The Effect of Prices on Oil Demand in the Transportation and Residential Sectors

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I. Introduction

The United States alone has less than 5% of the world's population, but uses 25% of the world's oil supply. This huge amount of oil is necessary to produce enough energy to support a highly industrialized society where 87% of people drive to work (*Annual Energy Review*, 2001). Gasoline demands account for about 17% of the energy consumption in the United States, and approximately 7.7 million Americans use petroleum as heating oil in their homes (*Residential Heating Oil Prices: What Consumers Should Know*, 2001). Unfortunately, the world supply of petroleum is predicted to last for only another 80 years at current rates of consumption. Though other fossil fuels such as natural gas may be available as a substitutable energy source in some cases, these supplies are also expected to be gone in 65 years if rates of consumption remain the same (Pearce, 1998). As a result, the United States is beginning to see more government action to regulate energy prices in an attempt to encourage efficient consumption of the remaining resources.

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This is definitely the case when considering the oil market in the United States. Past studies suggest that higher oil prices not only decrease the demand for oil in the United States, but also encourage a switch in consumption towards alternative energy sources such as natural gas for heating homes, or electric powered cars for transportation (Sweeney, 1984). These studies have attempted to establish the relationship between fluctuations in energy prices and the corresponding responses in demand. The drastic changes in the price of oil that began in the 1970's, and the corresponding demand changes for oil in both the transportation and residential sectors since that time can be explained by analyzing the supply and demand-side implications of these changes (Gately, 1984).

The goal of this study is to explain the consumer response to energy price fluctuations in the United States from 1949 to the present time. I will hypothesize that in the United States, the quantity of oil demanded in all areas of the transportation sector is inelastic in the short run, and therefore changes gradually when oil prices fluctuate. In the residential sector, I hypothesize that the quantity of oil demanded will be more elastic in the short run, since natural gas is available as a substitute source when petroleum prices rise. The results of this study can help to determine what types of government policies will be effective in ensuring a positive consumer response to price changes. Because this is currently such an important issue to address, an abundance of research exists with theories about energy supply and demand. Section II will establish the basic demand theory for oil and show how prior research supports this theory. Section III will develop an empirical model using data to analyze the relationship between oil prices and final demand in the transportation and residential sectors of the U.S. economy. The results of this statistical analysis will then be addressed in Section IV, and energy policy implications will be proposed based on this analysis in Section V.

II. Theoretical Background

Many studies attempt to describe the demand side effects of increases in oil prices, some of which include looking at the supply side as well. Several studies developed during the late 1980's to try and explain the huge oil shocks and corresponding productivity slowdown that occurred during the 1970's. A basic understanding of oil demand theory is necessary in order to interpret the implications of this past research.

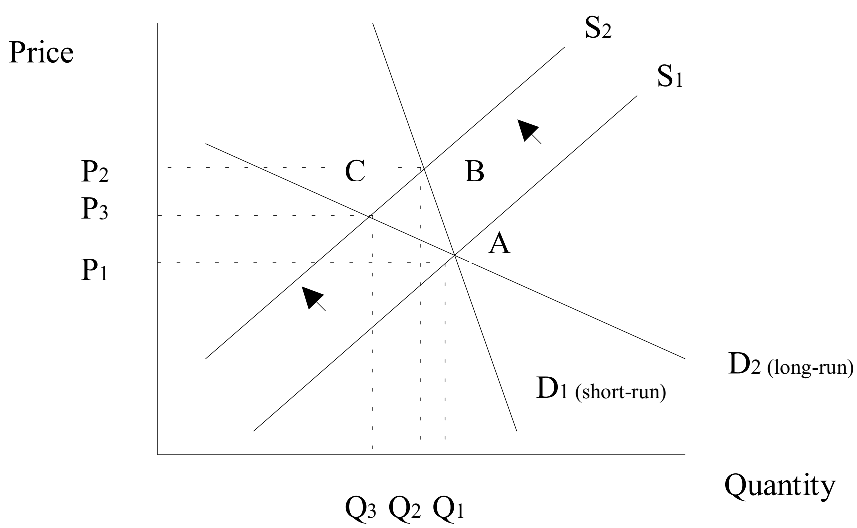
By focusing strictly on the demand for oil, there is a distinct difference between final demand responses to price changes in the short run versus the long run. In this microeconomic demand theory, GDP per capita is assumed to be directly correlated with the demand for oil, so that more oil would be demanded at higher levels of income (Askin and Kraft, 1976). Figure 1 illustrates the changes in oil demand that occur over time. When the supply of oil decreases from S_1 to S_2, prices rise due to the decreased supply, and the quantity of oil demanded moves along the demand curve D_1 from point A to point B. The demand for oil is inelastic because either people have no other alternative to this oil, or the alternative is more costly. However, as prices rise over time, technological improvements are developed, alternative energy sources become less expensive, and people have time to adopt energy saving technologies. In the long-run, the demand for oil becomes more elastic (D_2) because at the higher price levels, people have a choice to either consume the oil or switch to an alternative source that may be less expensive. Therefore, the oil price and quantity demanded are established in the long-run at point C in Figure 1.

This basic demand theory is supported by many studies. One of the best ways to evaluate the current energy situation is to look at these previous studies of final demand responses so that better policies to encourage future economic growth can be developed.

A study by Mancur Olson (1988) addresses the relationship between the oil shocks and the corresponding productivity slowdown that occurred during the 1970's. This study takes a microeconomic approach by explaining the effects of these oil shocks in terms of the impact of substituting away from imported oil. It effectively shows that when considering an energy crisis as a whole, it is necessary to consider the losses on both the supply and demand sides. When the costs of substituting away from more expensive oil are added to the higher costs on the supply side, it would seem possible that almost all of the losses in productivity were due to higher prices of imported oil. However, by running regressions over time, the research shows that "the direct productivity losses to both the supply and demand sides of the oil market only account for a fractional percentage of the total loss in GDP" (Olson, 1988). Thus, this study suggests the importance of including GDP as a factor in determining demand, and emphasizes a microeconomic approach to energy consumption.

FIGURE 1

Changes in Oil Demand Over Time



Hudson and Jorgenson (1978) propose that federal government price controls have prevented the full impact of oil price rises from being felt by energy consumers. Their econometric analysis shows that,

> Producers respond to higher energy prices and energy conservation regulations by altering input patterns so as to minimize unit costs in the face of the new price structure. These adjustments in input patterns involve reduced intensity of energy use. Final demand patterns alter in response to the policy measures, partly as a result of changing price structure and partly as a result of government regulations on energy pattern use (Hudson and Jorgenson, 1978).

Therefore, government policies that restrict prices from rising can prevent drastic changes in consumer demand from occurring.

James Sweeney (1984) has also analyzed the response of energy demand to higher prices. He says that the demand response usually involves energy conservation and interfuel substitution because the demand for energy is actually a derived demand for more basic end products such as transportation. His findings suggest that the demand adjustments to higher prices can be expected to be slow, and that the development of new technologies to combat higher energy prices can occur during this adjustment period as well. These findings follow the expectations of the oil demand theory previously stated, and emphasize the importance of interfuel substitution in determining the elasticity of demand. However, according to his research, at least 80 percent of the energy demand reductions in the long-run can be attributed to price and economic activity changes. Sweeney also emphasizes the difficulty involved in determining the long-run demand elasticity for natural gas, and therefore the effect of natural gas prices on the demand for other energy sources. Since the market for natural gas has remained somewhat constrained over the past few decades, the information for natural gas as a substitute energy source is limited (Sweeney, 1984).

Past research suggests that econometric models using regressions will be useful in determining the elasticity of demand for oil when prices fluctuate. It also seems possible that the elasticity of demand will differ between various sectors of the United States oil market. My hypothesis is that while the demand for oil in the transportation sector will be inelastic in the short-run, the demand for oil in the residential sector will be more elastic since alternative fuel sources are available.

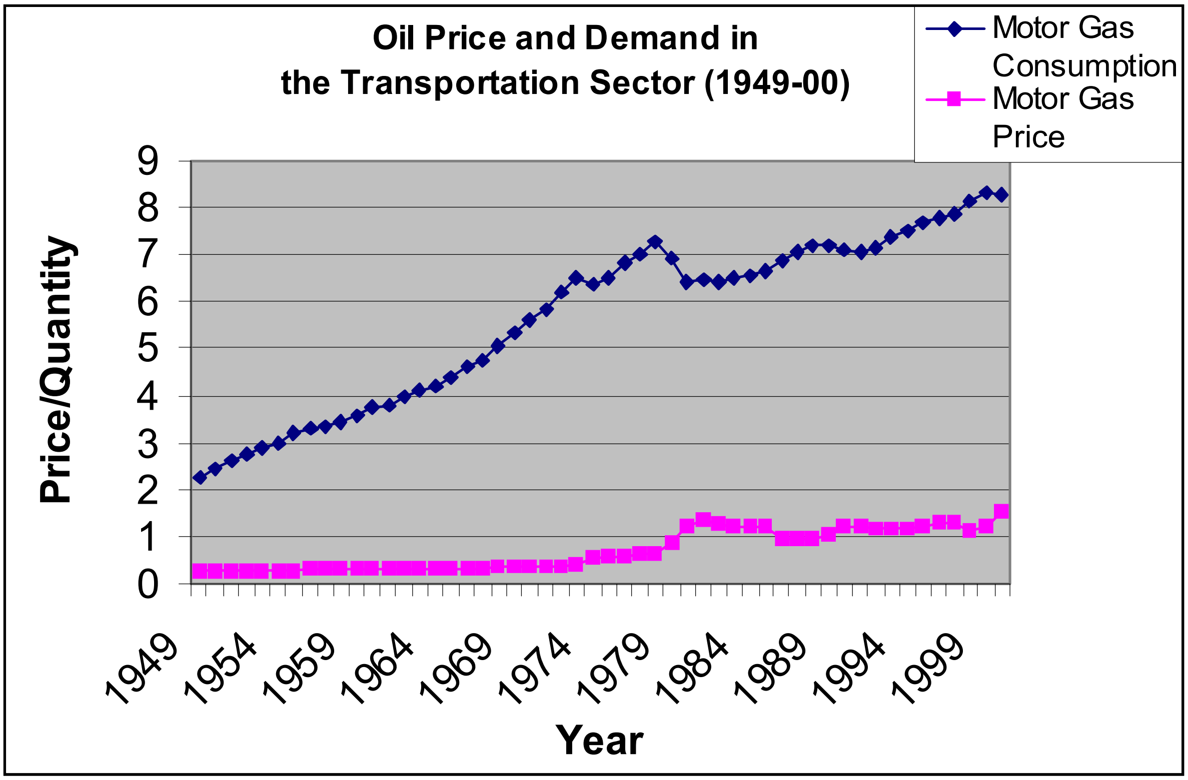
III. Research Design

In order to test my hypothesis, I use data from several different sources. The *Annual Energy Review* (2000) provides tables of energy consumption in the transportation sector of the oil market from 1949-2000, and in the residential sector of the oil market from 1983-2000. The *Energy Information Administration* (2000) lists charts of motor gasoline prices, diesel fuel prices, distillate fuel (or heating oil) prices, and natural gas prices for each year. The data for U.S. GDP per capita is calculated from the GDP and population statistics available on the *World Development Indicators CD-ROM* (2001).

According to the data for the transportation sector, the quantity of motor gasoline consumed increases steadily over time, with the exception of a drop in consumption during the late 1970's and early 1980's. The decreased demand for motor gasoline corresponds to an increase in prices during that same period. This change can most likely be attributed to the oil shocks that occurred at that time, causing prices to rise and consumption to fall (Lovins, 1998). After the oil shocks, the consumption of motor gasoline continued to rise, and the price of motor gasoline remained fairly consistent, but at a higher level than before the oil shocks. By looking at Figure 2 of the last 50 years, it appears that demand in the transportation sector has remained rather inelastic. Even with higher prices for gasoline, it seems that the consumption still grew over time (Cook, 2001). This corresponds with my hypothesis that the demand for oil in the transportation sector will be more inelastic in the short-run. Figure 2 depicts the trend as follows:

In the residential sector, prices for distillate fuel, used to heat homes, have not fluctuated greatly during the past two decades. However, the trend in consumption of distillate fuel appears to vary more frequently over the 17 year time period depicted in Figure 3. According to the chart, from 1983 until about 1989, the consumption of distillate fuel oil fell as prices were rising. Then, when prices fell in 1989, the demand for distillate fuel increased again. This relationship between distillate fuel price and demand continues throughout the chart. The trend suggests that the consumption of distillate fuel oil in the residential sector is more elastic than the consumption of motor gasoline in the transportation sector, which coincides with my hypothesis.

FIGURE 2



In order to determine the elasticity of demand for oil in both the transportation and residential sectors, I ran two separate double-logged regressions, one for each sector. All of the variables for the transportation sector use time series data for the United States from 1949-2000. However, all of the variables for the residential sector use only time series data from 1983-2000, since 1983 was the earliest year in which all of the information was available. In each equation, the consumption of motor gasoline and distillate fuel oil, respectively, in millions of barrels per day is the dependent variable representing demand. Three specific independent variables are also included in order to evaluate their effects on the elasticity of demand in each sector.

The retail sales prices of motor gasoline and distillate fuel oil are measured in dollars per gallon. As the price of gasoline for vehicles or distillate fuel to heat homes rises, one would expect the demand for that form of oil to decrease. Thus, the independent variables for the price of motor gasoline and the price of distillate fuel are expected to have negative coefficients.

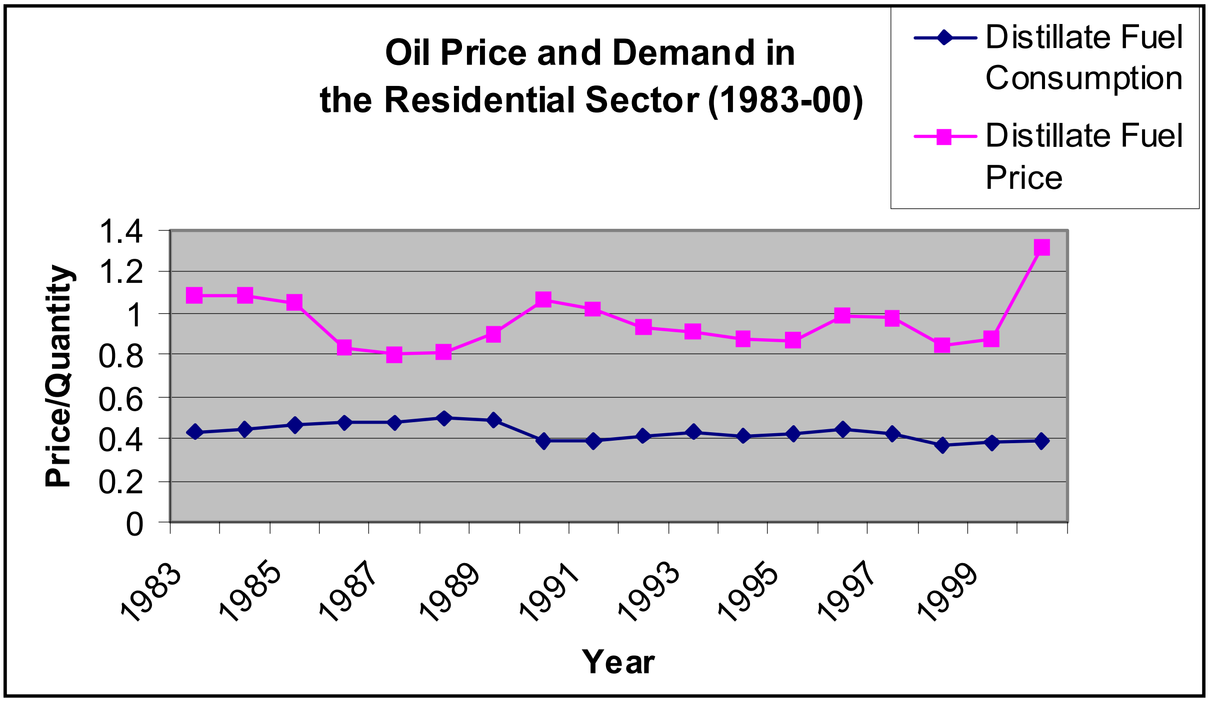
The independent variable for GDP per capita is included in both equations to account for the influence of income in the United States on the demand for oil. GDP per capita will most likely have a positive sign, since increased amounts of oil would be demanded at higher levels of income.

A third independent variable representing a substitute energy source is included in both equations as well. In the transportation sector, diesel fuel could represent an alternative to driving vehicles powered by unleaded gasoline. If the price of diesel fuel decreases, consumers might be more likely to switch and drive vehicles powered by this alternative energy source. In the residential sector, a decrease in the price of natural gas could influence consumers to decrease their demand for distillate fuel. The variable representing the substitute good in both equations should have a positive sign because an increase in the price of an alternative energy source would mean an increased demand for oil in the transportation or residential sectors.

Both the GDP per capita variable and the variables representing the price of a substitute good are responsible for the shifts in demand previously depicted in Figure 1. These variables are included in the equations in order to control for these shifts in the energy market so that the estimates of elasticity will be more accurate.

After recounting the importance of all these variables, the two equations can then be established as follows:

FIGURE 3



ln(Motor Gasoline Demand) = á +
â$_1$ ln(Motor asoline Price) + â$_2$ ln(GDP per capita)
+ â$_3$ ln(Diesel Price) **(1)**

ln(Distillate Fuel Demand) = á +
â$_1$ln(Distillate Fuel Price) + â$_2$ ln(GDP per capita)
+ â$_3$ ln(Natural Gas Price) **(2)**

IV. Results

Having run a double-logged regression for each of the two sectors, the results show a higher R-square value in the transportation sector (.968) than in the residential sector (.521). The signs of the coefficients are also different than the expected signs in some cases, meaning that the measures of elasticity may not actually be accurate. The elasticity of demand for motor gas prices and distillate fuel prices does however show the demand for motor gasoline to be slightly more inelastic than the demand for heating oil in the short-run. The results of the first regressions are depicted in the Table 1:

In the transportation sector regression, the elasticity coefficients for motor gas price and GDP per capita have the expected signs. However, the elasticity coefficient for the price of diesel fuel is negative instead of positive. This would mean that a decrease in the price of diesel fuel would coincide with an increase in consumption of motor gasoline, which is the opposite of what is expected. Also, only the GDP per capita appears to be significant at the .01 level. A test for correlation shows that the price of motor gasoline and the diesel fuel prices are highly correlated, which would account for their insignificance in the regression. Since the diesel fuel prices are only available for a five year period, this limited time frame probably caused the results of the regression to be skewed as well.

In the residential sector, only the elasticity coefficient for distillate fuel oil has the correct sign. GDP per capita has a negative sign, indicating that a decrease in income would result in a higher demand for oil. The price of natural gas also has a negative sign, meaning that a decrease in natural gas prices would result in an increase in distillate fuel consumption. Both of these signs differ from those expected. A test for correlation shows that the price of distillate fuel oil is highly correlated with the price of natural gas, which may help to explain their differing signs. By looking at Figure 4 that follows, it is evident that both distillate fuel prices and natural gas prices have not fluctuated greatly over time, nor does it appear that natural gas has been the substitute good when distillate fuel prices were high.

Thus, after considering the problems with correlation and insignificance among the variables in the first set of regressions, it is necessary to remove the substitute good variables for diesel fuel and natural

TABLE 1

Regressions #1 and #2 Results

	Expected Sign	R-square	Elasticity	t-stat	Sig Value
Motor Gasoline		.968			
Motor Gas Price	_		-.006397	-.019	.986
GDP per capita	+		.447*	7.300	.018
Diesel Price	+		-.07226	-.248	.828
Heating Oil		.521			
Distillate Fuel Price	_		-.197	-1.097	.291
GDP per capita	+		-.219	-1.991	.066
Natural Gas Price	+		-.09707	(-).271	.790

*NOTE: *=siginificant at the .01 level*

gas and run the double-logged regression for each sector again. This should produce a more accurate measurement of the elasticity of the demand for oil. The second regression for the transportation sector includes only the motor gasoline price and GDP per capita independent variables, and the residential sector regression includes only the distillate fuel oil price and the GDP per capita independent variables. Table 2 depicts the results of the second set of regressions. Despite a slightly lower R-square value in each regression, (.866) in the transportation sector and (.518) in the residential sector, the results of these regressions appear to represent the elasticity of the demand for oil much more clearly. It seems that by eliminating the substitute good variables, the problems with insignificance and correlation are solved.

In the transportation sector, the elasticity coefficients for the motor gasoline price and GDP per capita have the correct signs. Motor gasoline price is negative, meaning that consumption of gasoline will decrease at higher prices. GDP per capita is positive, since consumption of gasoline will increase at higher levels of income. A test for correlation proves that neither of the two variables are correlated, and thus both significantly contribute the explanation of motor gasoline consumption. The elasticity coefficient for motor gas price is -.314, which is more elastic than in the first regression, but still a relatively inelastic short-run representation of demand overall. This finding

FIGURE 4

Distillate Fuel Oil and Natural Gas Prices (1983-2000)

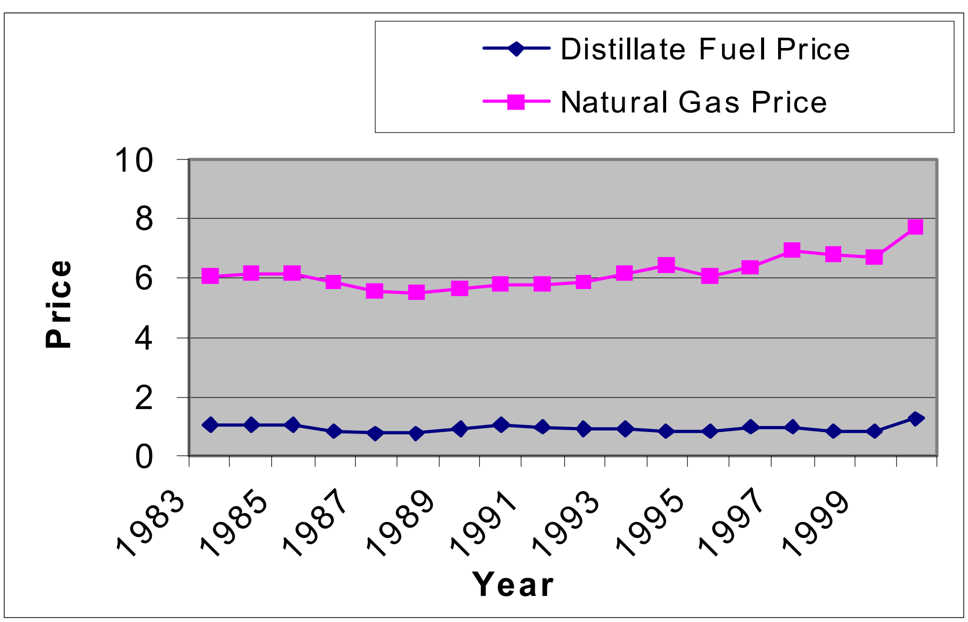


TABLE 2

Regressions #3 and #4 Results

	Expected Sign	R-square	Elasticity	t-stat	Sig Value
Motor Gasoline		.866			
Motor Gas Price	_		-.314*	-2.785	.008
GDP per capita	+		.560*	7.390	.000
Heating Oil		.518			
Distillate Fuel Price	_		-.230	-1.762	.098
GDP per capita	+		-.242*	-3.602	.003

*NOTE: *=significant at the .01 level*

agrees with the original hypothesis that demand is inelastic in the transportation sector.

The results in the residential sector, however, turn out differently than expected in the original hypothesis. Although the distillate fuel price have a negative sign, indicating that demand for oil would rise as prices fall, the GDP per capita variable also has a negative sign. This means that at higher levels of income, people demand less distillate fuel oil to heat their homes. A test for correlation proves that neither of the two variables are correlated, although only the GDP per capita variable is significant at the .01 level. The elasticity value for distillate fuel price suggests that the short-run demand for oil in the residential sector is also inelastic. In fact, these regressions show the demand for oil in the transportation sector to be slightly more elastic than the demand in the residential sector.

V. Conclusion and Policy Implications

Various factors could account for the discrepancies in my results. For example, in the second transportation sector regression, the results are more accurate without the diesel fuel variable. This could be because of the limited data available on diesel fuel prices, as previously suggested, or also because diesel fuel is not a direct alternative to unleaded gasoline. In order to actually switch to diesel fuel, major technological improvements may need to be made, or an individual might have to purchase a new vehicle altogether. These would have more of a long-run effect on the demand elasticity for oil in the transportation sector. Therefore, diesel fuel is not a possible substitute energy source in the short-run.

Since the results for the transportation sector were so significant, some assumptions can then be made about the relationship between prices and demand in this market. For example, if the price of motor gasoline increases by $1.00, then demand for motor gasoline should decrease by about .314 million barrels per day. If the government wanted to limit the amount of motor gasoline being consumed, this relationship between prices and demand would be important to consider.

When natural gas is removed as a substitute good in the second equation for the residential fuel sector, the significance of both distillate fuel prices and GDP per capita increases, but the overall R-square value decreases. This may indicate that natural gas does play a role in determining distillate fuel oil demand; however, perhaps the price of natural gas is not the correct variable to consider. Instead, it is more likely that the availability of natural gas influences demand. Since the availability of this fuel source varies throughout the United States as more pipelines are being constructed, there is no reasonable way to measure the availability variable. Thus, it must be suggested that the availability of natural gas could cause the demand for distillate fuel oil to be more elastic. The absence of a measure for availability of natural gas might also explain the negative coefficient sign for GDP per capita. Perhaps when natural gas is available, individuals at higher income levels will demand less distillate fuel oil because they are demanding more natural gas.

Because there are more problems with the significance of variables in the residential sector, the relationship between distillate fuel prices and demand is not as accurate. However, if the government wanted to try and influence individuals to switch to an alternative energy source such as natural gas, they would need to raise prices by $1.00 to reduce consumption by .230 million barrels of oil.

Overall, the fluctuations in demand in both the transportation and residential sectors are fairly inelastic in the short run, though the transportation sector may actually be slightly more elastic than the residential sector. Although this disproves my hypothesis that demand would be more elastic in the residential sector than in the transportation sector, I think that if a measure for the availability of natural gas could be included, the results might turn out differently.

The implications of this study are important to understand because as the world supply of petroleum is depleted, it will become increasingly necessary to switch to alternative energy sources (Pearce, 1998). Policy makers need to understand where to set prices so that people will only demand a certain amount of one resource before making the switch to a more affordable alternative (*A Primer on Gasoline Prices,* 2001). If demand is fairly inelastic, as this project proposes, then the government needs to make an investment in technological improvements for alternative energy sources so that these become less expensive and more realistic as substitute goods.

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