Accounts, 2008; TxDOT, 2012). The availability of other alternative fuels, the limited availability of public LPG fueling stations, and decisions by some equipment manufacturers to stop producing and selling LPG vehicles, have contributed to the decreased size of LPG fleets (Texas Comptroller of Public Accounts, 2008).

LPG is a colorless, odorless, and nontoxic gas whose boiling point is below room temperature. The pressure at which LPG becomes liquid, called its vapor pressure, varies depending on composition and temperature; for example, it is approximately 32 psi (220 kilopascals) for pure butane at 68 °F (20 °C), and approximately 320 psi (2.2 megapascals) for pure propane at 131 °F (55 °C). LPG is heavier than air, unlike natural gas, and thus will flow along floors and tend to settle in low spots. For easy transportation and storage, LPG is stored as a liquid in a moderately low-pressure vehicle fuel tank (about 150 pounds per square inch) (AFDC, 2013). LPG has a high-octane value compared to gasoline (104 to 112 compared with 87 to 92 for gasoline) that allows for a higher compression ratio in the engine and greater engine efficiency (EPA, 2002; AFDC, 2013). The service life of LPG vehicles is 2-3 years longer compared to gasoline powered vehicles and requires less frequent maintenance (AFDC, 2013). In liquid state, LPG has the lowest flammability range of any alternative fuel and is not harmful to soil or water. However, overfilled LPG fuel tanks have potential safety and emissions implications (Werpy *et al.*, 2010). The energy density of LPG is about 73% that of gasoline, thus requiring more fuel to travel an equivalent distance (AFDC, 2013). LPG vehicles have longer driving ranges compared to CNG vehicles. LPG vehicles can either be conversions from gasoline vehicles or purchased from authorized vehicle dealers. Auto-manufacturers such as Ford and General Motors offer light- and medium-duty dedicated and bi-fueled LPG vehicles (U.S. DOE, 2013). Gasoline powered vehicles can also be converted to LPG fuel use. The conversion cost of a light-duty vehicle from gasoline to propane use ranges from $4,000 to $12,000 (AFDC, 2013). In converted vehicles, the propane fuel system increases the weight of the vehicle by approximately 100 pounds (EPA, 2002). There are also two types of fuel-injection systems available: vapor injection and liquid propane injection. In both types, LPG is stored as a liquid in a relatively low-pressure tank (AFDC, 2013).

The price of LPG fuel is relatively lower than gasoline, but higher than compressed natural gas (CNG). U.S. DOE reported that the average LPG price in the Gulf Coast area in January 2013 was $2.17 per liquid gallon. In Texas, the State excise tax is not collected at the pump so adding $0.15 per gallon brings the actual price to about $2.32 per gallon. If one applies the $0.50 per gallon federal tax credit, the LPG price becomes $1.80 per gallon. Gasoline fuel in the same region was priced around $3.11 per gallon. While this might appear to be a significant LPG price advantage, if one adjusts for the energy density of the two fuels by dividing the LPG price by 0.73, the LPG energy density compared to gasoline, the LPG price becomes $2.49 per equivalent gallon or about $0.62 less than gasoline fuel. However, like gasoline the price of LPG fuel also fluctuates as it depends on a number of factors, some of them are common to all petroleum products, and others are specific to propane (EIA, 2012). Since LPG is used not only as a vehicle fuel but also as an energy source for home heating, and cooking, as well as, as a replacement for chlorofluorocarbon or hydrofluorocarbon refrigerants, the market price for LPG fuel is influenced by the product demand in the other LPG market segments. Although some LPG is derived from natural gas, the primary source of LPG is crude oil so its cost is clearly influenced by the cost of crude oil. The production of LPG by refineries and gas processing plants is relatively steady year-round, however, the demand for it is subject to changes in weather and inventory levels, among other factors. Seasonal demand or supply shortages are difficult to mitigate by importing LPG due to relatively long travel times. The price of LPG fuel is related to the price of gasoline, which makes it less popular as a hedge against fluctuating gasoline prices in the U.S.

2. ANALYSIS AND RESULTS

LPG-fueled vehicle range and driving performance are similar to gasoline-fueled vehicles. LPG has been used for light-duty vehicles, such as pickup trucks and taxis, and for medium-duty vehicles such as school buses. The energy density of LPG is roughly 73 percent compared to gasoline and 64 percent compared to diesel. Therefore, LPG is generally considered primarily as an alternative fuel for light-and-medium duty gasoline powered vehicles. If LPG will primarily compete with gasoline in the vehicle fuel market, estimates of its market intrusion might be related to the overall gasoline fuel market. The gasoline consumption model described in Chapter 3 was applied to this LPG analysis. To estimate the gasoline consumption model, combinations of independent variables and three different functional forms of time series analysis were examined to arrive at the best alternative annual forecast model. Data issues, model specifications, critical assumptions, and forecast performance are described in Chapter 3. Two different forms of dependent variables were considered: gasoline consumption in millions of gallons and the natural logarithm ($\log_e$) of gasoline consumption in gallons. The second model gives a better R-squared value for all the cases considered. Time series data for the dependent and explanatory variables were collected from year 1981 to 2011. The gasoline consumption model is estimated using data from year 1981 to 2009. Two years of data (year 2010 and 2011) are used to validate the model results and to evaluate model performance.

Explanatory Variables

The gasoline consumption model development process of Chapter 3 included review of the fuel demand (gasoline and/or diesel) models used by other state DOTs and agencies to get a clear picture of the state of practice. Explanatory variables were used to estimate the fuel consumption model include fuel efficiency, real per-capita personal income, population, population growth, wages, salary growth, vehicle miles traveled, real gasoline price, real disposable income, vehicle fleet size, and employment data (Berwick and Malchose, 2012; WSDOT, 2010). Fuel price and VMT variables were excluded in order to avoid the complexity of their estimation for future periods. Moreover, these variables are more likely to be endogenous to the response variable gasoline consumption. The variables tested to obtain the final model specification include, population, per capita personal income, and GDP.

Data Sources

Multiple sources of data and information are used to support the analyses and conclusions in this report. The dependent variable of this study is the annual gasoline sales to on-highway consumers in Texas. Gasoline consumption data from 1981 to 2011 was collected from U.S. Energy Information Administration (EIA). Yearly population data was obtained from Texas Department of State Health Services. Per capita personal income and GDP data were collected from the Bureau of Economic Analysis (BEA). Federal and State tax rates were collected from the FHWA website to enable estimation of revenue generated from gasoline consumption.
The estimated model specification and results are presented in the following section.

Revenue Forecast

Using the gasoline consumption forecast presented in Chapter 3, current Federal and Texas State tax rates and the time series model with explanatory variables (model 3) are used to estimate the revenue generated from gasoline consumption. The tax rates used in revenue calculation are presented in Table 19.

Table 13. Tax rates used in revenue calculation.

Texas and Federal Motor Fuel Excise Taxes		
Current Nominal Rates		
	Gasoline	LPG
	$/gallon	$/gallon
Federal	0.184	0.136
State	0.200	0.150
Adjusting for Taxes Received by Texas [Texas receives 83.9% of Federal Tax from Gasoline and 88.4% of Federal Tax from LPG]		
Federal	0.154	0.120
State	0.200	0.150
Adjusting for Energy Equivalent Volumes [LPG contains 73% of the energy per gasoline gallon]		
Federal	0.154	0.165
State	0.200	0.205
Effective Texas Rate Per Liquid Gallon		
Total $/gallon	**0.354**	**0.370**

The current nominal excise tax rates shown in Table 19 are adjusted to account for the fractions of collected federal taxes that are currently being returned to the State of Texas, specifically 83.9% of federal gasoline taxes and 88.4% of federal taxes for LPG. Additionally, LPG is taxed and sold as a liquid like gasoline, but an LPG gallon contains approximately 73 percent of the energy contained in a gallon of gasoline, so consumers must purchase more than a gallon of LPG to travel the same distance as would be possible with a gallon of gasoline. This adjustment for "energy density" is also applied in Table 4 and the cumulative effect of the two "adjustments" produces an effective excise tax for LPG that is higher than gasoline. The effective tax rates show that almost 1.6 cents more tax would be collected for each gasoline gallon equivalent (GGE) of LPG fuel compared to each gallon of *gasoline*. Additionally, although current federal law (through 31 December 2013) provides a $0.50 per GGE Alternative

Fuel Excise Tax Credit for LPG purchases, this rebate is paid from general revenue not the Highway Trust Fund. Therefore, the Alternative Fuel Excise Tax Credit for LPG is excluded from the transportation revenue calculations.

Based on the estimated gasoline consumption and the revenue generated from gasoline consumption, we estimate the revenue for three scenarios where 10%, 20%, and 50% gasoline consumption would be replaced by LPG consumption. The revenue calculation takes into account the current state and federal tax rates. The revenue calculation for Texas assumes that Texas receives about $0.839 per dollar of collected federal tax from gasoline consumption and $0.884 per dollar of collected federal tax from LPG consumption. Inflation rates are not considered in the revenue calculation and we assume the tax rates will remain the same for the forecast periods. Figure 22 shows the estimated average revenue for four scenarios from year 1981 to 2025.

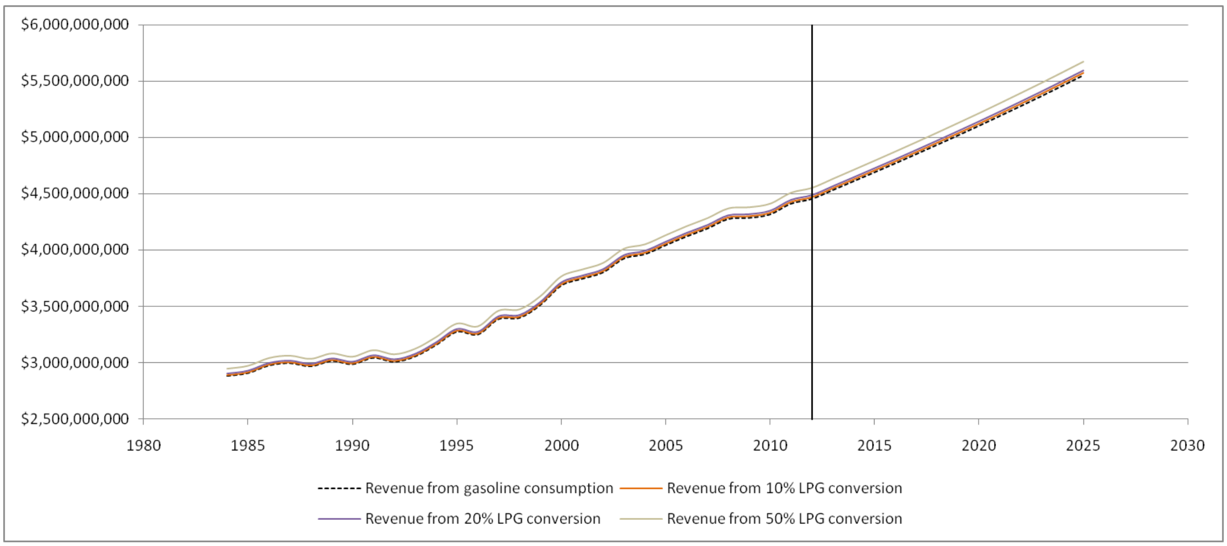

Figure 16. Estimated Annual Revenue.

Figure 23 shows the revenue comparison only for the forecast years. The forecast shows LPG conversion results in an increase in Texas State revenues compared to the base case (for base case revenue is calculated assuming only gasoline is consumed and no LPG conversion). The magnitude of increased revenue increases as more LPG replaces gasoline consumption. The added benefit can be contributed to the fact that 1.37 gallons of LPG are required to get the same energy as 1 gallon of gasoline.

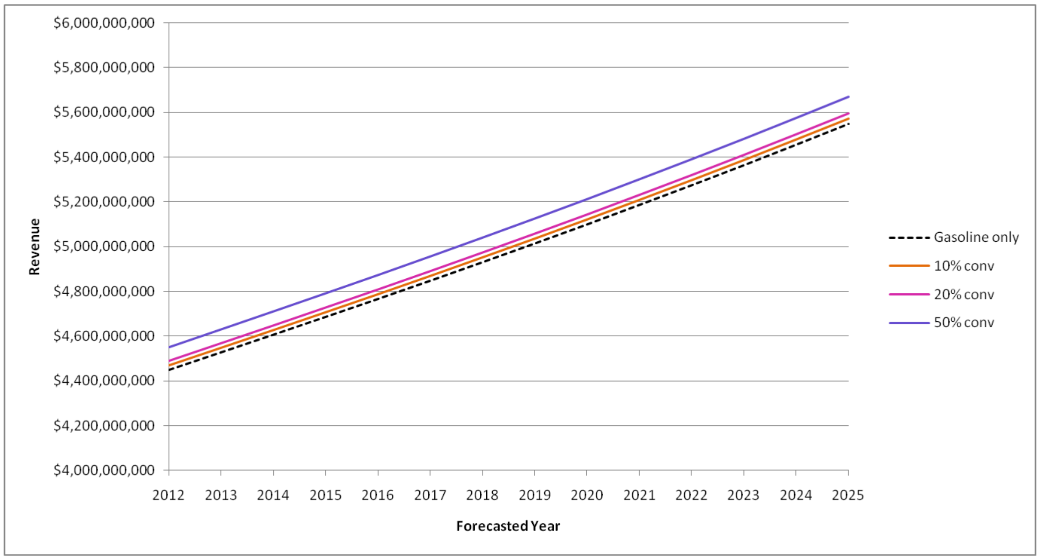

Figure 17. Forecast Years Annual Revenue Estimates.

The added revenue generated after conversion is calculated for all three scenarios and presented in Table 20. The LPG conversion can potentially increase revenues more than $ 20 million if LPG substitutes for 10% of gasoline consumption in year 2013. For the same year, 20% substitution would add more than $40 million in revenue and 50% substitution would add close to $101 million.

Table 14. Estimated Revenue from LNG Conversion.

Year	Gasoline Only	10% LPG + 90% Gasoline	20% LPG + 80% Gasoline	50% LPG + 50% Gasoline	Additional Revenue generated from LPG use		
					10% LPG	20% LPG	50% LPG
2012	$4,450,593,154	$4,470,428,600	$4,490,264,046	$4,549,770,382	$19,835,446	$39,670,891	$99,177,228
2013	$4,529,164,025	$4,549,349,646	$4,569,535,266	$4,630,092,129	$20,185,621	$40,371,242	$100,928,105
2014	$4,607,739,457	$4,628,275,274	$4,648,811,091	$4,710,418,541	$20,535,817	$41,071,633	$102,679,084
2015	$4,687,209,333	$4,708,099,332	$4,728,989,331	$4,791,659,327	$20,889,999	$41,779,998	$104,449,994
2016	$4,767,096,314	$4,788,342,354	$4,809,588,394	$4,873,326,514	$21,246,040	$42,492,080	$106,230,199
2017	$4,848,344,859	$4,869,953,008	$4,891,561,157	$4,956,385,604	$21,608,149	$43,216,298	$108,040,746
2018	$4,930,978,171	$4,952,954,601	$4,974,931,031	$5,040,860,322	$21,976,430	$43,952,860	$109,882,150
2019	$5,014,518,378	$5,036,867,130	$5,059,215,883	$5,126,262,142	$22,348,753	$44,697,506	$111,743,764
2020	$5,099,473,915	$5,122,201,298	$5,144,928,682	$5,213,110,832	$22,727,383	$45,454,767	$113,636,917
2021	$5,186,387,374	$5,209,502,114	$5,232,616,854	$5,301,961,075	$23,114,740	$46,229,480	$115,573,701
2022	$5,274,254,701	$5,297,761,049	$5,321,267,397	$5,391,786,441	$23,506,348	$47,012,696	$117,531,741
2023	$5,363,610,668	$5,387,515,259	$5,411,419,849	$5,483,133,621	$23,904,591	$47,809,181	$119,522,953
2024	$5,455,025,972	$5,479,337,983	$5,503,649,995	$5,576,586,028	$24,312,011	$48,624,022	$121,560,056
2025	$5,547,444,551	$5,572,168,454	$5,596,892,357	$5,671,064,067	$24,723,903	$49,447,806	$123,619,516

3. CONCLUSIONS

The environmental benefit of LPG over gasoline and the difference in fuel price between LPG and gasoline makes LPG an alternative fuel to gasoline. However, the price of LPG fuel shows high seasonal fluctuation. Additionally, the cost of conversion of gasoline vehicles to LPG is still expensive. The conversion of gasoline powered vehicles to LPG powered vehicles or the purchase of new LPG vehicles will change the State revenue that is generated from fuel taxes.

In this study, we estimate a gasoline consumption model based on historical data to evaluate the impact of such substitution. Three different forms of time series models are developed using data from years 1981 to 2009. The first model is a trend stationary model that includes only time as the explanatory variable. The second model incorporates per capita personal income and population in addition to time as independent variables. We estimate a third model that exclusively considers serial correlation between the error terms.

Model validation shows that the third model performs better compared to the first and second models. The third model is selected to forecast gasoline consumption for year 2012 to 2025. The estimated gasoline consumption is used to calculate the state revenue generated. Then we estimate the revenue for three scenarios where 10%, 20%, and 50% gasoline consumption would be replaced by LPG consumption. All these cases show that substitution of gasoline demand by LPG would result in higher revenue for the state of Texas contingent upon present tax rates remaining the same for the forecast years.

CHAPTER 5. CONCLUSIONS AND RECOMMENDATIONS

The transportation sector accounts for more than half of world oil consumption (Hirsch et al., 2005). In the United States, about 90% of the fuel used for on-road vehicular travel is petroleum-based, which includes gasoline and diesel (Ribeiro et al., 2007). Alternative fuel vehicles (AFV) offer solutions to both the transportation sector's dependence on oil and air quality concerns.

Vehicle characteristics and movement behavior of freight hauling trucks make them an attractive market for promoting alternative fuels. A variety of alternative fuels and advanced propulsion technologies have been explored for heavy trucks, including battery electric, hybrid electric, biodiesel, ethanol, propane, dimethyl ether (DME), LNG, CNG, and both liquefied and gaseous hydrogen (Myers et al., 2012). Natural gas is one of the cleanest burning fuels and can be used in vehicles in the form of either CNG or LNG. LNG is more suitable for heavy-duty vehicles because it has much higher energy density than CNG and can provide a safe traveling distance of up to 600 miles between refueling stops (Myers et al., 2012).

Three different forms of time series models were developed using data from 1981 to 2009. The first model is a time stationary model that includes only time as the explanatory variable. The second model incorporates per capita personal income and population in addition to time as independent variables. We estimate a third model that exclusively considers serial correlation between the error terms.

Due to cost of fuel conversion and physical size of LNG on-board vehicle fuel tanks, trucks rather than passenger cars are the most suitable vehicle type for LNG fueling. Since the truck fleet is largely fueled by diesel, this report forecasts diesel consumption through 2025 and then considers the impacts of converting from diesel to LNG at the rates of 10, 20, and 50%. Current tax rates for diesel and LNG fuel are \$0.44 and \$0.269 per liquid gallon, including both Texas state and federal excise taxes. However, Texas receives approximately 87.9% of the federal tax collected in Texas for both fuels, yielding the effective tax rates of \$0.4145 and \$0.2546 for diesel and LNG, respectively. LNG provides only about 60% of the energy of an equivalent volume of diesel, meaning the user must purchase 1.67 gallons of LNG to travel the same distance as on 1 gallon of diesel. Because users must buy more LNG to go the same distance, after adjusting for the fraction of federal tax received by Texas, the effective tax rates are \$0.414 per gallon of diesel and \$0.424 per energy equivalent gallon for LNG. Although the trucking community has some interest in LNG, this interest seems to be based primarily on LNG prices being less than diesel fuel. Current pump prices at Texas retail outlets selling LNG fuel are approximately \$2.75 per gallon compared to about \$3.90 per gallon for diesel. However, the LNG energy equivalent price (computed by dividing \$2.75 by 0.6) is \$4.58 per gallon. Current federal law (through December 31, 2013) provides a \$0.50 per gallon tax rebate for LNG purchases. This rebate is paid from general revenue, not the Highway Trust Fund. All these cases show that substituting LNG for diesel would result in greater revenue for the state of Texas (contingent upon the present tax rates remaining the same for the forecast years).

Light-duty vehicles, including passenger cars and light-duty trucks, are the most suitable vehicles for CNG fueling because the driving ranges of CNG-fueled vehicles are limited. CNG has only 25% of the energy density of diesel fuel. Since the light-duty vehicle fleet is largely fueled by gasoline, this report forecasts gasoline consumption through 2025 and then considers the impacts of converting from gasoline to CNG at the rates of 10, 20, and 50%. The current tax rate for gasoline is $0.384 per liquid gallon and for CNG fuel is $0.333 per GGE (this figure includes both Texas state and federal excise taxes). However, Texas receives approximately 83.9% of the federal tax collected in Texas for gasoline and approximately 93.3% of the federal CNG tax collected in Texas. Applying these adjustments, the effective tax rates are $0.354 and $0.321 for gasoline and CNG, respectively. Given the current effective excise tax rates for gasoline versus CNG, TxDOT will lose revenue as CNG replaces gasoline as a vehicle fuel. Based upon current federal and state tax rates and percentages of federal taxes returned to Texas, increasing the current $0.15 per GGE CNG state tax rate to $0.1836 per GGE will provide equivalent effective tax rates for gasoline and CNG.

Interest in CNG within the light-duty vehicle community seems to be based primarily on CNG *reducing* consumer costs. Current pump prices are favorable: Texas retail outlets are selling CNG fuel for $2.10 per GGE compared to about $3.50 per gallon for gasoline. In Texas, the state excise tax is not collected at the pump, so adding $0.15 per gallon brings the actual price to about $2.25 per GGE. Additionally, current federal law (through December 31, 2013) provides a $0.50 per GGE Alternative Fuel Excise Tax Credit for CNG purchases. This rebate is paid from general revenue, not the Highway Trust Fund. The cost to convert a currently owned or newly purchased light-duty vehicle to CNG is approximately $10,000 or more. If an LNG user drives 12,000 miles per year, has an overall fuel economy of 28 miles per gallon, saves $1.25 per gallon using CNG instead of gasoline, and receives the $0.50 per GGE federal tax credit, then (ignoring inflation) almost seven years will be required to amortize the CNG conversion cost. The difference in fuel price between CNG and gasoline, coupled with the price fluctuations of gasoline, can potentially induce consumers to buy more CNG vehicles. However, presently the cost of conversion of old gasoline vehicles to CNG vehicles is expensive.

All these cases show that substituting gasoline consumption with CNG would result in lower revenue for the state of Texas if the current tax rates remain the same for the forecast years. A moderate increase in the Texas state tax rate for CNG fuel has the potential to overcome the loss in revenue. Applying the same state tax rate to both CNG and gasoline would result in added Texas excise tax revenue from light-duty vehicles because Texas receives a slightly higher percentage of collected federal excise taxes for CNG compared to gasoline.

Although the primary market for LPG has traditionally been residential heating, it is a viable fuel for light and medium duty vehicles including passenger cars, and light-and-medium duty trucks since the energy content of LPG is generally about 73% that of gasoline or 64% of diesel fuel. Current nominal tax rates for gasoline and LPG fuel are $0.384 and $0.286 per liquid gallon including both Texas State and federal excise taxes. However, Texas receives approximately 83.9 percent of the federal gasoline tax collected in Texas and approximately 88.4 percent of the federal LPG tax collected in Texas. Adjusting the nominal rates for the fractions of federal taxes returned to Texas and adjusting for the fact that LPG contains about 73 percent of the energy of gasoline per unit volume the effective tax rates are $0.354 and $0.370 for gasoline and LPG, respectively. Interest within the light- and medium-duty vehicle community in LPG seems to be based primarily on LPG *reducing* consumer costs. Current pump prices are slightly favorable. Gulf coast retail outlets are selling LPG fuel for $2.17 per gallon. In Texas, the State excise tax is not collected at the pump for LPG so adding $0.15 per gallon brings the actual price to about $2.32 per gallon. The federal tax credit of $0.50 per gallon of LPG fuel reduces the price per gallon to $1.82. Taking into account the energy density of LPG fuel the gasoline gallon equivalent price of LPG fuel is $2.49 compared to about $3.11 per gallon for gasoline. Additionally, the federal tax credit (through 31 December 2013) of $0.50 per gallon of LPG is paid from general revenue not the Highway Trust Fund. Conversion costs for either currently owned or newly purchased light duty vehicles are not so favorable at approximately $4,000 or more. If one drives 12,000 miles per year, has overall fuel economy of 28 miles per gallon, saves $0.62 per gallon using LPG instead of gasoline (this includes the $0.50 per GGE federal tax credit) ignoring inflation, almost fifteen years will be required to amortize the LPG conversion cost.

All these cases show that substitution of gasoline demand by LPG would result in higher revenue for the state of Texas contingent upon present tax rates remaining the same for the forecast years. However, the price of LPG fuel shows high seasonal fluctuation. Additionally, the cost of conversion of gasoline vehicles to LPG is still expensive. The conversion of gasoline powered vehicles to LPG powered vehicles or the purchase of new LPG vehicles will change the State revenue that is generated from fuel taxes.

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APPENDIX

APPENDIX A

Table 15. Listing of Texas Diesel Consumption, Per Capita Personal Income and Population Data (1984–2011).

year	Texas Diesel Consumption (Gallons)	Per Capita Income ($)	Population (million)	GDP ($Million)
1984	1514092000	13377	16.007	2030.73
1985	1550447000	14110	16.273	2452.35
1986	1437192000	14182	16.561	2600.85
1987	1319054000	14453	16.622	2648.83
1988	1296067000	15245	16.667	2886.37
1989	1387059000	16165	16.807	3072.24
1990	1384705000	17260	16.987	2957.21
1991	1554493000	17763	17.349	3006.67
1992	1575936000	18765	17.656	3273.54
1993	1686844000	19413	18.031	3499.52
1994	1916678000	20161	18.378	3789.43
1995	1946843000	21070	18.724	3935.74
1996	2156993000	22260	19.128	4164.01
1997	2250646000	23812	19.439	4437.75
1998	2433408000	25376	19.760	4759.90
1999	2538263000	26399	20.044	5077.25
2000	2793809000	28506	20.852	5515.13
2001	2976807000	29185	21.325	6021.60
2002	3093602000	28966	21.780	6342.86
2003	2991379000	29622	22.119	6706.04
2004	3464411000	31115	22.490	7310.64
2005	3611156000	33220	22.860	7628.85
2006	3962862000	35287	23.508	7827.80
2007	4234133000	37098	23.904	8244.89
2008	4186631000	39615	24.327	9036.79
2009	3711173000	36595	24.782	9685.53
2010	3849991000	38222	25.146	10544.14
2011	4114193000	40147	25.675	11474.04

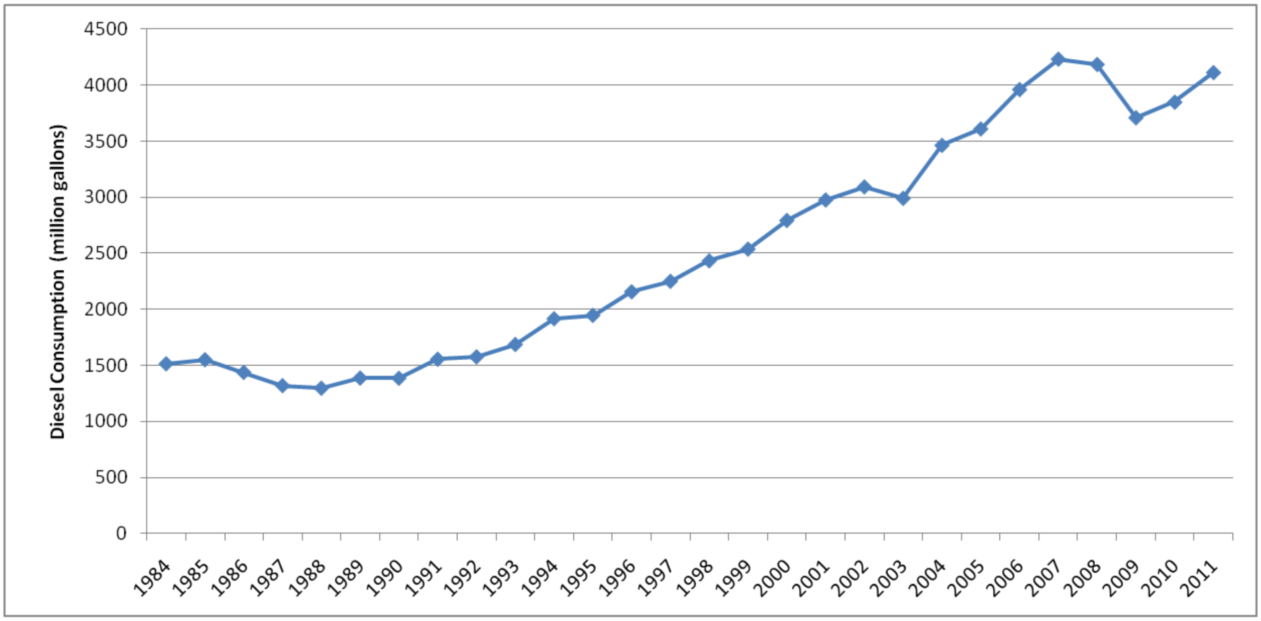

Figure 18. Annual Diesel Consumption Historical Data.

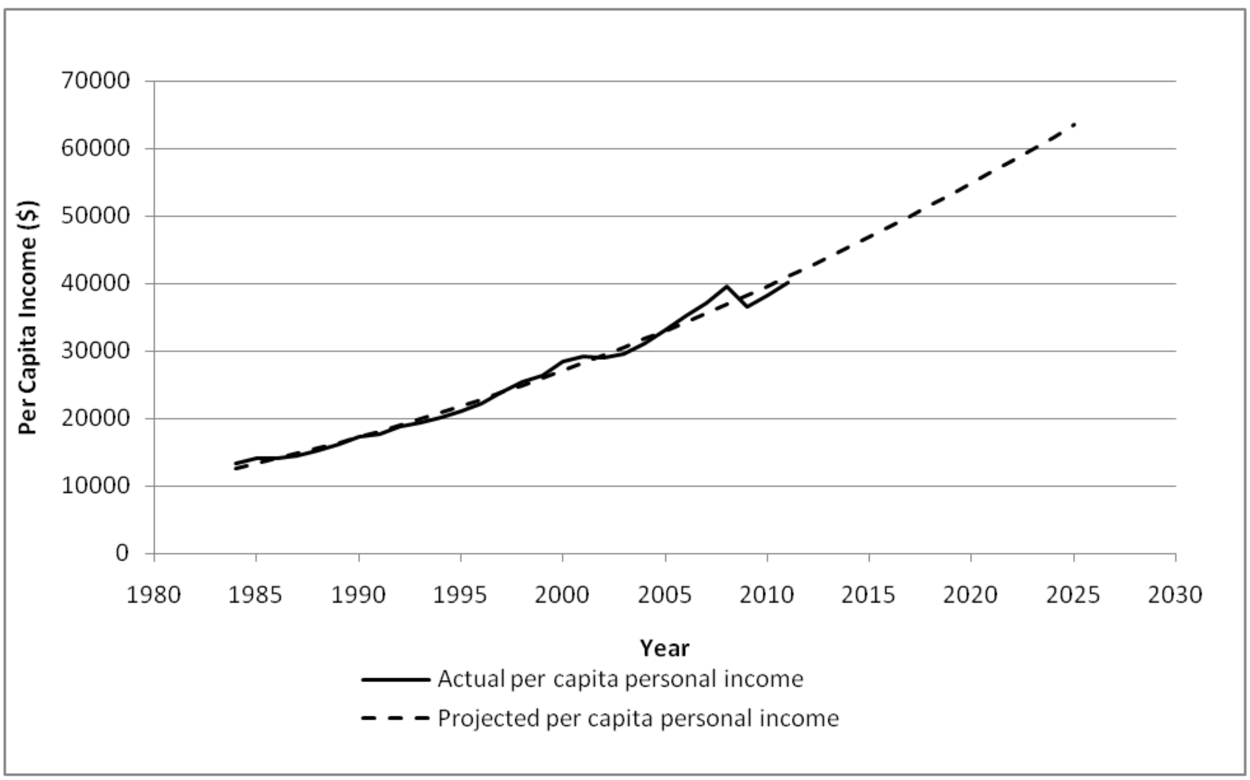

Figure 19. Projected Per Capita Income ($).

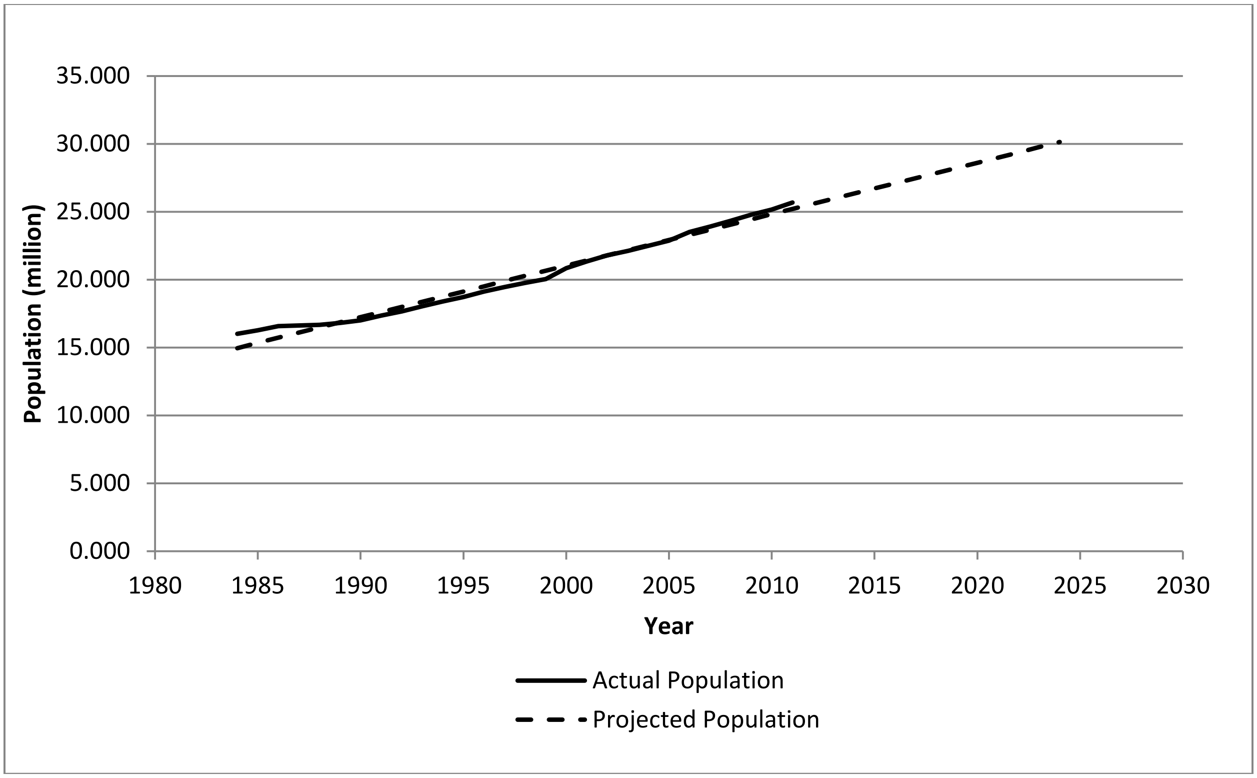

Figure 20. Projected Texas Population.

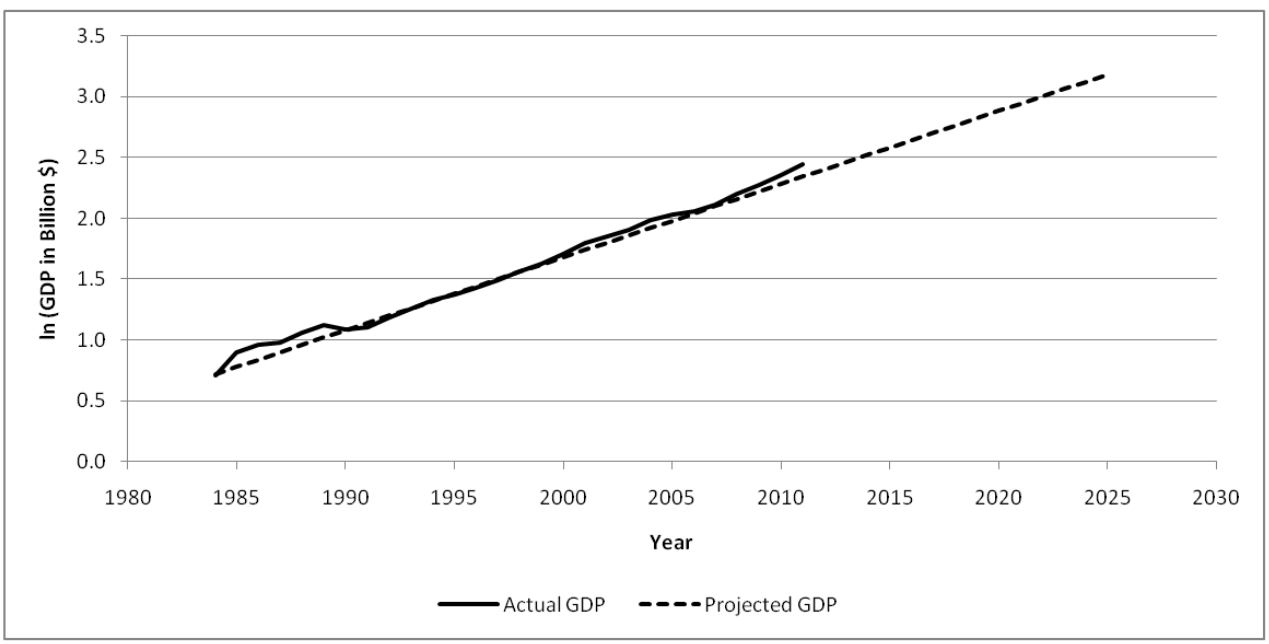

Figure 21. Projected Texas GDP.

APPENDIX B

Diesel ConsumptionValidation/Model Performance Evaluation

We first plot the residuals (difference between the estimated diesel consumption and the actual diesel consumption) of the estimated models to visually examine the residuals' distribution. The residual plot for the first model (Figure B1) shows that most of the residuals for the first model are located above zero (over-estimating consumption). The residuals of the adjacent periods are observed to have the same sign and also exhibit stickiness between the adjacent periods, indicating the presence of serial correlation between the error terms of this model. On the other hand, the residual distribution for Model 2 (Figure B2) shows a fairly random scatter plot around zero. Very few adjacent residuals are observed to have similar values and display less stickiness compared to the first model, indicating that the explanatory variables remove most of the serial correlation. The magnitudes of the residuals are also smaller compared to the first model residuals. The third model residual plot (Figure B3) also shows a random scatter plot around zero. However, the magnitudes of the residuals are higher compared to the second model.

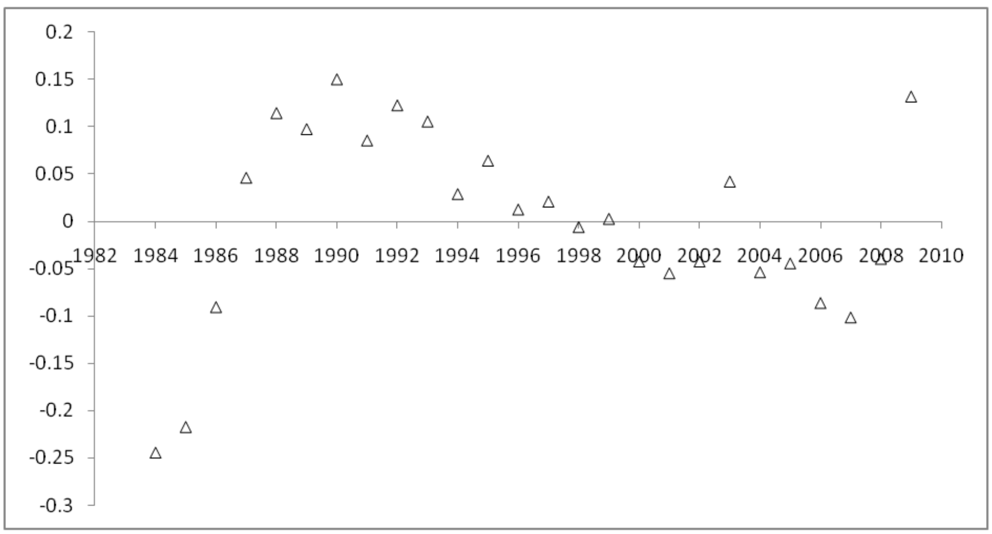

Figure 22. Residual Plot for Time Stationary Model (Model 1).

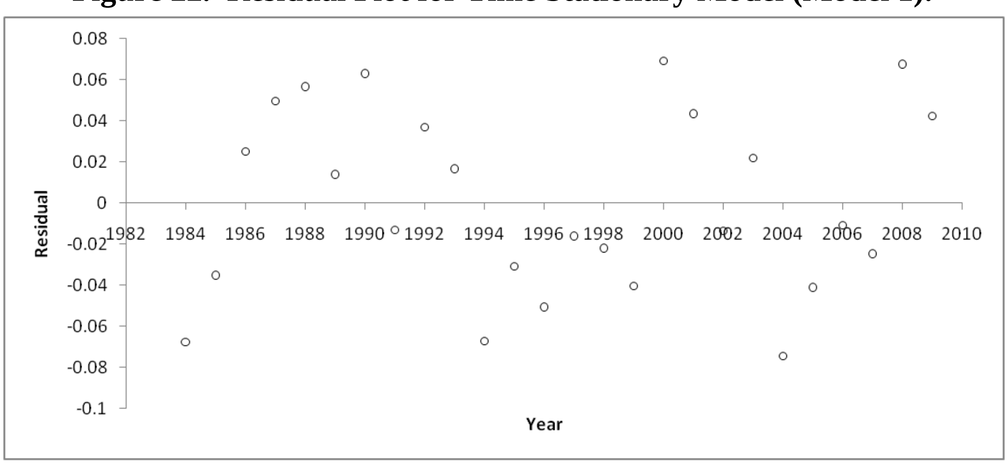

Figure 23. Residual Plot for Time Series Model with Explanatory Variables (Model 2).

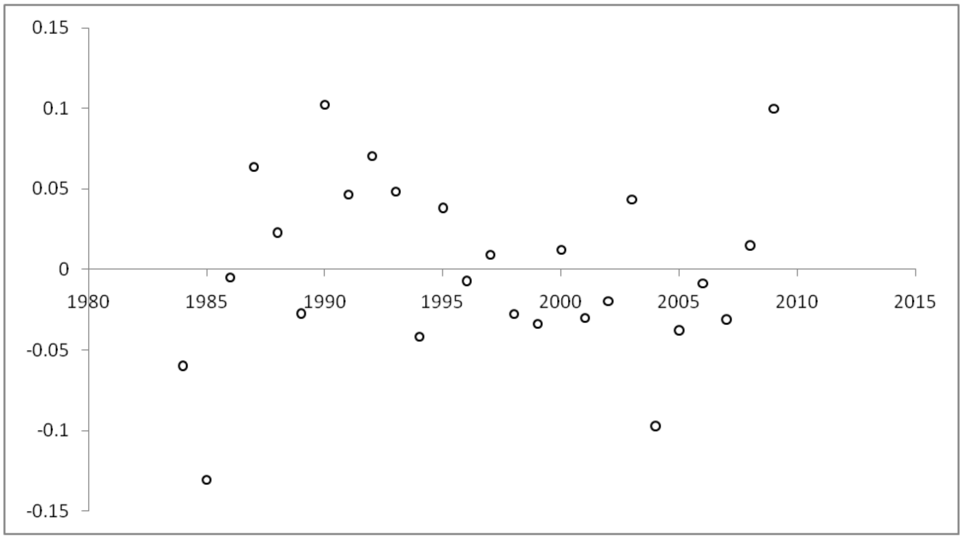

Figure 24. Residual Plot for First-Order Autoregressive Model (Model 3).

The estimated coefficients for the models are used to forecast the diesel consumption for year 2010 and 2011. The forecasted values are compared with the actual diesel consumption data to calculate the performance measures. The calculated performance measures for the models are presented in Tables 22-24.

Table 16. Model 1 Performance Measures

Model 1: Trend-Stationary Model			
ln (Diesel Consumption)		$\sum_{t=2010}^{T=2011} \lvert y_t - y_{t,Forecast} \rvert$	$\sum_{t=2010}^{n=2011} (y_t - y_{t,Forecast})^2$
Forecasted	Actual		
22.218	22.071	0.146	0.021
22.268	22.138	0.131	0.017
		0.277	0.038

Table 17. Model 2 Performance Measures.

Model 2: Time Series Model with Exogenous Variable			
ln (Diesel Consumption)		$\sum_{t=2010}^{T=2011} \lvert y_t - y_{t,Forecast} \rvert$	$\sum_{t=2010}^{n=2011} (y_t - y_{t,Forecast})^2$
Forecasted	Actual		
22.108	22.071	0.037	0.001
22.179	22.138	0.041	0.002
		0.078	0.003

Table 18. Model 3 Performance Measures.

Model 3: First-Order Autoregressive Time Series Model			
ln (Diesel Consumption)		$\sum_{t=2010}^{T=2011} \lvert y_t - y_{t,Forecast} \rvert$	$\sum_{t=2010}^{n=2011} (y_t - y_{t,Forecast})^2$
Forecasted	Actual		
22.123	22.071	0.051	0.002
22.183	22.138	0.046	0.002
		<u>0.096</u>	<u>0.004</u>

The sum of the absolute residuals for the two-year model-testing period is much lower for the second model compared to the first model. The sum of the squares of the residuals for the forecasted two-year period is also smaller for Model 2 compared to Model 1 and Model 3. Both of the measures show that Model 2 (the model with explanatory variables) performs better in forecasting diesel consumption compared to the other two models.

APPENDIX C

Table 19. Listing of Texas Gasoline Consumption, Population, and GDP Data (1981–2011).

Year	Gasoline (million gallons)	Population (million)	GDP (million $)
1981	7713.05	14.746	245.235
1982	7944.55	15.331	260.085
1983	8066.31	15.752	264.883
1984	8095.84	16.007	288.637
1985	8347.96	16.273	307.224
1986	8521.13	16.561	295.721
1987	8350.31	16.622	300.667
1988	8488.87	16.667	327.354
1989	8260.14	16.807	349.952
1990	8348.47	16.986	378.943
1991	8086.64	17.340	393.574
1992	8185.84	17.650	416.401
1993	8561.45	17.997	443.775
1994	9024.16	18.338	475.99
1995	8791.40	18.680	507.725
1996	9331.43	19.006	551.513
1997	9265.16	19.355	602.16
1998	9729.51	19.712	634.286
1999	10093.69	20.044	670.604
2000	10377.19	20.852	731.064
2001	10573.25	21.335	762.885
2002	11058.85	21.723	782.78
2003	11092.66	22.103	824.489
2004	11319.97	22.490	903.679
2005	11440.97	22.929	968.553
2006	11723.67	23.508	1054.414
2007	11997.47	23.904	1147.404
2008	11924.26	24.327	1209.267
2009	11950.39	24.782	1129.537
2010	12163.49	25.146	1222.904
2011	11888.02	25.675	1308.132

Table 20. CNG State Tax Rates.

State	CNG Tax
Arkansas	$0.05
Oklahoma	$0.05
Montana	$0.05
California	$0.07
Pennsylvania	$0.08
Utah	$0.09
New Jersey	$0.09
South Dakota	$0.10
Tennessee	$0.13
Texas	$0.15
Indiana	$0.16
Iowa	$0.16
Louisiana	$0.16
South Carolina	$0.16
Georgia	$0.17
Missouri	$0.17
Virginia	$0.18
Mississippi	$0.18
Alabama	$0.19
Idaho	$0.20
Colorado	$0.21
Nevada	$0.21
Delaware	$0.22
Massachusetts	$0.23
Kansas	$0.23
North Dakota	$0.23
Maryland	$0.24
Maine	$0.24
Wisconsin	$0.25
Minnesota	$0.25
Kentucky	$0.26
Connecticut	$0.26
Nebraska	$0.26
Rhode Island	$0.32
Florida	$0.33
Illinois	$0.33
West Virginia	$0.33
North Carolina	$0.38

Source: IFTA Fuel Tax Rate Sheet, 2012

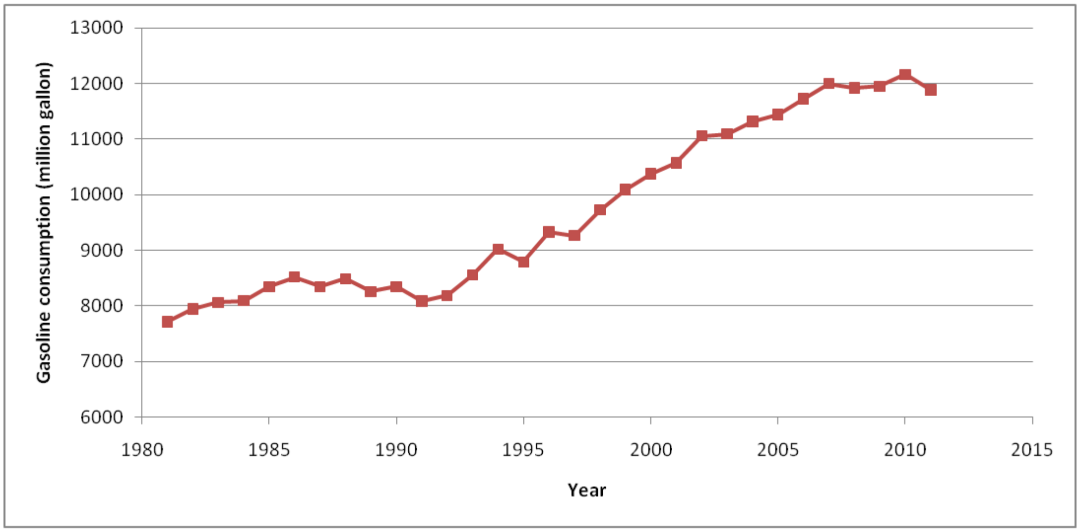

Figure 25. Annual Gasoline Consumption Historical Data.

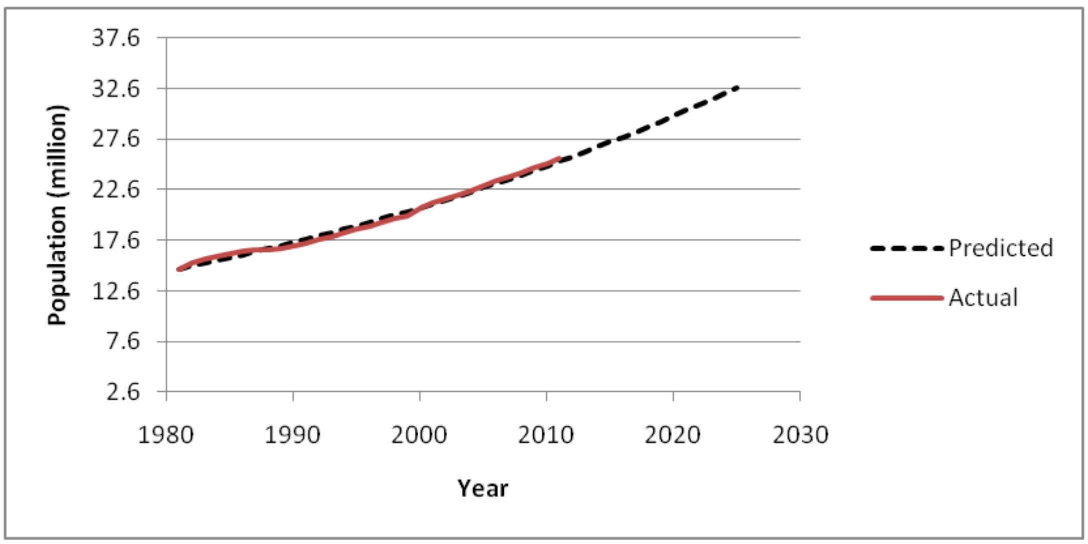

Figure 26. Projected Texas Population.

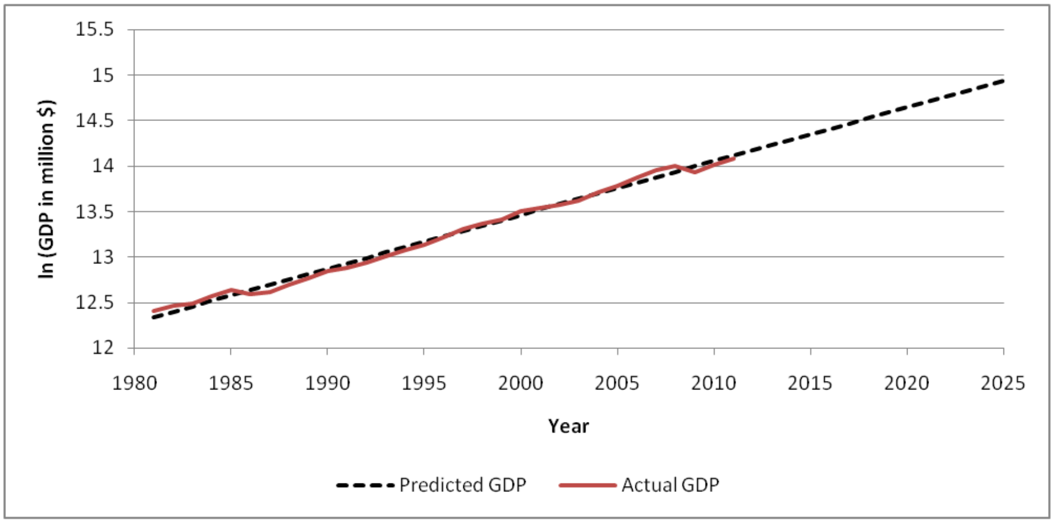

Figure 27. Projected Texas GDP.