

AN ESTIMATION OF THE DEMAND FOR GASOLINE IN MONTANA, AND
PROJECTIONS OF FUTURE GASOLINE CONSUMPTION

by

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A thesis submitted in partial fulfillment
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of

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in

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Dedication

I would like to dedicate this work to my wife. I am confident that without her I would not have finished this. I hope that I can do the same for her some day as well.

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ABSTRACT

How gasoline consumption responds to changes in its own price is of interest to many different groups. States fund a large portion of their road construction and maintenance by a direct tax on gasoline. The federal government also receives revenue by directly taxing gasoline. Automobile manufacturers are interested in how consumers' demand for fuel efficiency changes with changes in the price of gasoline. For these reasons, and more, it is important to understand how gasoline consumption will respond to changes in price.

Other researchers have already attempted to measure gasoline demand at the national level. However, very little work has been done at a state level. This thesis attempts to apply a model similar to the previously developed national models at a state level. The state examined here is Montana. This state is of particular interest because it differs from the national average in several key characteristics, including more vehicles per capita, less fuel efficient vehicles, and few alternatives to driving such as public transportation.

The model employed simultaneously estimates the demands for vehicle miles traveled and fuel efficiency. By estimating the demands for both of these variables, it is possible to indirectly determine the demand for gasoline. When estimated, it appears that Montana's consumption of gasoline is less responsive to changes in gasoline prices, and more responsive to income changes, than the nation as a whole.

The estimated model is used to project future gasoline consumption. The projections were developed using potential future levels of income, population, and gasoline prices. These projections indicate that it would require gasoline prices rising considerably before per capita consumption would decline.

CHAPTER 1

INTRODUCTION

A growing concern among state governments is the recent trend of rising gasoline prices. This trend has the potential of reducing gasoline consumption through the direct effect of a reduction in the quantity of gasoline demanded given the vehicle fleet and through the indirect effect of increased vehicle fuel efficiency. Through these channels state and federal governments face a potential decline in the revenues they receive through their taxes on gasoline. This decline in funding will strongly influence projects currently funded through these taxes. By being able to estimate the demand for gasoline, it is possible to predict what effects these new prices will have on revenues.

The last time the U.S. faced such a strong rise in gasoline prices in such a short time was during 1978-1980 (Figure 1.1). During that time gasoline prices rose from \$2 a gallon in real (inflation adjusted) terms to \$2.91. As a result, national gasoline consumption declined by 12% from 1978 to 1982. Recently gasoline prices have increased again, approaching and exceeding the record highs of the late seventies in real terms. If such a decline in consumption occurs again, gasoline tax revenues will decline as well.

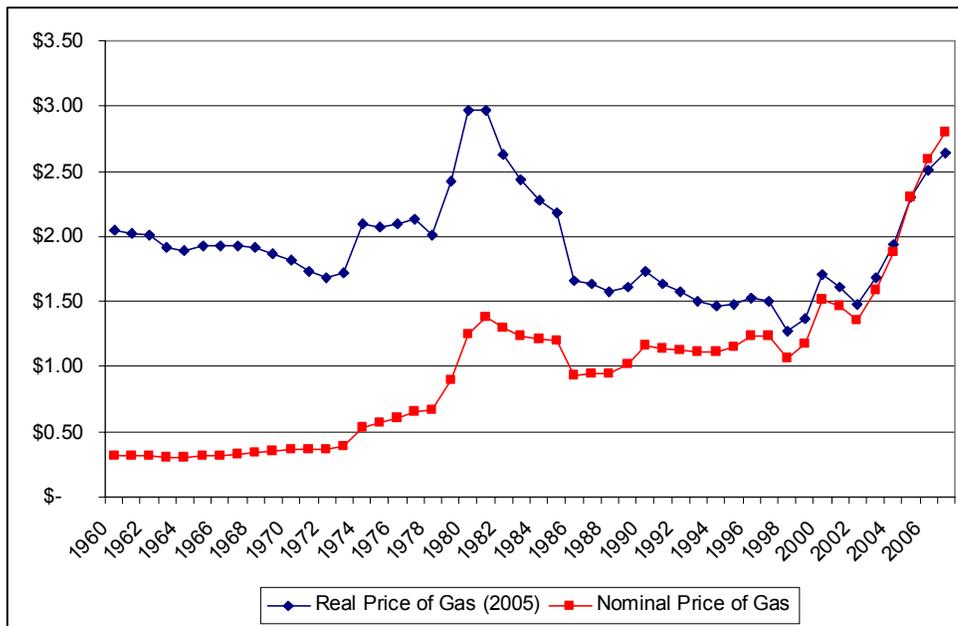


Figure 1.1 Historical Gasoline Prices

Source: Retail Motor Gasoline Prices, Energy Information Administration

The federal government implemented fuel efficiency requirements for new automobiles during the late seventies. These corporate average fuel efficiency (CAFE) standards were constant from 1990 to 2005, primarily due to relatively low gasoline prices. With prices reaching near record highs, the federal government has updated these standards, and these standards will begin to take effect in 2008. What influences these new prices and standards will have on gasoline consumption are of large concern to government agencies that depend on gasoline tax revenues for funding.

A majority of the work done in estimating the demand for gasoline in the U.S. has been done at the national level, using data ranging as far back as 1950. While there has been considerable work done in this area, there appears to have been little analysis done that develops results for individual states. This may not be of particular concern when dealing with states that closely correspond to the national average. However, applying

these models to areas that differ will cause accuracy to suffer. The purpose of this thesis is to attempt to develop a demand model for the state of Montana in the hopes of producing a more accurate model. The model in this thesis is based on yearly time series data from Montana ranging from 1960 to 2005.

Montana differs from the national average in several potentially important characteristics. The first of these is that Montana has had more vehicles per capita than the national average for over forty years (Figure 1.2). This trend has continued even today. This abundance of vehicles could be explained by how few of Montana's citizens live in metropolitan areas. (Figure 1.3)

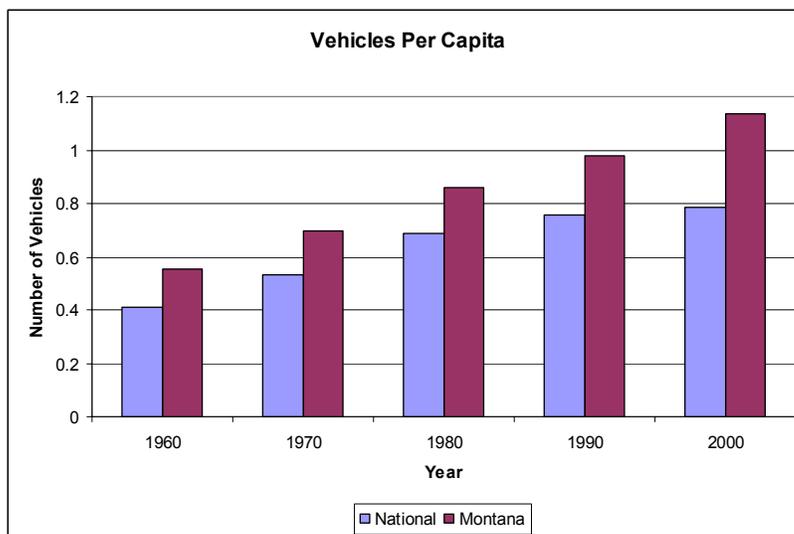


Figure 1.2 National and Montana Vehicles Per Capita
Source: Highway Statistics, Federal Highway Administration

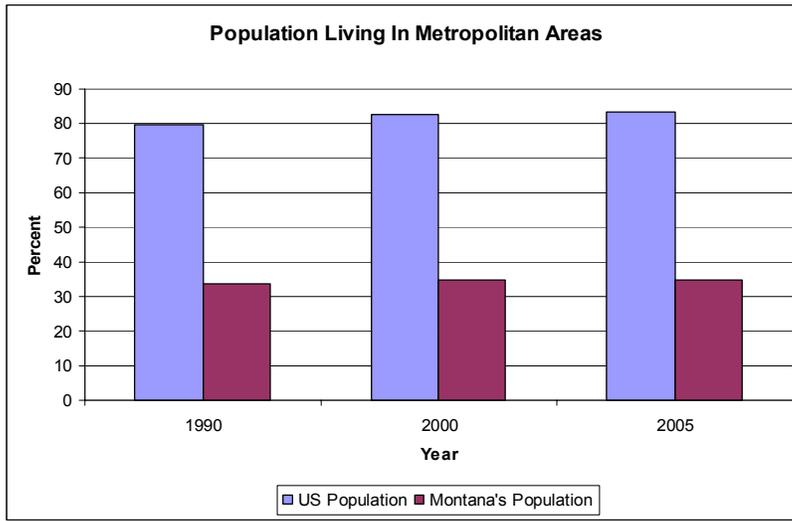


Figure 1.3 National and Montana Population Living In Metropolitan Areas
Source: County Population Estimates, U.S. Census Bureau

Previous work has indicated that urbanization has a negative effect on vehicle miles traveled (VMT's). With a lower level of urbanization, Montana's per capita VMT's are expected to be higher than the national average. This increase in VMT's is likely to be caused by the limited alternatives to private automobile use.

Montana's difference from the national average is not limited to the number of vehicles. Differences continue when also considering the fleet's make up. Montana's vehicle make up consists of a higher proportion of trucks when compared to the rest of the nation. (Figure 1.4) This is relevant given that trucks¹ tend to attain lower fuel efficiency performance than automobiles. This could explain why Montana has consistently had an average fuel efficiency of about 1 MPG less than the rest of the nation (Figure 1.5). Fuel purchases may therefore constitute a larger portion of personal income. All of these characteristics indicate that Montana has the potential to respond differently to price

¹ The term "trucks" refers to light passenger trucks and sport utility vehicles.

changes than national models would suggest. Knowing this, a Montana-specific model could provide more accurate predictions of gasoline demand.

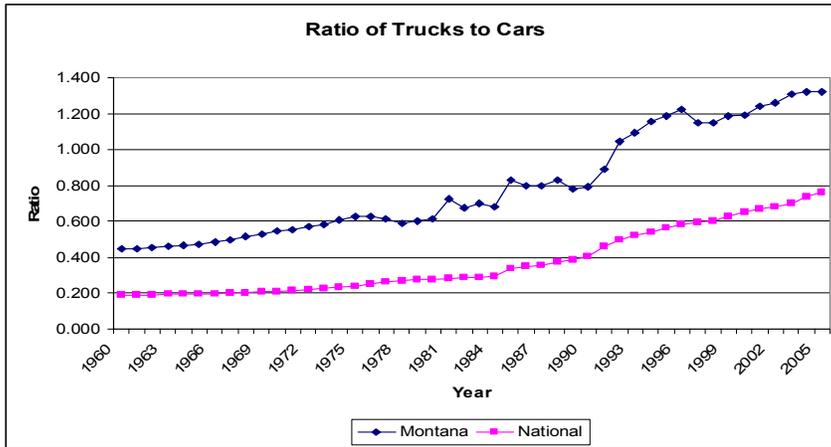


Figure 1.4 National and Montana Proportion of Trucks to Cars
Source: Highway Statistics, Federal Highway Administration

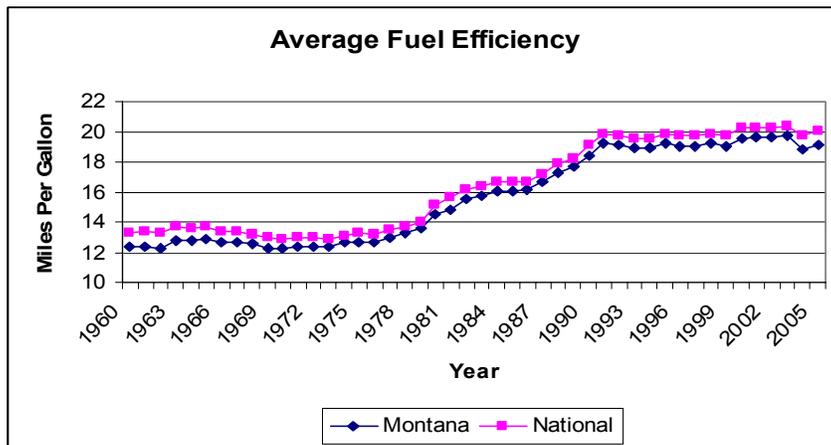


Figure 1.5 National and Montana Average Fleet Fuel Efficiency
Source: Highway Statistics, Federal Highway Administration

The purpose of this thesis is to estimate the demand for gasoline in the state of Montana. Due to what has been defined as the “rebound effect” this demand estimation needs to simultaneously account for price’s direct effect on vehicle travel, as well as its indirect effect on fuel efficiency. This model assumes a simultaneous aggregate demand

for vehicle miles traveled and fuel efficiency. The model is statistically estimated using three stage least squares. By incorporating the price of fuel into both equations, as well as other variables such as CAFE, several useful estimations can be generated. It is possible to measure the effect that changes in the price of fuel may have not only on the amount of fuel that will be consumed, but also on the number of miles that individuals will travel. This could prove useful for Montana's Department of Transportation by allowing them to project needed funding for road maintenance due to the amount of vehicle travel. Estimation of the effect that the recent changes in CAFE requirements will have on fuel consumption will also be possible.

Using the model developed it is possible to project several potential quantities of gasoline consumption based on different potential levels of the exogenous variables such as income, population, and gas prices. Based on this model, gasoline consumption is projected to the year 2030. The projections indicate that even with high gasoline prices, the consumption of gasoline will continue to increase as long as real incomes increase by 1.5% each year. With high gasoline prices and a 1.5% annual increase in real income, Montana's total gasoline consumption could increase by approximately 100 million gallons of gasoline from 2005 to 2030. This rise in consumption even with high gasoline prices would indicate that the state of Montana can continue to expect gasoline tax revenues to increase for the immediate future as long as real incomes continue to rise as well.

CHAPTER 2

ECONOMIC THEORY

Initially it may not seem that much work would be needed to develop a demand function for a given commodity such as gasoline. Any intermediate economics text book will describe what is necessary for this demand estimation. That is the inclusion of income, the price of the good, as well as the prices of any substitute or complement of that good. For gasoline this process becomes a bit more difficult. The difficulty is, it is not gasoline that individual's desire. It is the transportation that gasoline provides that people want. This would not be an issue if gasoline provided the same transportation capacity over time. However increases in vehicle fuel efficiency have increased the output that each gallon of gasoline provides. Another difficulty is that increases in fuel efficiency tend to be strongly influenced by gasoline prices. This correlation continues when examining the federal fuel efficiency standards. Minimum fuel efficiency requirements tend to be increased only in the face of rising gasoline prices. As a result, fuel prices and fuel efficiency are highly correlated. Even in the face of such difficulties, there has already been a great deal of previous work done in attempting to estimate the demand for gasoline.

The cost per mile is one of the many factors that influence how much each individual will drive. The difficulty is that the price of fuel does not directly influence how much individuals drive. They are instead influenced by the price of fuel relative to how fuel efficient their vehicles are. This per-mile fuel cost (P_m) is what individuals use when choosing their vehicle miles traveled (VMT). Early work done that involves P_m has

assumed that fuel efficiency is an exogenous variable. Greene (1992) makes such an assumption when attempting to estimate the “rebound” effect. It is likely that an increase in the price of fuel creates incentives for increases in fuel efficiency. This would imply that when examining data with variation in the price of fuel there would be variation in fuel efficiency as well. Ignoring this effect would cause any Pm estimates to be incorrect. More recent models have attempted to correct for this problem by assuming that fuel efficiency is endogenous to the model. Small and Van Dender (2007) do this by setting up a model that simultaneously estimates VMT's and Fuel Efficiency. Their process is applied in this thesis.

By definition, fuel consumption equals the amount that people drive, divided by how far each vehicle can travel with each gallon of gasoline. This can be written as:

$$F = M/E$$

Where F is the amount of fuel consumed (gallons), M is total VMT's, and E is the fleet fuel efficiency (Miles/Gallon). This formula allows forecasts of the amount of fuel that will be consumed in the future by estimating how much people will travel (M) and the fuel efficiency of the fleet (E). By simultaneously estimating the demand for both VMT's and fuel efficiency, gasoline demand is implicitly estimated as well.

When Small and Van Dender (2007) estimated their demand model, they also included an equation for the number of vehicles. Johansson and Schipper (1997) included a similar variable in their model. In this thesis the model does not include any measure of the vehicle fleet. This is due to the lack of good data on the vehicle fleet at the state level in Montana. In other studies, vehicle fleet data has come from the Federal Highway

Administration. Unfortunately the reliability of this source in regard to vehicle registrations believed to be highly questionable. Upon viewing this data for Montana, there are large variations in registrations for the years 1975- 1993 that cannot be reasonably explained (Figure 2.1). Due to this questionable data, the model in this thesis has been restricted to only VMT's and fuel efficiency.

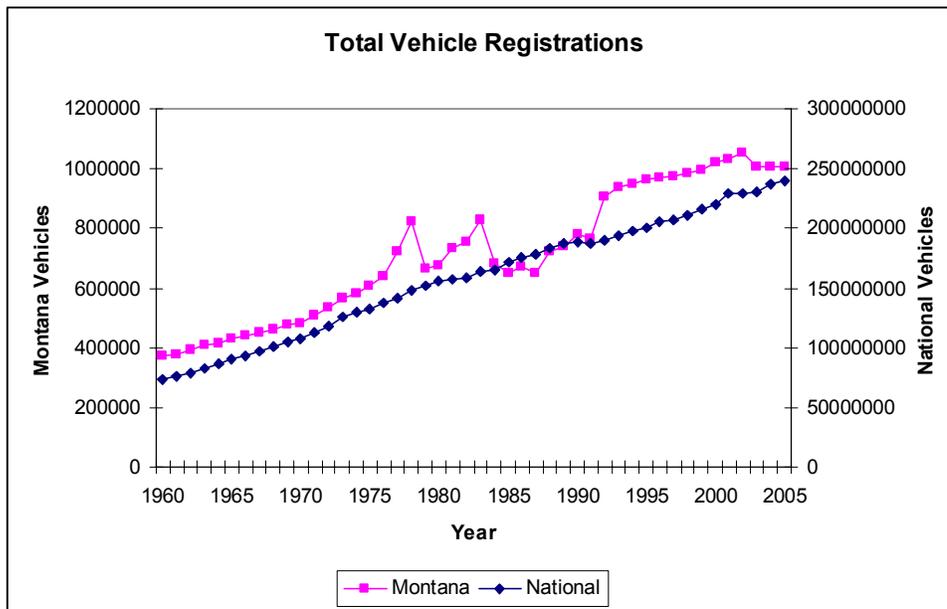


Figure 2.1 Total Vehicle Registrations
Source: Highway Statistics, Federal Highway Administration

As is common in the existing literature, this thesis attempts to estimate both VMT's and fuel efficiency. It is similar in the inclusion of determining factors that are included in estimating the model. These factors include: income, per mile fuel cost, and the price of gasoline. There is also strong reason to believe that there is some lag in individuals adjusting their fuel consumption. This lag is due to the adjustment period it would take individuals to purchase new vehicles or change where they live. Due to the high cost of changing these factors it may be some time before individuals are able to completely

adjust their fuel consumption. Urbanization also appears to negatively influence how much people drive (Small and Van Dender (2007)). Due to this, a variable is included as an explanatory factor. A dummy variable to adjust for the price controls that were in effect from 1971 to 1979 is also included. In order to adjust for any structural changes, such as technological or regulation changes, a time trend is included as well. Finally, since 1978 the government has influenced fuel efficiency by implementing CAFE standards. These standards require some adjustment to the model to estimate their effects. Given these explanatory factors it is possible to develop the system:

$$M = f(\text{Per Mile Fuel Cost, Income, Urbanization})$$

$$E = g(\text{VMT, Price of Gasoline, Income, CAFE})$$

$$\text{Per Mile Fuel Cost} = \text{Price of Gasoline} / \text{Fuel Efficiency}$$

It is easy to understand why the desired fuel efficiency would depend on VMT's. If individuals need to travel only a small amount, then the per-mile cost of travel relative to income will be small, regardless of how fuel efficient their vehicles are. Alternatively, as the amount of travel individuals engage in increases, the increased fuel efficiency has the potential to significantly reduce the per-mile fuel cost of travel.

It is expected that as vehicle miles traveled increases fuel efficiency is going to increase as well. At the same time, increases in fuel efficiency is going to reduce the per mile fuel cost of traveling. This will cause increases in fuel efficiency to have a positive effect on vehicle miles traveled. The price of gasoline is expected to have different effects on vehicle miles traveled and fuel efficiency. First, higher gasoline prices are expected to increase fuel efficiency. Higher gasoline prices will also increase the per mile fuel cost of

travel, leading to a negative effect on vehicle miles traveled. Increases in incomes are also going to have two different effects in the model. Assuming that travel is a normal good, increased incomes will lead to increased vehicle miles traveled. At the same time, as incomes increase the per mile fuel cost becomes a smaller portion of incomes. This is expected to cause income growth to have a negative impact in fuel efficiency. Finally, fuel efficiency standards (CAFE) are expected to have a positive effect on fuel efficiency.

Corporate Average Fuel Efficiency Standards

Since 1978 vehicle manufactures have been required to meet specific fuel efficiency requirements for passenger vehicles. These government mandates have the potential to require new automobiles to be more fuel efficient than they would be otherwise. If this effect is left unaccounted for in the model, the fuel efficiency estimates could be inaccurate. However, adjusting for this effect has proven difficult in previous studies. The difficulty is in part due to the multicollinearity problem caused by efficiency standards being raised in times of increasing gasoline prices. This multicollinearity problem could be significant given the small sample size of data available for Montana (Wooldridge, Pg. 103). In fact there has yet to be any accepted standard in controlling for this factor.

The most basic attempt to control for this CAFE standard is by including a dummy variable beginning in 1978. Schimek (1996) uses this approach when attempting to estimate the “rebound” effect. The problem with using such an approach is that it would capture any structural change during that time period, not just the CAFE requirements. It

would also fail to account for the changes that have occurred in the CAFE standards over time. Other attempts have simply used the fuel efficiency standards set for passenger cars each year. This treatment fails to adjust for the standard being different for both passenger cars and light trucks. Small and Van Dender (2007) attempt to correct these problems by developing their own variable that attempts to predict the difference between desired fuel efficiency and what the CAFE standards require. The difficulty in using this variable is that their model attempts to predict desired fuel efficiency based on data from 1966-1977. This may not be a problem if the time period that is being predicted is relatively close to that time period. As time extends beyond that initial time period the accuracy of those predictions is going to decline. If this variable were going to be used in this thesis, the accuracy of the desired fuel efficiency is likely to be low by the year 2005. This problem would become increasingly worse when applying it to the predictions of fuel consumption by 2030. It is due to these problems that none of the above methods are used in this thesis.

This thesis attempts to address this fuel efficiency problem by developing a weighted average fuel efficiency standard. This variable is based on the standards for light trucks and passenger cars with each being weighted respectively by the number of light trucks and passenger cars registered in Montana each year. By weighting the CAFE standards this new variable is able to adjust to changes in the types of vehicles that individuals are driving. This allows for the variable to pick up the adjustments that the efficiency standards potentially caused when people began shifting their vehicle purchases to SUVs in the 1990's. It is believed that this weighted variable will more accurately represent the effects that fuel efficiency standards have had on the desired fuel efficiency.

The Rebound Effect

When people decide how much they wish to travel, they consider several factors. Among these factors are how fuel efficient their vehicles are, as well as the price of gasoline. So, when the price of gasoline increases, the per-mile cost of driving increases as well. This encourages people to drive less. However this also creates incentives for individuals to drive in a more fuel efficient manner. This is accomplished by either purchasing more fuel efficient vehicles or driving more efficiently. Switching to more fuel efficient travel reduces the per-mile cost of driving, which encourages individuals to drive more miles. It is this process that has been called the “rebound” effect. There are examples of this process in any energy process, such as residential space heating and cooling, appliances, and transportation (Greening, Greene, Diffusion, 2000). This effect could have some important implications when considering the effect that rising gasoline prices have on gasoline consumption.

There has already been a great deal of work done attempting to measure this rebound effect on gasoline. Greene (1992) attempted to estimate this effect by using yearly time series data for the U.S. from 1966-1989. He estimated the rebound effect to be between 5% and 15%, with 12.7% being his best estimate. This estimate implies that a doubling of vehicle's fuel efficiency would result in gasoline consumption to decline by only 87%. Within his model Greene assumes that the per mile fuel cost is an exogenous variable and does not include any lagged variables. He found strong autocorrelation within the data, and also found lagged values to be insignificant when the model was corrected

for autocorrelation. Jones (1993) expands on Greene's work by expanding the data set to 1990, and includes lagged dependent variables. With the inclusion of the lagged variables, Jones found short-run estimates of 11% and long-run estimates of 31% for the rebound effect. Other similar studies of the rebound effect that included lagged dependent variables found similar results to Jones (Schimek (1996)). Small and Van Dender (2007) estimated the rebound effect to be approximately 4.5% in the short-run and 22.2% in the long-run. Their short-run elasticity estimates are slightly smaller than previous estimates. Small and Van Dender (2007) believe that this may be a sign that previous estimates may be overstated due to some endogeneity bias.

Gasoline Elasticity Estimates

Most previous estimates of gasoline demand have been performed at either the national or multi-national level. Graham and Glaister (2002) gathered much of this data and provided the price and income elasticities that each model developed. While the results of previous studies may differ from the Montana specific model, they do provide a point of reference on what the results should look like.

In an early attempt at demand estimation, Drollas (1984) examines some of the previous literature while also developing gasoline demand elasticity estimates for European countries. Within the reviewed literature there were many different estimates of elasticity with regard to income and price (Table 2.2). However the general view is that long-run price elasticity of demand is about -0.80. Long-run income elasticity is thought to be slightly below unity. One difficulty with examining these models is that only some of

them provide for both long- and short-run effects. When performing his analysis, Drollas includes lagged values to allow for both long- and short-run effects. His results reveal long-run price elasticity between -0.6 and -1.2 depending on the country, with estimated short-run price elasticity falling between -0.26 and -0.53. This inertia in gasoline demand is believed to be caused by slowly changing vehicle stocks.

Table 2.2 Gasoline Demand Elasticity Estimates

Gasoline Demand Elasticity Reported By Dahl (1995)				
	Price Elasticity		Income Elasticity	
	Short Run	Long Run	Short Run	Long Run
Taylor (1977)	-0.1 to -0.5	-0.25 to -1.0	-	-
Bohi (1981)	-0.2	-0.7	-	≈ 1.0
Kouris (1983)	-	-1.09	-	-
Bohi and Zimmerman (1984)	0.0 to -0.77	0.0 to -1.59	-0.18 to 1.20	-0.34 to 1.35
Dahl (1986)	-0.29	-1.02	0.47	1.38
Dahl and Sterner (1991a, 1992b)	-0.26	-0.86	0.48	1.21
Goodwin (1992)	-0.27	-0.71 to -0.84	-	-

Source: Dahl (1995), Graham and Glaister (2002).

Blum *et al.* (1988) reviewed demand estimation efforts performed specifically for West Germany and Austria. In doing so they found short-run price elasticities between -0.25 and -0.83. They also found short-run income elasticities that fell between 0.86 and 1.90. One very interesting result indicated that the elasticity of fuel consumption for cars with respect to efficiency is 0.61. This would indicate that a doubling of fuel efficiency would only reduce fuel consumption by about 60%. The different geographical location could explain why this rebound effect estimation is larger than others.

After reviewing the different literature on gasoline demand estimation, Graham and Glaister draw two conclusions. The first is that in the long-run, there will be a

significant response to gasoline consumption relative to price, although the small short-run response may be small. Additionally, the long-run income elasticity of fuel demand is found to be around 1.1 to 1.3. This implies that fuel prices would need to rise faster than the rate of income growth in order to stabilize gasoline consumption at current levels.

Although there has been little work done in gasoline demand estimation for Montana, there has been a lot of similar work done for other geographical areas. This work provides some useful information regarding what to include when estimating gasoline demand. It has also provided a means of comparing the generated estimates with others to estimate the accuracy of the predictions. Other works done in examining the rebound effect have also provided several useful comparisons. While the results in this thesis should differ to some extent from other works, the results should be comparable.

CHAPTER 3

THE EMPIRICAL MODEL AND RESULTS

The empirical work in this thesis is based on estimating two simultaneous demand equations: vehicle miles traveled (VMT) and fleet fuel efficiency (E). The amount of fuel that people use (F) must be equal to vehicle miles traveled divided by fuel efficiency. Thus, when vehicle miles traveled and fleet fuel efficiency are both estimated, the quantity of gasoline that will be demanded would be estimated as well.

$$F = \text{VMT} / E$$

It is assumed that VMT's will depend on the per-mile fuel cost of driving (Pm), the individual's income, and the proportion of the population that lives in urban areas. Fuel efficiency is determined by how much individuals drive (VMT), the price of gasoline (Pg), the individual's income (Inc), and fuel efficiency standards (CafeMT). Based on these assumptions it is possible to develop the model:

$$\text{VMT} = f(Pm, \text{Inc}, \text{Urban})$$

$$E = g(Pg, \text{VMT}, \text{CafeMT}, \text{Inc})$$

In determining the empirical specification of the model, several assumptions are made. The first is that both VMT and fuel efficiency take time to adjust to changes in exogenous variables. Thus, lagged dependent variables are included in both equations. This also allows for long- and short-term effects to be estimated. The second assumption is that some structural changes occurred over the 46-year sample period. To adjust for this, a time trend must be included in both equations. The third is that a dummy should also be

included for the years 1971 through 1979 in the VMT equation to try to control for price controls that were in effect during those years. Finally, the variables in both equations are in logarithmic form. The coefficients are then elasticity estimates. From these assumptions the following system is developed:²

$$(3.1) \ln(VMT)_t = \beta_1 + \beta_2 \ln(VMT)_{t-1} + \beta_3 \ln(Pm)_t + \beta_4 \ln(Inc)_t + \beta_5 \ln(Urban)_t + \beta_6 D7179 + \beta_7 Trend + U_t^1$$

$$(3.2) \ln(Eff)_t = \alpha_1 + \alpha_2 \ln(Eff)_{t-1} + \alpha_3 \ln(VMT)_t + \alpha_4 \ln(Pg)_t + \alpha_5 \ln(Inc)_t + \alpha_6 \ln(CafeMT) + \alpha_7 Trend + U_t^2$$

This model assumes that the error terms in both equations are not serially correlated, or heteroskedastic. The error terms of both equations are allowed to be correlated with each. Also, because this model examines Montana specifically, the yearly data set that is used in the above model will be very small. In fact it will only have 46 total observations. This small sample size becomes a particular problem when dealing with the subject of gasoline prices and fuel efficiency standards.

In the past, the government has passed more stringent fuel efficiency standards during times of significantly rising gasoline prices. This process becomes important when attempting to differentiate the effect that rising gasoline prices and fuel efficiency standards have on fuel efficiency. Because of this it is possible that this problem and the small sample size will lead to a multicollinearity problem, for which there is no definitive test. Based on this model, the most appropriate way to show that this problem exists would be to omit one of the collinear variables and see if the other variables become significant. If this problem is large enough, then either or both of these variables could appear insignificant. Unfortunately the only way to correct this problem would be to increase the

2 Other studies using similar models have included a Pm*Inc variable. However, this variable was not found to be significant in the Montana data.

sample size, and this could only be achieved by expanding the geographic area (Wooldridge, Pg. 103 and Mirer, Pg. 257). Given the scope of this thesis, expanding the geographic area is simply not possible. Without being able to correct for this collinearity problem, the standard errors for the price of gasoline and CAFE variables are likely to be larger than they would have been otherwise. This could increase the possibility of making a type II error for the price of gasoline and CAFE variables.

Another difficulty with the interaction between the price of gasoline and fuel efficiency standards arises when examining these standards. As mentioned above, fuel efficiency standards tend to increase with gasoline prices, but they generally don't decrease when the price of gasoline decreases. This leads to fuel efficiency standards remaining the same after the price of gasoline declines. Therefore, the effect that the price of gasoline has on the desired fuel efficiency may be understated. This problem may be represented by car buyers, shifting from buying passenger cars to buying SUVs and light trucks which face lower fuel efficiency standards. Including a weighted average fuel efficiency standard for Montana should reduce this effect's influence on our results. This weighting is performed by multiplying the fuel efficiency standards of cars and light trucks by the respective number of vehicles that were registered during that year. However, it is unlikely that this weighted average variable will completely correct for this effect.

To compensate for the potential interactions between the price of gasoline and fuel efficiency standards, another model has been estimated that does not include the CAFE standards:

$$(3.3) \ln(Eff)_t = \lambda_1 + \lambda_2 \ln(Eff)_{t-1} + \lambda_3 \ln(VMT)_t + \lambda_4 \ln(Pg)_t + \lambda_5 \ln(Inc)_t + \lambda_6 Trend + U_t^3$$

The lagged dependent variable is necessary in all equations to account for a lagged adjustment period. This lagged adjustment process would be the result of individuals needing time to adjust their behavior. Both VMT and fuel efficiency would not be able to completely adjust in only one time period, so they each have a lagged variable. This lagged adjustment means that there will be both short-run and long-run effects.

Additionally, because both equations are influenced by the other included equation, short- and long-term cross effects will influence our elasticity estimates. To adjust for these cross effects equations (3.1) and (3.2) are written in matrix form and represented as equation (3.4). Equation (3.4) is then solved for Y_t . This process is displayed within equations (3.5) and (3.6). Where Y_t is the vector of the endogenous variables, and x is the vector of exogenous variables.

$$(3.4) A_0 Y_t = A_1 Y_{t-1} + Bx + \varepsilon$$

$$(3.5) Y_t = A_0^{-1} A_1 Y_{t-1} + A_0^{-1} Bx + \varepsilon$$

$$(3.6) Y_t = (I - (A_0^{-1} A_1))^{-1} (A_0^{-1} B)x + \varepsilon$$

Solving for Y_t provides both the short- and long-run elasticities that include the cross effects inherent to this simultaneous model. The matrix $A_0^{-1} B$ contains the short-run elasticities and the matrix $(I - (A_0^{-1} A_1))^{-1} (A_0^{-1} B)$ contains the long-run elasticities. This simultaneous model could cause the long- and short-run elasticities to differ considerably.

3 Including the lagged fuel efficiency variable eliminates the problem of being under identified. This assumes that $\ln(Eff)_{t-1}$ is uncorrelated with the error term U_t^3 , which in turn requires that U_t^3 is serially uncorrelated.

In the short-run, it is unlikely that the cross effects will strongly influence the elasticity results due to the expected lagged adjustment period. Once these cross effects are adjusted for in the long-run the potential exists for the elasticities to adjust considerably and potentially change signs. It is this potential for a considerable change in results that requires this process be implemented.

Data Sources

This thesis focuses on the state of Montana, for the years 1960-2005. A table of all summary statistics is provided in Table 3.7.

Table 3.7 Summary Statistics

Summary Statistics for Selected Variables					
Variable	Definition	Mean	Std. Dev	Min.	Max.
VMT	VMT per adult	8617.7	2324.6	4080	12098
ln(VMT)		9.0188	0.31103	8.3138	9.4008
Efficiency	Average Fuel Efficiency	15.642	2.9591	12.265	19.693
ln(Efficiency)		2.7324	0.1898	2.5067	2.9803
Inc	Real 2005 Per Capita	22031	4160.5	13396	32741
ln(Inc)	Income	9.9724	0.1923	9.5027	10.273
Pg	Real Price of Gasoline	1.9202	0.38685	1.28	2.99
ln(Pg)		0.63378	0.19298	0.24686	1.0953
Pm	Real Per Mile Fuel Cost	0.12933	0.040256	0.067	0.205
ln(Pm)		-2.0974	0.3382	-2.7031	-1.584
Urban	Fraction of Population	0.6017	0.032279	0.538	0.648
ln(Urban)	Living in Urban Areas	-0.50945	0.054625	-0.6199	-0.43386
CafeMT	Montana Weighted	13.971	11.413	0	24.4
ln(CafeMT)	CAFE Variable	1.9053	1.5459	0	3.1946

Endogenous Variables

1. Vehicle Miles Traveled (VMT): This variable equals Montana's total estimated vehicle miles traveled divided by the annual population. The data provided do not

break down the total vehicle miles traveled into gasoline and other fuel use miles. This means that there is the potential for some loss in consistency in the data⁴. (See 5, 9, and 10 in Appendix A)

2. Fuel Efficiency (Eff): This variable was developed based on both national and Montana-specific data. The average fuel efficiency of both passenger cars and light trucks has been separately estimated at the national level. These values were then weighted using the number of passenger cars and light-trucks registered in Montana each year. Using these, a weighted average of the fleet vehicle fuel efficiency was developed. (See 7 and 8 in Appendix A)

3. Per Mile Fuel Cost (Pm): The per mile fuel cost was developed from the fuel efficiency estimates, as well as the gasoline price data. The per mile fuel cost is equal to the price of gasoline divided by the average fleet fuel efficiency. It is expressed in real 2005 prices using the urban west CPI estimates provided by the U.S. Bureau of Labor Statistics. (See 2, 7, 8, and 11 in Appendix A)

Exogenous Variables

1. Price of Gasoline (Pg): The price data used in this model is the average price of gasoline for the entire United States in metropolitan areas. It would have been preferable to use Montana-specific gasoline prices; however it has only been possible to locate this data for 1983-2005. Using this data would have required the

⁴ It was possible to find Montana VMT data for the years of 1966-2005. The years of 1960-1965 were estimated using OLS based on the data available at the national level for the missing years. The estimation used national data from the years of 1966-1976.

model's time span to be reduced considerably. This would have required the study to omit a large portion of the data where gasoline prices were rising. Omitting this data would have been more detrimental to the estimates than using the national data. When comparing the Montana and national data, the results are highly correlated indicating that the use of the national data should still provide accurate results. The prices have been adjusted to real 2005 dollars. (See 2 and 11 in Appendix A)

2. Urbanization (Urban): The urbanization variable measures the proportion of Montana's population living in metropolitan and micro-population counties. These counties were determined by the Census Bureau for 2005. These include the following counties: Carbon, Cascade, Flathead, Gallatin, Hill, Jefferson, Lewis and Clark, Missoula, Silver Bow and Yellowstone. The Census Bureau also provided the county population data for 1970-2005. However, they lacked data for 1960-1970. For this time period statistical estimates of each county's population were developed by Montana's Research and Information Systems Division within the Department of Community Affairs. These figures are statistically estimated and are not exact numbers. However, these figures do follow a very similar path to the population figures provided by the Census Bureau. (See 5 in Appendix A)
3. Income (Inc): The personal income figures for Montana provided by the Bureau of Economic Analysis were used with the population estimates from the Census Bureau to determine the per capita income for Montana. These estimates have been adjusted to 2005 dollars to provide real per capita figures. (See 2, 3, and 5 in

Appendix A)

4. Montana Adjusted CAFE (CafeMT): This variable was derived in an attempt to more accurately represent CAFE's true effects on Montana. The variable is derived from a weighted average of passenger car and light truck CAFE standards relative to the number of passenger vehicles and light trucks licensed in Montana. (See 1, and 7 in Appendix A)
5. D7179: This is a dummy variable for the years of 1971-1979. During this time period the United States implemented oil and gasoline price controls. During 1971-1973, these price controls took the form of end user and crude oil price controls (Taylor and Van Doren, Pg, 9). While the end user price controls are believed to be mostly non-binding, it is likely that gasoline consumers modified their consumption behavior. During the years 1974-1981 the price controls were generally removed for end users of petroleum products (Taylor and Van Doren, Pg, 10). They were instead moved to crude oil prices for domestically produced oil. Even though these new price controls were not imposed directly on consumers of gasoline, it is assumed that these controls still influenced the behavior of end users. These price controls were officially in place until the early 1980s. The variable used here ends in 1979. While the price controls were still officially in place during the early 1980's, they had already begun to be eliminated during the end of the 1970's. The year 1979 was included because of the energy crisis that occurred that year. No further years were included in the dummy variable beyond this point due to the lack of any evidence that the price controls were still binding

and influencing consumption for those years.⁵

Stationarity and Cointegration

When using economic time series data, the issue of non-stationary variables becomes a real concern. If this issue is not addressed, the econometric results could indicate significant correlation where there is none (Pindyck and Rubinfeld, Pg. 507). This problem has been defined as the “spurious regression problem.” Upon examination of the variables used in this thesis a majority of them appear to be non-stationary. If these variables did not follow a random walk, then this problem could be adjusted for by including a trend variable (Pindyck and Rubinfeld, Pg. 508).

It appears that all but one of the variables in this thesis appears to be unit root (Table 3.8). A time trend is still included in the model to pick up structural changes that occur over time. Because the variables appear to follow a random walk and are unit root, they need to be cointegrated or it will be necessary to difference the unit root variables. If the variables are cointegrated, then they can be left in their level form. Because the dependent variable for the vehicle miles traveled equation does not appear to follow a unit root path, there is no need to be concerned about spurious results in that equation (Wooldridge, Pg. 647). However the dependent variable for the fuel efficiency equation does appear to follow a unit root path, causing the potential for spurious results.

⁵ Two separate dummies were initially used for the time periods of 1971-1973 and 1974-1979. However, testing failed to reject the hypothesis of both dummies being equal. It was decided to combine them into a single variable.

Table 3.8 Augmented Dickey-Fuller Tests for Unit Root

Variable	ADF Test Statistic
Vehicle Miles Traveled	-3.7
Fuel Efficiency	-1.38
Income	-2.56
Urban	-2.15
Price of Gasoline	-2.01
Per Mile Fuel Cost	-1.44
CAFÉ Standard	-1.18
Critical t-value at $\alpha = 0.05$ is -2.986	
Lagged Once	

If the current variables are going to be used without differencing them, they will need to be cointegrated. If the variables are cointegrated, then the variables move together in a meaningful manner. Because they move together, the results of regressing them in level form will provide meaningful results. However, before it is possible to test for cointegration, it is going to be necessary for the variables to be of the same order. To test this, each variable is lagged once and tested to see if it follows a unit root path. Upon testing it appears that all of the unit root variables are of the order $I(1)$ at the 90% confidence level (Table 3.9). Because all the unit root variables are of the same order it is important to test for cointegration.

Table 3.9 Differenced Augmented Dickey-Fuller Tests for Unit Root

Variable	ADF Test Statistic
Vehicle Miles Traveled	-4.29
Fuel Efficiency	-2.68
Income	-5.83
Urban	-3.42
Price of Gasoline	-4.73
Per Mile Fuel Cost	-4.39
CAFÉ Standard	-4.59
Critical t-value at $\alpha = 0.10$ is -2.60	
Lagged Once	

If the variables are cointegrated leaving them in level form will provide meaningful results. After testing, it is reasonable to reject the null hypothesis that the residuals follow a unit root path (Figure 3.10). This means that the residuals appear to be of the order $I(0)$. This indicates that the unit root variables are cointegrated and it is not necessary to be concerned about a “spurious regression problem.” This allows each variable to be left in their level form.

Table 3.10 Residual Augmented Dickey-Fuller Tests for Unit Root

Residuals	ADF Test Statistic
Vehicle Miles Traveled	-4.697
Fuel Efficiency	-3.875
Critical t-value at $\alpha = 0.01$ is -3.621	
Lagged Once	

Regression Estimates and Output

Estimation of equations (3.1), (3.2) and (3.3) are performed using three-stage least squares method of estimation. This system of estimation performs the necessary simultaneous estimation process and corrects any statistical difficulties caused by correlated error terms. The results for the VMT equations are:

Table 3.11 3SLS Results for the Vehicle Miles Traveled Equations

Variable	Estimated Using CafeMT		Estimated Without CafeMT	
	Coefficient	Standard Error	Coefficient	Standard Error
Vehicle Miles Traveled Lagged Once	0.7461	0.0699	0.7470	0.0697
Per Mile Fuel Cost	-0.0777	0.0247	-0.0775	0.0247
Income	0.5408	0.1299	0.5445	0.1271
Urban Population	0.5996	0.5632	0.5808	0.5575
Dummy – 1971-1979	-0.0584	0.0179	-0.0589	0.0178
Trend	-0.0067	0.0019	-0.0067	0.0019
Constant	-2.7754	1.4861	-2.8287	1.4746
R-Squared	0.9925		R-Squared	0.9925
S.E. of Reg.	0.0289		S.E. of Reg.	0.0289
Durbin-Watson	2.1427	46 Observations	Durbin-Watson	2.1468

The estimated values for the coefficients are similar across both models. All but the urban variables are found to be significant at the 99% confidence level. This consistency and high level of precision demonstrates plausible results. Durbin-Watson values of 2.1 suggest that there is no serial correlation on the disturbances. The R-squared values indicate that 99% of the variation in the VMT variable is explained for both models. The significance of the lagged variable shows that full adjustment in VMT's take more than a single time period. The negative coefficient for the per mile fuel cost is in the expected direction and indicates that an increase in fuel costs will lead to reduced travel.

The positive coefficient for income is also in the expected direction. This indicates that increased income will lead individuals to increase their travel. The dummy included for the years 1971-1979 reveals a reduction in travel of 6% during that time period. This is consistent with the expectations that price controls reduce travel. Only the variable to control for changes in the urban population has been found to be insignificant.

For the fuel efficiency equation several important results were obtained. The results are listed in Table 3.12.

Table 3.12 3SLS Results for the Fuel Efficiency Equations

Variable	Estimated Using CafeMT		Estimated Without CafeMT	
	Coefficient	Standard Error	Coefficient	Standard Error
Fuel Efficiency Lagged				
Once	0.8199	0.0823	0.9104	0.0763
Vehicle Miles Traveled	0.1076	0.0527	0.1715	0.0471
Price of Gasoline	0.0112	0.0206	0.0419	0.0167
Income	-0.1911	0.0845	-0.2466	0.0861
CAFEMT	0.0105	0.0045	-	-
Trend	0.0016	0.0016	0.0010	0.0016
Constant	1.3693	0.7074	1.1166	0.7435
R-Squared	0.9927		R-Squared	0.9916
S.E. of Reg.	0.0174		S.E. of Reg.	0.0185
Durbin-Watson	1.8554	46 Observations	Durbin-Watson	1.7341

In the model that includes the CAFE standard, several important things need to be addressed. The first is that the lagged coefficient is significant. It is larger than the lagged coefficient for VMT's meaning that individuals adjust their vehicles fuel efficiency slower than they adjust how much they travel. Secondly, the results show a significant positive coefficient for VMT's. This indicates that as individuals increase their travel they also increase the fuel efficiency of their vehicles. Third, a positive coefficient for the CAFE standard indicates that increasing fuel efficiency standards do increase fuel efficiency.

Values of 1.85 and 1.73 for the Durbin-Watson statistic indicate that there is likely to be little or no serial correlation in the disturbance terms. These models also have very high R-squares with values around 0.99. All of these results are consistent with expected results.

When examining the coefficient on the price of gasoline, however, the results indicate a positive but insignificant coefficient. A zero coefficient would conflict with the expected results. However if this model does have some multicollinearity between the price of gasoline and the CAFE variable the results could show an insignificant coefficient when their true relationship is positive.

To determine if there is a multicollinearity problem within the previous model, another model was estimated that excludes the CAFE variable. If there is a collinearity problem, the price of gasoline should become significant in the absence of the CAFE variable. In this model the price of gasoline is found to be positive and significant at the 95% confidence level. The other variables included in the model have similar coefficients to the previous model. This indicates that there is a probable multicollinearity problem with regards to the price of gasoline and the CAFE variables. Unfortunately, there is no way to correct for this problem without either increasing the sample size or dropping one of the collinear variables. The first option is not possible due to the constraints of limiting this work to Montana, as well as a lack of monthly or quarterly data for the time periods necessary. This leaves only the second option, and for the rest of the results both models are included.

Short- and Long-Run Elasticity Estimates

The models employed in this thesis simultaneously determine vehicle miles traveled and fuel efficiency. Due to the simultaneous nature of these models, elasticities depend on not only the variable's coefficients but on all the effects that each other variable has on the variable in question. Because of this process, it becomes necessary to examine the model in the reduced form that was developed in equation (3.6). When this reduced form process is performed on the model with the CAFE variable, the following short- and long-run elasticities are generated:

Table 3.13 Short- and Long-Run Reduced Form Elasticity Estimates for the CAFE Model

Vehicle Miles Traveled			Fuel Efficiency		
	Elasticities			Elasticities	
Variable	Short-Run	Long-Run	Variable	Short-Run	Long-Run
Price of Gasoline	-0.0774	-0.3510	Price of Gasoline	0.0029	-0.1476
Income	0.5304	2.2098	Income	-0.1340	0.2598
Urban	0.6047	2.8908	Urban	0.0651	1.7286
CAFEMT	0.0008	0.0218	CAFEMT	0.0106	0.0712
Dummy – 1971 -1979	-0.0590	-0.2819	Dummy – 1971 -1979	-0.0063	-0.1685
Trend	-0.0066	-0.0287	Trend	0.0009	-0.0081

The price of gasoline is found to have VMT short and long-run elasticity estimates of -0.0774 and -0.3510. The efficiency elasticities with regards to price are 0.0029 in the short-run and -0.1476 in the long-run. These results indicate that a 10% increase in the price of gasoline will decrease vehicle miles traveled by 0.7% in the short-run and 3.5% in the long-run. This same increase in price will cause fuel efficiency to increase by 0.03% in short-run, and in the long run it will decrease by 1.5%.

This change in sign in the long-run for efficiency is in the opposite direction than was expected and is thought to have been caused by the indirect effects that gasoline prices have on efficiency through its effect on vehicle miles traveled. An increase in the price of gasoline directly causes fuel efficiency to increase; this is indicated by the positive short-run elasticity result. It also directly causes vehicle miles traveled to decline. This direct effect that the price of gasoline has on vehicle miles traveled causes the price of gasoline to have an indirect effect on efficiency. This indirect effect is caused by vehicle miles traveled direct effect on efficiency. These effects mean that a rise in the price of gasoline will cause efficiency to directly increase; indirectly it will cause efficiency to decline due to the reduced vehicle miles traveled. The negative long-run elasticity indicates that the indirect effect that prices have on efficiency are larger than the direct effects.

This change in sign for the long-run elasticities also occurs in another variable: income. Income is found to have a vehicle mile traveled elasticity value of 0.5304 in the short-run and a value of 2.21 in the long-run. For efficiency, the elasticities in the short and long-run are found to be -0.1340 and 0.2598. The cause of the efficiency's income elasticity change is similar to the sign change for the own price elasticity. Directly, income has a positive effect on vehicle miles traveled as well as a negative effect on efficiency. This means that an increase in income will cause people to drive more, while also reducing fuel efficiency. However because vehicle miles traveled influences efficiency, there is also an indirect effect on efficiency due to income through changes in vehicle miles traveled. The same increase in income will cause people to drive more; this

increased travel will encourage efficiency to increase as well. Ultimately the long-run elasticity sign will be determined by which effect will be larger, the direct or indirect.

Higher fuel efficiency standards do not appear to increase vehicle miles traveled in the short-run. In the long-run however a 10% increase in the standards will cause an increase of 0.2% in vehicle miles traveled. Fuel efficiency standards do influence short-run levels of efficiency with an elasticity of 0.01. In the long-run this elasticity increases to 0.07 so that fleet efficiency will increase by almost 1% if standards are increased by 10%. Based on these elasticities, the updated 2007 fuel efficiency standards, which require a 40% increase, will cause: vehicle miles traveled to increase by almost 1% in the long-run, and efficiency to increase by almost 3% in the long-run in Montana.

This same process was also employed on the model that excludes the CafeMT variable. The results of this process are in Table (3.14).

Table 3.14 Short- and Long-Run Elasticity Estimates for the Non-CAFE Model

Vehicle Miles Traveled			Fuel Efficiency		
	Elasticities			Elasticities	
Variable	Short-Run	Long-Run	Variable	Short-Run	Long-Run
Price of Gasoline	-0.0752	-0.3937	Price of Gasoline	0.0290	-0.2861
Income	0.5325	3.1626	Income	-0.1553	3.3015
Urban Dummy – 1971-1979	0.5887	5.5467	Urban Dummy – 1971-1979	0.1009	10.6206
Trend	-0.0597	-0.5623	Trend	-0.0102	-1.0767
	-0.0596	-0.5541		-0.0092	-1.0499

In this model income is found to have short-run elasticity estimates (0.5325 for VMT and -0.1553 for fuel efficiency) very similar to those in the previous model. The long-run estimates differ quite a bit however. Income is found to have a long-run elasticity of 3.1626 for VMT and 3.3015 for fuel efficiency. Urbanization is found to have a

positive short-run elasticity of 0.5887 and 5.5467 in the long-run. For fuel efficiency urbanization has an elasticity of 0.1 in the short-run, which increases drastically to 10.6 in the long-run. The elasticity of the price of gas on VMT's is very similar to the previous model, with short- and long-run effects of -0.0752 and -0.3937 respectively. For fuel efficiency, the gasoline price elasticity increases considerably from 0.029 in the short-run to -0.2861 in the long-run. Similarly to the CAFE model, the gasoline price elasticity moves from being positive, with regards to fuel efficiency, in the short-run to being negative in the long-run.

Using the results developed from the previous models it is possible to determine how gasoline consumption will respond to increases in gasoline prices, as well as increases in incomes and CAFE standards. This model is based on the identity that fuel consumption must be equal to the amount of miles that are driven divided by average fuel efficiency. Thus it is possible to determine the elasticity of gasoline consumption relative to price by comparing the elasticities of vehicle miles traveled and fuel efficiency with respect to the price of gasoline. Because the results are in logarithmic form, they are subtracted from each other. This process is represented below, where Q is the number of gallons of fuel consumed per person:

$$3.15: Q = \text{VMT} / \text{Eff}$$

$$3.16: \ln(Q) = \ln(\text{VMT}) - \ln(\text{Eff})$$

$$3.17: \frac{d \ln(Q)}{d \ln(p_g)} = \frac{d \ln(\text{VMT})}{d \ln(p_g)} - \frac{d \ln(\text{Eff})}{d \ln(p_g)}$$

$$3.18: \epsilon_Q^{Pg} = \epsilon_{\text{VMT}}^{Pg} - \epsilon_{\text{Eff}}^{Pg}$$

Based on this identity, the final elasticity equation is developed so that gasoline's own price elasticity is equal to the difference in the vehicle miles traveled and fuel efficiency price elasticities. Based on this process it is possible to determine the own price elasticity of gasoline. Using the values developed in both models (Tables (3.13) and (3.14)) the following elasticities were determined:

Table 3.19 Own Price, Income and CAFE Elasticities for the Quantity of Gasoline Consumed

Estimated Using CafeMT			Estimated Without CafeMT		
Elasticities			Elasticities		
Variable	Short-Run	Long-Run	Variable	Short-Run	Long-Run
Pg	-0.0803	-0.2034	Pg	-0.1042	-0.1076
Inc	0.6644	1.95	Inc	0.6875	-0.1389
CafeMT	-0.0098	-0.0494	CafeMT	-	-

The model that includes the CafeMT variable shows that a 10% increase in the price of gasoline will cause the consumption of gasoline to decline by 0.8% in the short-run. In the long run this increase in the price of gasoline will cause gasoline consumption to decline by 2%. Using the same model, a 10% increase in real incomes will cause gasoline consumption to increase 6.6% in the short-run and 20% in the long-run. A similar increase in the CAFE requirements would cause gasoline consumption to decline by 0.01% in the short run and 0.5% in the long-run.

If the model that does not include the CafeMT variable is used, then the results tend to differ in the long-run. Based on this model a 10% increase in gasoline prices would cause gasoline consumption to decline by 1% in the short and long-run. The same increase

in real incomes would lead to an increase in gasoline consumption of almost 7% in the short-run. However in the long-run gasoline consumption would decline by 1.4%.

The fact that these models have very similar short-run elasticity results provides some confidence in the strength of the basic model. However the unlikely long-run results provided by the CafeMT omitting model makes it an unlikely candidate for the use in projections. It is because of these long-run differences and the omission of a fuel efficiency standard variable that the projections developed in the next section use on the CafeMT model.

CHAPTER 4

PROJECTIONS

Using the long-run model developed in the previous chapter, it is possible to project several potential levels of gasoline consumption in the future. The projections will depend on how the variables in the model change over the projected time periods. The initial projections forecast potential consumption based on above- and below-average values for all the variables in the model. This is an attempt to determine the highest potential quantities of gasoline consumption as well as the lowest potential values. While all the variables are important to the model, the one that varies most is the price of gasoline. Because of this high variability, additional projections are made that attempt to examine what consumption would be, given various changes to this variable. These projections examine gasoline consumption based on expected low, medium, and high gasoline prices. Income and population are assumed to increase at their historical rates. A final set of projections assume that the VMT elasticity with respect to the price of gasoline is double the estimated value. This projection is performed in an attempt to provide projections closer to elasticity estimates developed in other models.

Data Sources for the Years 2008-2030

Gasoline Prices: In 2008, the U.S. Energy Information Administration (EIA) released its annual estimates of projected gasoline prices from 2008 to 2030. These projections provide a low, reference, and high estimate of potential gasoline prices for the

entire time period. However, these projections do not include the \$4 per gallon gasoline prices that have occurred in 2008. To correct for this, the EIA projections were adjusted upward so that in 2008 the price of gasoline increased to \$4 per gallon in nominal terms (\$3.77 in 2005 dollars).

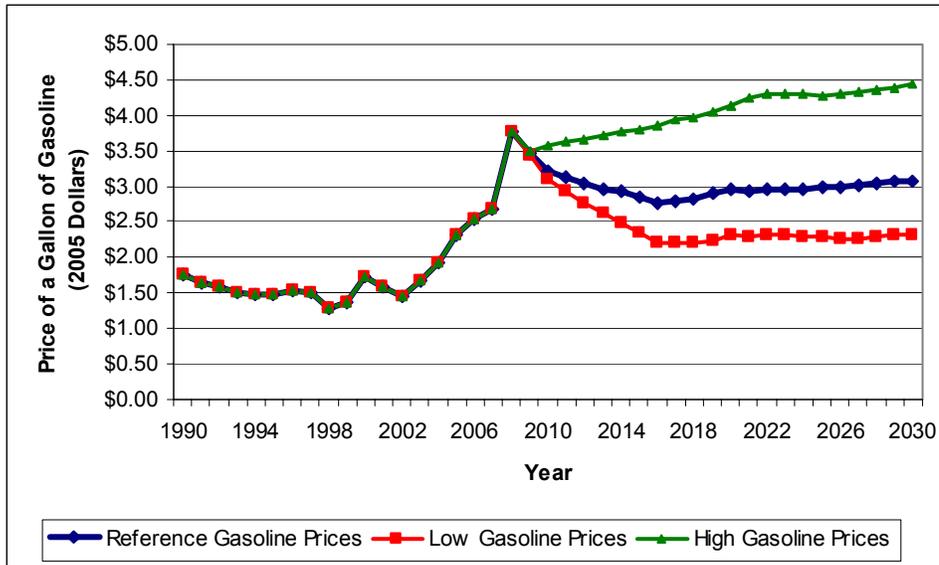


Figure 4.1 Projections of Future Gasoline Prices, as of 2008

Source: U.S. Energy Information Administration Annual Energy Outlook 2008

CAFE Standards: Leading up to 2005, CAFE standards had remained fairly constant since 1990. During this time the standard for passenger cars remained unchanged. However with the increase in gasoline prices that began in 2000, new standards have updated the requirements to new levels. Light truck standards were revised so that by 2010 they must average a fuel efficiency rating of 23.5 mpg. In 2007, a new set of standards were also included in the Energy Independence and Security Act. This act required that, beginning in 2009, all passenger cars and light trucks must reach a combined average fuel

efficiency of 35 mpg by 2020.⁶ The exact specifics of how this will occur have yet to be determined at the time of this thesis.

Because no clear policy specifies how this new fleet average fuel efficiency level will be achieved, some assumptions must be made. The method used to determine the CAFE variable in the empirical model was repeated for the years of 2006-2009,⁷ where the standards for passenger cars and light trucks are weighted based on the number of vehicles registered in Montana in each category. However, beginning in 2010 it is assumed that the average fuel efficiency requirements for the entire fleet will increase linearly, so that by 2020 the mandated 35 mpg standards will be met. For 2021-2030 it is also assumed that these standards will remain constant at the 35-mpg level reached in 2020. This is believed to be a reasonable assumption due to the standards remaining constant following the last period when higher requirements had been reached.

Real Income: During 1990-2005, Montana's real income per person increased by an average of 1.5% each year. For most of the projections, it is assumed that real incomes in Montana will continue to increase at this rate until at least 2030. For the projections that examine the maximum and minimum potential levels of gasoline consumption, high and low values of income growth are used in place of the average rates. The high value assumes that real incomes grow at a rate of 2.5%. The low level of consumption assumes that real incomes only increase by 0.5% each year.

6 United States Cong. Senate., H.R. 6 *Energy Independence and Security Act of 2007*, 110th Cong. Washington: 2007

7 During this time period it is assumed that the ratio of cars to trucks is the same as the ratio for the year 2005. This seems reasonable given that this ratio has remained fairly constant during the past 10 years.

Urban: From 1990 to 2005 the proportion of Montana's population that lives in either a metropolitan or metropolitan county has increased from 62% to 65%. This indicates that over a 15-year span, the proportion of the population increased by about 0.2% each year. For the projections this rate is assumed to continue during the entire time period. Given this rate of increase by 2030, the proportion of Montana's population living in these urban areas will increase to 68%.

Population: The population of Montana increased by an average of 1% each year from 1990-2005. As with the income variable, population growth rates varied when developing the maximum and minimum projections of gasoline consumption. The population growth rates of 0.5% and 2% are used for the low and high rates of gasoline consumption, respectively.

High and Low Total Gasoline Consumption Projections

To determine potential levels of gasoline consumption that could occur during 2005-2030, three different projections are made. The first assumes that all of the factors that contribute to total gasoline consumption increase at the reference rates. This requires that population, the price of gasoline, and incomes all increase at the reference rates. This provides a base line with which to compare how much the next two projections differ from the expected level of consumption. The second projection is an attempt to determine the maximum level of gasoline consumption that could be expected if all the inputs push gasoline consumption beyond the expected levels. This projection assumes: population grows at 2% each year; incomes grow at 2.5% each year; and the price of gasoline follows

the low projection of price provided by the EIA. The final projection is an attempt to determine how low gasoline consumption could be if all the factors work towards lowering consumption. This projection assumes: population growth of 0.5%; income growth of 0.5%; and that real gasoline prices increase according to the adjusted EIA high price projections. Based on these assumptions each of the projections is represented in Figure 4.2. The values for 1990 to 2005 are the actual values used in estimation of the model, and the values for 2006 to 2030 are obtained by solving the estimated model.⁸

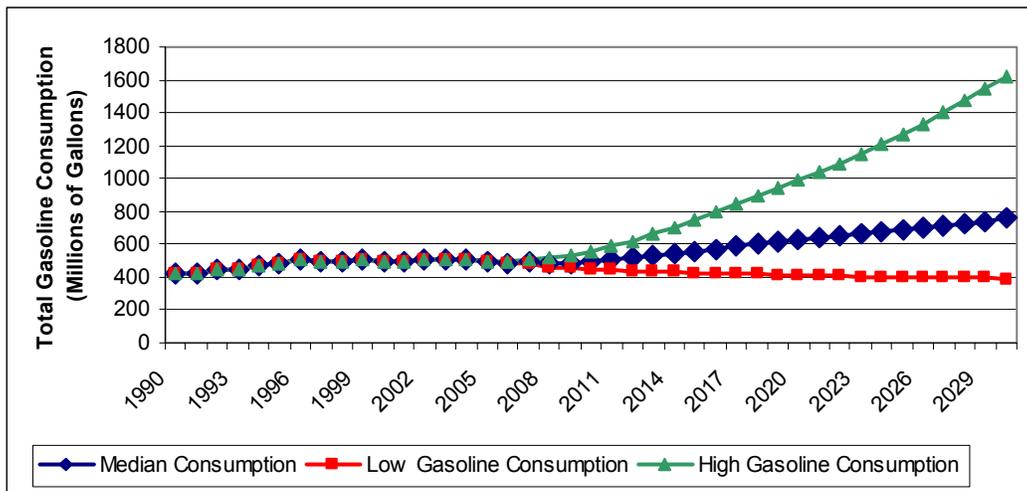


Figure 4.2 High and Low Projections of Gasoline Consumption

A large potential exists for differences in the levels of gasoline consumption if all the variables work toward either increased or decreased gasoline consumption (Figure 4.2). If Montana follows the reference levels of consumption, then the total amount of gasoline that will be consumed should increase from 500 million gallons in 2005 to 750 million gallons by 2030. If all of Montana’s factors push toward increased consumption, then by 2030 Montana’s consumption could more than triple from its 2005 quantity and

⁸ In all predictions the estimated quantity of gasoline was adjusted. This was performed so that the quantity of gasoline that was estimated in 2005 was equal to the actual quantity of gasoline consumed.

reach 1.6 billion gallons. If however, all factors move toward decreasing gasoline consumption, then the total quantity of gasoline consumed could decline to 400 million gallons. This provides for a variation of gasoline consumption of 1.1 billion gallons by 2030. It should be noted, however, that it is unlikely that every factor will push toward either more or less gasoline consumption. While these projections provide a basis for potential levels of consumption, they are unlikely to provide for actual levels of future gasoline consumption.

Gasoline Consumption Based on Price Changes

In the beginning of this thesis, it was mentioned that the Montana government is concerned that rising gasoline prices could lower tax revenues. Due to these concerns, a set of predictions were developed that attempt to examine how gasoline consumption would change due to changes in gasoline prices. For these projections, it is assumed that real incomes and the population of Montana both increase at the rates of 1.5% and 1% annually. Based on these levels of income and population growth, it is possible to project the expected levels of gasoline consumption based on potential gasoline prices. Three different levels of gasoline prices were developed to use in these predictions. Based on the different price levels, three separate projections were developed (Figure 4.3).

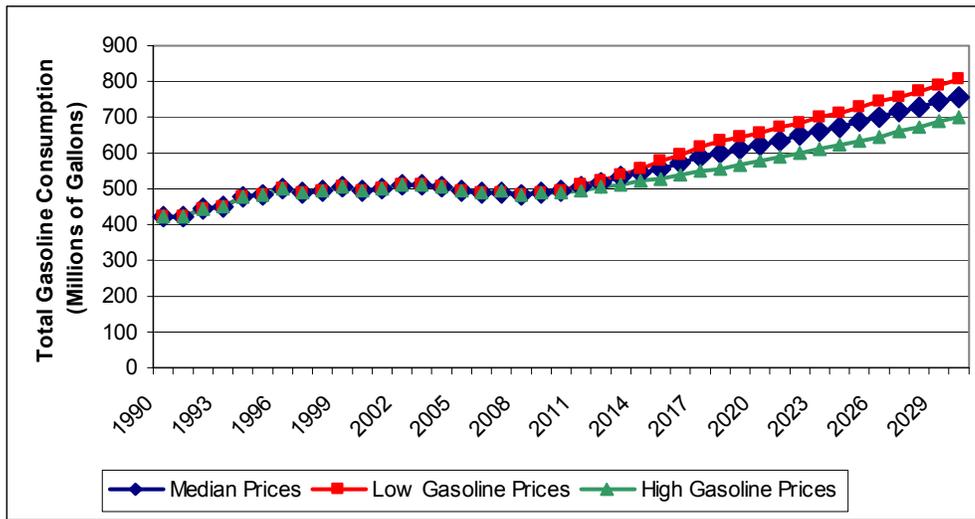


Figure 4.3 Projected Consumption Based on Price Changes

Several important implications become evident when examining the projections above. First, income appears to influence gasoline consumption more than the price of gasoline. This is represented in the vast differences between the models that examine only a change in the price of gasoline relative to the models that assume both increasing incomes and population, as well as changes in gas prices. Secondly, the only time that gasoline consumption declined was when the real price of gasoline increased \$1, or 30%, from 2007 to 2008. This indicates that it would take gasoline prices increasing by a third for gasoline consumption to actually decline. Also, with low gasoline prices, the quantity of gasoline that will be consumed in Montana will continue to increase from 500 million gallons in 2005 to 800 million gallons in 2030. Even with the projections based on the high gasoline prices, the total quantity of gasoline that will be consumed will increase from 500 million gallons in 2005 to 700 million gallons by 2030. This indicates that even with high gasoline prices the total quantity of gasoline that will be consumed in Montana will also continue to increase.

Gasoline Consumption Based on Large Price Elasticities

The long-run elasticities developed in this model differ from other elasticity estimates with regard to gasoline. While this lower elasticity estimate could be an accurate representation of Montana, it could still prove insightful to examine what effects a larger own price elasticity could have on gasoline consumption. Because of this, another set of projections have been performed that examines gasoline consumption based on doubling the elasticity estimate from the VMT equation with regards to the price of gasoline from -0.077 to -0.155.

Using this enlarged elasticity in the VMT equation, another set of projections examine fuel consumption changes with regards to changes in the price of gasoline. These projections can be seen in Figure 4.4.

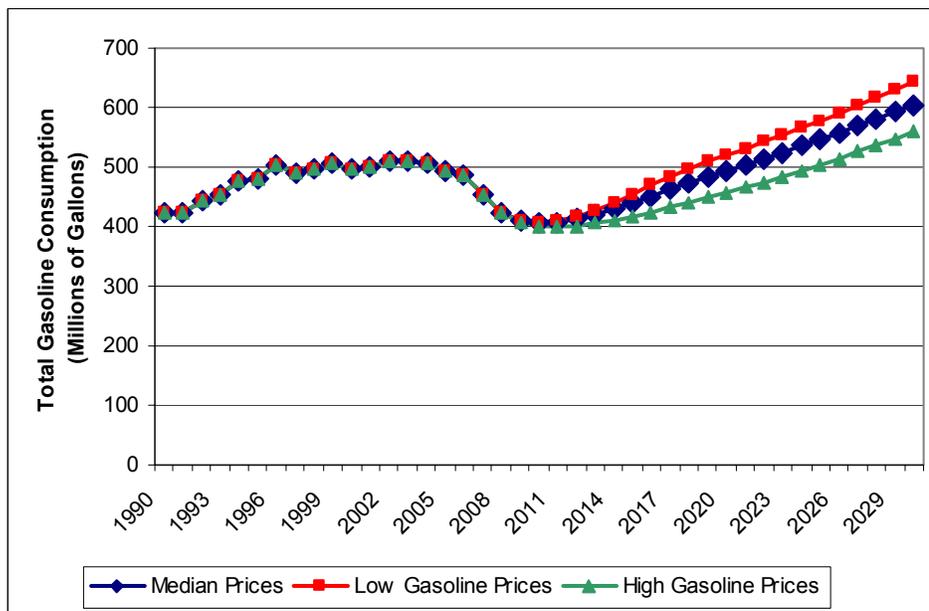


Figure 4.4 Gasoline Consumption Projections Based on Fuel Elasticity of -0.155

Based on these projections, high prices would lead to a decline in gasoline consumption from 2007 - 2012. After this point, consumption would begin to increase again each year on average by 9 million gallons. This differs from the previous projections, which had gasoline consumption increasing on average 10.9 million gallons each year. If gasoline prices follow the low price projections, estimates then show that per capita consumption will increase to 640 million gallons in 2030. This level of consumption is similar to the high price projections based on the original model. These results indicate that a doubling of the fuel elasticity in the VMT equation can significantly influence how much gasoline individuals will consume. However, even with the elasticity increasing to -0.7, gasoline consumption continued to increase each year after 2012.

Projected Consumption

The quantity of gasoline that Montana will consume is going to depend on how the contributing factors change over time. If all contributing factors move in a way to support increased gasoline consumption, then the per capita quantity of gasoline consumed could increase significantly. Inversely, if the factors move in directions that suppress the consumption of gasoline, then the total quantity of gasoline consumed by Montana by 2030 would be on par with consumption before 1990. However, neither of these projections is particularly likely due to their significant differences compared to historical levels of gasoline consumption. The high projection indicates that the total quantity of gasoline consumed in Montana would need to increase each year by 32 million gallons, however during the time period of 1990-2005 total gasoline consumption increased

annually by only 5 million gallons. The low projection also provides a significantly different level of consumption by requiring consumption to decline each year by 6.7 million gallons. Even the reference projection deviates from the previous historical increases by 5 million gallons. When compared to the historical average increases in gasoline consumption, the most similar projection assumes the high level of gasoline prices with all the other factors at their reference values, which provides the value of 9 million gallons.

While the extreme high and low values may not provide the most likely levels of consumption they provide a range of potential consumption levels. The predictions that assumed the reference levels of income and population growth are most likely to occur. The third set of projections, which assumes the larger own price elasticity, is the only set of projections that showed significant reductions in consumption when the other exogenous variables were at their reference levels. However, these projections assume that the elasticity estimates are incorrect, which would call for questioning all the results. Due to this the third model would not provide a very strong confidence in its predictive accuracy.

Even with high gasoline prices our model predicts above average growth in gasoline consumption. This could be consistent with the assumption that the Energy Information Administration's prices are too low. It could also be an indication that the estimated price elasticity is low. Using the original set of elasticity estimates a set of predictions can be developed. With high gasoline prices, gasoline consumption is expected to increase about 10 million gallons each year. At these rates, by 2030, gasoline

consumption will increase to about 600 million gallons each year. These projections indicate that, as long as real incomes increase at their historical rate, real gasoline prices are going to have to increase considerably faster for consumption to actually decline.

CHAPTER 5

CONCLUSION

Large increases in gasoline prices could significantly reduce the quantity of gasoline consumed, as previous research has estimated. Small and Van Dender (2007) developed an estimate for the entire United States, while other papers have attempted to estimate the effect for areas such as Europe (Johansson and Schipper, 1997). However, until now, very little work has been done to develop an estimate of these effects at a state level.

Using the national model would not be a problem if the smaller area in question had very similar characteristics to the entire United States. However, when these models are applied to states with characteristics that do not resemble the entire country, the results could prove inaccurate. If an area does differ from the national average, then a new set of elasticities will need to be developed for that specific region. Upon examination, Montana does differ from the nation in several ways, and because of these differences, Montana responds differently to changes in key variables.

Since the beginning of the time series, Montana has had more vehicles per capita than the rest of the country. At the same time, less than half of Montana's population has lived in metropolitan areas. The effect these two factors would have on per capita consumption is unclear. The increased number of vehicles could be due to the lack of suitable substitutes in the state, an argument strengthened by Montana's dispersed population. Thanks to the dispersed population, travel distances increase considerably. If

this is the case Montana might be more inelastic with regard to changes in gasoline consumption and changing prices. Alternatively, since gasoline purchases constitute a larger portion of individuals' expenditures, a change in prices could have a large effect on incomes. This potential impact of changing gasoline prices could make individuals more sensitive to price changes. These conflicting factors make it difficult to determine how Montana would respond to changes in gasoline prices. It is because of these uncertainties that Montana-specific elasticity estimates are required.

This thesis attempts to estimate how Montana gasoline consumption will respond to changes in several factors. Data were collected for the time period of 1960-2005. Using this data, a model was developed that estimated gasoline consumption by simultaneously estimating vehicle miles traveled and fuel efficiency. Due to the simultaneous nature of the model, the regression estimation method of three-stage least squares was used. This method not only performs the necessary simultaneous estimation but also corrects for correlation in the error terms that may exist in the data. To develop elasticity estimates, the model is estimated in double log form.

Elasticity Comparisons

Using the model described above, elasticity estimates were developed for Montana. Based on the first equation, the state has a vehicle miles traveled price elasticity of -0.35 in the long-run. In the second equation, fuel efficiency responds to a change in the price of gasoline with an elasticity of -0.1476 in the long-run. Given these elasticity estimates, gasoline's own-price elasticity has been estimated at -0.08 in the short-run and

-0.2 in the long-run.

Other models have attempted to estimate models similar to the ones in this thesis. When Johansson and Schipper (1997) estimated their model for vehicle miles traveled (mean annual driving distance) their price elasticity estimates ranged from -0.061 to -0.47. At the same time, their fuel-intensity estimates ranged from -0.011 to -0.45. Small and Van Dender (2007) performed similar estimates, with their fuel-intensity elasticity being -0.046. The vehicle miles traveled elasticity estimate developed in this thesis falls within the range of values developed by Johansson and Schipper (1997).

The results for gasoline's own-price elasticity are smaller than those provided by previous work. Graham and Glaister (2002) estimated that short-run price elasticities generally fall between -0.2 and -0.3. These values increase in the long-run to -0.6 and -0.8. Based on these elasticity values, it appears Montana's consumption is significantly less responsive to changes in the price of gasoline. This statement holds true for both the short- and long-run values. More recent models have been estimated using newer data. When the results of these more recent models are compared to those developed in this thesis, the estimated elasticity results are a lot similar.

Using the model that they developed to estimate the "rebound effect," Small and Van Dender (2007) were also able to provide some estimates of the own-price elasticity of fuel consumption. They estimated that the short-run elasticity at the sample average was -0.0839. In the long-run this elasticity increased to -0.4268. These results are closer to the ones developed in this thesis with the short-run estimates here appearing to be almost identical to Small and Van Dender (2007). Parry and Small (2005) compared more recent

elasticity estimates and developed an own-price elasticity estimate of -0.55. These recent models provide estimates closer to the values developed in this thesis. However, the long-run values developed for Montana are still significantly below the estimates for the nation as a whole. This lower elasticity value indicates that Montana will be less responsive to long-run changes in the price of gasoline.

A set of elasticities that measured how fuel consumption changed when per capita incomes changed was also developed in this thesis. Montana is estimated to have a short-run income elasticity of 0.66 and a long-run estimate of 1.95. The estimates reported by Graham and Glaister provide a short-run elasticity of income between -0.18 and 0.48. Their elasticity estimates increase in the long-run from -0.18 to 1.38. Johansson and Shipper provide a long-run income elasticity estimate of 1.2. Both the short- and long-run income elasticities for Montana are larger than those estimated for other geographic areas. These larger values indicate that people in Montana respond to increases in income by driving more, or using more fuel-intensive vehicles than the nation as a whole.

After comparing the elasticities developed for Montana and those that have already been developed for other areas, several conclusions can be made. The values developed in this model do differ from the estimates from other models. However, this thesis's results are similar enough that it provides some confidence in their values. Based on the developed results, Montana is less responsive to changes in the price of gasoline and more sensitive to changes in incomes. This reduced responsiveness to changes in price could be explained by the lack of substitutes that exist within Montana, while the sensitivity of consumption with respect to income could be caused by Montana's lower per capita

income relative to the rest of the country. Whatever the explanation, these results provide some additional insights into Montana's demand for gasoline that are not provided by national models.

Caveats

While the results developed in this model are similar to the results developed in other models, there are several items that need to be considered. The coefficients in the VMT equation were quite robust with regard to changes in the model. However, the fuel efficiency equation is sensitive to changes in its specification. This sensitivity of the fuel efficiency equation is compounded by the lack of a statistically significant coefficient for the price of gasoline. Both of these difficulties have occurred with other similar models (Small and Van Dender (2007)).

All of the previous work that has attempted to model gasoline demand has had difficulty adjusting for fuel efficiency standards set by governments. Even with all this work, an accepted method for accounting for this effect has yet to be developed. This lack of a standard method is due to each model being highly sensitive to the specification of this variable. The cause of this sensitivity is believed to be caused by a collinearity problem between the price of gasoline and fuel efficiency standards. This collinearity problem can be minimized by having as large a sample size as possible. However, this method cannot be applied in this thesis due to the lack of any additional data. This small sample size, in combination with the above-mentioned collinearity problem, is likely the cause of the statistically insignificant price variable. This lack of a statistically significant

price coefficient is discouraging given the large role that prices play in the projections that were developed.

When developing the projections of future gasoline consumption, the price variable was the primary focus of the models. If the true value of the price coefficient is different from the estimated value, then the projections could provide some inaccurate results. It was because of this problem that another set of projections is developed that assumed that the price coefficient was closer to values developed in other models. However, even with this larger coefficient, the developed projections still predict that total gasoline consumption will increase almost every case. Based on these results, it is probable that gasoline consumption will increase in Montana unless the price of gasoline increases considerably in a very short time. This may be observed in 2008, when gasoline prices are projected to increase by 40% over the previous year's prices. This large increase in the price of gasoline is projected to cause consumption to decline by 5%.

A CafeMT fuel efficiency elasticity coefficient of 0.07 indicates that a 10% increase in CAFE standards is going to increase Montana's fleet fuel efficiency by almost 1%. The size of this elasticity is smaller than originally expected. However, when the dynamics of the CAFE standards are considered it is not impossible. Beginning in the late eighties, the price of gasoline reached record lows when adjusted for inflation. These low gasoline prices discouraged fuel efficiency. At the same time, CAFE standards were increased during this time. Individuals responded to the record low prices and the high mandated fuel efficiency requirements by shifting their vehicle use from passenger cars to

light trucks and SUV's. This substitution made it possible for individuals to partially adjust to their desired fuel efficiency in spite of the CAFE standards.

There is some concern with this adjustment process with regards to the fuel consumption projections. In 2007 the CAFE standards were updated so that by 2020 the vehicle fleet must reach 35 mpg. These updated standards also changed the distinction between passenger cars and light trucks. The new standards require that the entire new vehicle fleet must meet the 35 mpg requirements. This will eliminate the fuel efficiency advantage that light trucks and SUVs had previously. When these updated CAFE standards take effect, the model used in the projections are likely to underestimate the effect that CAFE has on fuel efficiency.

Projections for the Future

The purpose of this thesis was to estimate the demand for gasoline for the state of Montana, and project future gasoline consumption. Even before the coefficients were estimated, problems presented themselves. The small sample size, in conjunction with specification difficulties caused by fuel efficiency standards, made the estimation process hard. However, given these inherent complications, the model and results developed have been robust in some respects. The VMT coefficients were quite consistent as the model specification changed. The only area of difficulty was with the fuel efficiency equation. While it is important to keep these complications in mind, some relevant information has still been revealed.

Montana appears to differ from the national average in several important characteristics. Based on the model's elasticity results, Montana will be less responsive to long-run changes in the price of gasoline. It is potentially because of this inelastic own-price response that Montana will continue to increase its total gasoline consumption, even if gasoline prices remain high over the next 20 years. This continued increase in consumption is also influenced by Montana's larger income elasticity.

For a majority of work that has been done in estimating the demand for gasoline, the income elasticity has generally been found to be near unity. For Montana however, the long-run income elasticity with respect to gasoline consumption appears to be significantly larger, with a value around 2. This indicates that, at a national level, a 10% increase in incomes will lead to a 10% increase in gasoline consumption. However, for Montana, a similar 10% increase in incomes will cause gasoline consumption to increase by 20%. This large income elasticity drives the increase in gasoline consumption that will likely occur in Montana until 2030.

Using the elasticities developed in this model it was possible to project gasoline consumption in the future. Based on the estimated results, gasoline consumption will increase in Montana even when gasoline prices remain high. Even when the own price elasticity was doubled gasoline consumption only temporarily declines with high sustained gasoline prices. Based on the results of the model, as long as incomes continue to increase at their historical levels, gasoline prices will have to increase considerably for consumption to decline.

Montana does differ from the rest of the nation when it comes to gasoline consumption. Not only is Montana less responsive to changes in prices, but it is also more sensitive to changes in incomes. These factors will lead to Montana increasing its gasoline consumption in the future, unless prices continue to rise at very high rates. Individuals concerned with future gasoline consumption in Montana should be more concerned with how real incomes change over time, due to their larger elasticities. Because, unless real incomes begin to decline, the real price of gasoline will have to increase considerably before consumption is going to decline.

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APPENDICES

APPENDIX A

DATA SOURCES

Data Sources

1. Corporate Average Fuel Economy Standards (Miles Per Gallon)
1960-2005: National Highway Traffic Safety Administration (NHTSA), New passenger car and light truck fuel efficiency requirements.
<http://www.nhtsa.dot.gov/CARS/rules/CAFE/CAFEData.htm>
2. Consumer Price Index – All West Urban Consumers
1960-2005: Bureau of Labor Statistics (BLS), CPI (1982-84=100)
<http://www.bls.gov/cpi>
3. Personal Income (\$/year, 2005 dollars)
1960-2005: Bureau of Economic Analysis (BEA) Table SA1-3
<http://www.bea.gov>
4. Gasoline Consumption (thousands of gallons per year)
1960-2005: Federal Highway Administration, *Highway Statistics*, annual editions, Table G-2 Number of gallons of gasoline taxed
5. Montana Population
1960-2005: Montana department of labor and industry, annual population estimates
<http://www.ourfactyourfuture.org>
6. Montana County Population
1960-1969: County Population Estimates, Montana Department of Community Affairs
1970-2005: Historical Population Estimates, U.S. Census Bureau
<http://www.census.gov>
7. Car and Truck Vehicle Registrations
1960-1995: Federal Highway Administration (FHWA) Highway Statistics Summary to 1995 Table MV-201
1996-2005: Federal Highway Administration, Annual Highway Statistics Table MV1
8. National Car and Truck Average Fuel Efficiency
1960-1995: Federal Highway Administration (FHWA), Highway Statistics Summary to 1995, Table VM-201A
1996-2005: Federal Highway Administration, Annual Highway Statistics Table
9. National Vehicle Miles Traveled
1960-2005: Federal Highway Administration (FHWA), Annual Highway Statistics Table VM-2

10. Montana Vehicle Miles Traveled
1966-2005: Federal Highway Administration (FHWA), Annual Highway Statistics
Table VM-2

11. National Average City Gasoline Prices
1960-1975: Energy Information Administration, Retail Motor Gasoline and On-
Highway Diesel Fuel Prices, Price of Leaded Regular Gasoline
1976-2005: Energy Information Administration, Retail Motor Gasoline and On-
Highway Diesel Fuel Prices, Price of Unleaded Regular Gasoline
<http://www.eia.doe.gov/emeu/aer/txt/ptb0524.html>

12. Projected Gasoline Prices
Energy Information Administration, Annual Energy Outlook 2008
<http://www.eia.doe.gov/>