THE ECONOMIC COST OF FUEL PRICE SUBSIDIES IN GHANA

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ABSTRACT

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I adapt the Harberger formula for deadweight loss to develop approximations for the deadweight loss created by multiple fuel price subsidies. I also estimate the own-price, cross-price, and income elasticities of demand for gasoline and diesel in Africa. I use data on fuel prices and sales in combination with my formulas and elasticity estimates to calculate the deadweight loss of fuel price subsidies in Ghana from 2009 to 2014. I show that the average efficiency cost of the gasoline and diesel price subsidies in Ghana is 0.8% of fuel price subsidy transfers. This result stresses the futility of basing subsidy reforms on economic efficiency losses, which are relatively small due to very inelastic energy demand, and the need for such reforms to be motivated by the poor-targeting of subsidies to low-income households and the impact of subsidies on government debt-financing.

ACKNOWLEDGMENTS

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CHAPTER 1 - INTRODUCTION

1.1 Background and Rationale

In recent years, Ghana has recorded commendable developments. According to the Ministry of Finance (MOF), Ghana's real Gross Domestic Product (GDP) grew at a record 15% in 2011. In addition, the country discovered crude oil in commercial quantities in 2007, and began producing oil in 2010. The government of Ghana has been equally faced with challenges of inadequate revenue generation and over-spending. Sources of such challenges include the implementation of the new public sector salary policy, Single Spine Pay Policy, in 2010 and the subsidization of refined petroleum products. Expenditure on compensation of employees was 74.4% of tax revenue for the first three quarters of 2013 (MOF). With a budget deficit of 12.1% of GDP in 2012, and a total public debt of about 49% of GDP in August 2013 (MOF), Ghana is surely facing fiscal difficulties.

Explicit fuel subsidies to the Tema Oil Refinery (TOR) and oil distributors reached 2.2% of GDP in 2004 (Coady et al, 2006). According to the African Development Bank (2012), fuel consumption subsidies in Ghana amounted to US$ 276 million in 2011. The government spent US$ 85 million on fuel subsidies in the second quarter of 2014 (IMANI Ghana, 2015). The budgetary cost of fuel subsidies in Ghana has been increasing partly as a result of the depreciation of the Ghana Cedi (GHS) against the United States Dollar (US$). The GHS-US$ exchange rate increased from 0.16:1 in 1996 to 1.95:1 in 2013, with an average of 0.92:1 over the period. With an estimate of US$ 410 billion in total expenditure globally on fuel subsidies in 2010, subsidy reforms are necessary since subsidies deprive economies of scarce resources (African Development Bank, 2012).

To save government the cost of providing fuel price subsidies, and to allow for a more effective use of public funds, the government of Ghana took a bold step to implement the politically unfriendly decision of fuel price deregulation on July 1, 2015. This means the government will no longer determine fuel prices and provide subsidies for gasoline, diesel, kerosene, and liquefied petroleum gas (LPG). Bulk Distribution Companies (BDCs) and Oil Marketing Companies (OMCs) set their own prices based on an agreed pricing formula. Conversely, residual fuel oil and premix fuel, which are consumed by industrial plants and fishing boats, respectively, are still being subsidized, and their prices are set by the government.

Whether the government will be able to sustain the deregulation is an open question. Political promises during national elections and oil price hikes may lead to pressure from political opponents, interest groups, and civil societies to force the government to return to the subsidization of fuel prices in the near future. Thus, evaluating the cost of fuel price subsidies in Ghana is important, as the government reinforces its resolve to permanently abolish fuel subsidies to enable more prudent use of public funds to address critical expenditures in health, education, and infrastructure.

The goal of this research is to estimate the economic cost of fuel price subsidies in Ghana. First, I estimate the own-price, cross-price, and income elasticities for gasoline and diesel demand in Africa. Second, I extend the comprehensive Harberger formula to approximate the deadweight loss associated with fuel price subsidies in Ghana from 2009 to 2014. Naively ignoring the impact of cross-price effects on deadweight loss, the total cost of fuel price subsidies for gasoline and diesel is GHS 26.38 million (US$ 15.40 million) from 2009 to 2014, with a cost of GHS 4.40 million (US$ 2.57 million) per year. Accounting for cross-price effects, however, the total cost of fuel price subsidies for gasoline and diesel falls almost by half to GHS 13.61 million (US$ 8.27 million) from 2009 to 2014, with an annual cost of GHS 2.27 million (US$ 1.38 million). A gasoline subsidy, by inducing consumers to choose gasoline over diesel, partially mitigates the distortion caused by a diesel subsidy, and vice versa. Thus, the combined deadweight loss of the two subsidies together is significantly less when accounting for these cross-price substitution effects. On average, the cost of fuel price subsidies for gasoline and diesel in Ghana is less than 1% of subsidy transfers by the government. I also show that changes in the absolute magnitude of demand elasticities results in a proportional change in the size of calculated deadweight loss.

Chapter 1 continues with a review of fuel consumption and subsidies in Ghana. After presenting the theory of deadweight loss in Chapter 2, Chapter 3 follows with the estimation of fuel demand elasticities for the African region using a panel data model. Chapter 4 follows with the calculation of the economic cost of fuel price subsidies for gasoline, diesel, kerosene, and LPG in Ghana from 2009 to 2014. Chapter 5 concludes with a summary and agenda for future research.

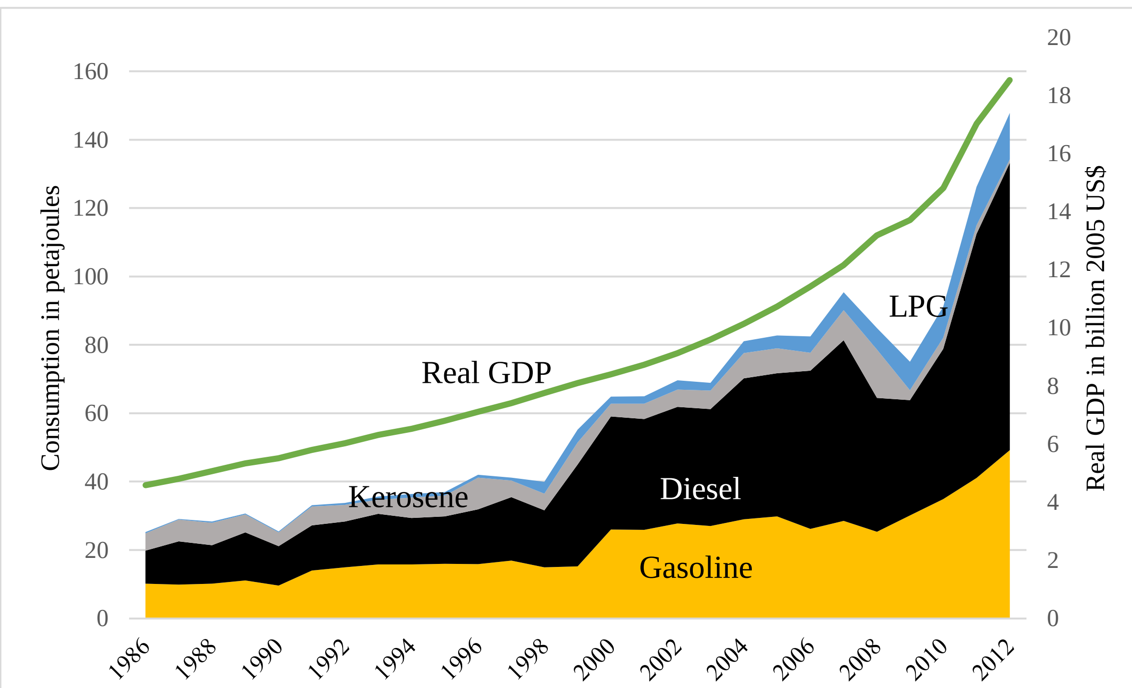
1.2 Fuel Consumption in Ghana

Refined petroleum product consumption in Ghana has been on the rise over the past three decades. According to data from the Energy Information Administration's (EIA) online database, total fuel consumption for gasoline, diesel, kerosene, and LPG was 12,000 barrels per day (bbl/d) in 1986.

With a yearly average consumption of 29,000 bbl/d and a growth rate of about 8%, total consumption for these fuels increased to 70,000 bbl/d in 2012. Natural gas consumption increased from 0.1 billion cubic meters (bcm) in 2010 to 0.4 bcm in 2012. Coal consumption in 2013 was 30,000 metric tons.

Real GDP has also been on the increase at an increasing rate year-on-year over the same period, with a record high growth rate of 15% in 2011. Based on data from The World Bank's online database, real GDP increased from US$ 4.58 billion to US$ 18.52 billion, with an average growth rate of 6% per year from 1986 to 2012. Figure 1.1 shows the trend in fuel consumption and real GDP over the period in Ghana.

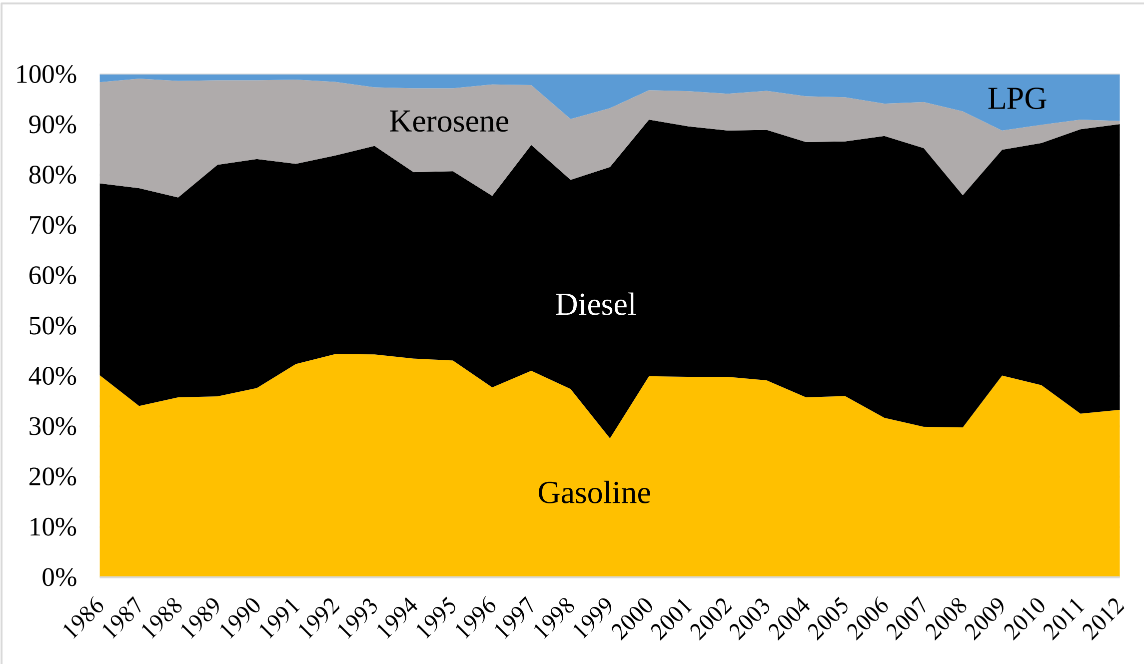
Figure 1.1 Fuel Consumption and Real GDP in Ghana, 1986-2012



The relation between fuel consumption and real GDP in Ghana is no surprise since various studies have shown that there is a strong relationship between energy consumption and economic growth. Abaidoo (2011) used the Granger-causality test to show the existence of a unidirectional causal relationship running from GDP growth to energy consumption in Ghana, finding that a 1% increase in GDP induces approximately a 2% growth in electric energy consumption. Adom (2011), using the Granger-causality test, also revealed the existence of unidirectional causality running from economic growth to electricity consumption in Ghana. Bildirici (2012) estimated the causal relationship between electricity consumption and economic growth with Markov Switching Vector Auto Regression and Markov Switching Granger Causality methods for several emerging countries (Brunei, Cameron, Côte d'Ivoire, Nigeria, South Africa, Togo and Zimbabwe) and provided evidence of bi-directional Granger-causality between GDP and electricity consumption. Bartleet and Gounder (2010) showed Granger-causality from real GDP to energy consumption in New Zealand.

Trends in the composition of fuel consumption in Ghana have changed over the years. Starting in 1986, gasoline accounted for the largest share at 40%, followed by diesel at 38%, kerosene at 20%, and LPG at 2%. In 2012, diesel accounted for the largest share at 57%, followed by gasoline at 33%, LPG at 9%, and kerosene at 1%. According to the National Petroleum Authority (NPA), the higher demand for diesel is driven mostly by the industrial sector, but gasoline dominates the transportation sector in terms of consumption. As income increases, households tend to use more LPG and less kerosene as cooking fuels. Also, some commercial drivers have found the use LPG to be cheaper than gasoline and diesel in some parts of the country (Biscoff et al, 2012). These dynamics have led to an increase in LPG consumption at the expense of kerosene during the period. Figure 1.2 shows the shares of fuel consumption from 1986 to 2012.

Figure 1.2 Shares of Fuel Consumption in Ghana, 1986-2012



Data from the National Petroleum Authority (NPA) shows an upward trend in retail prices for all four fuels from 1989 to 2012. The retail prices, which are largely driven by international crude oil prices, exchange rates, and subsidies, have been increasing over the period. Trends and annual log-changes (variations) in retail prices and the consumption for each fuel are displayed in Figures 1.3 to 1.10. Notice that annual quantity changes and annual price changes often move in opposite directions. Below, I use this variation (and similar variation from other African countries) to estimate demand elasticities.

Figure 1.3 Trends in Gasoline Consumption and Retail Prices in Ghana

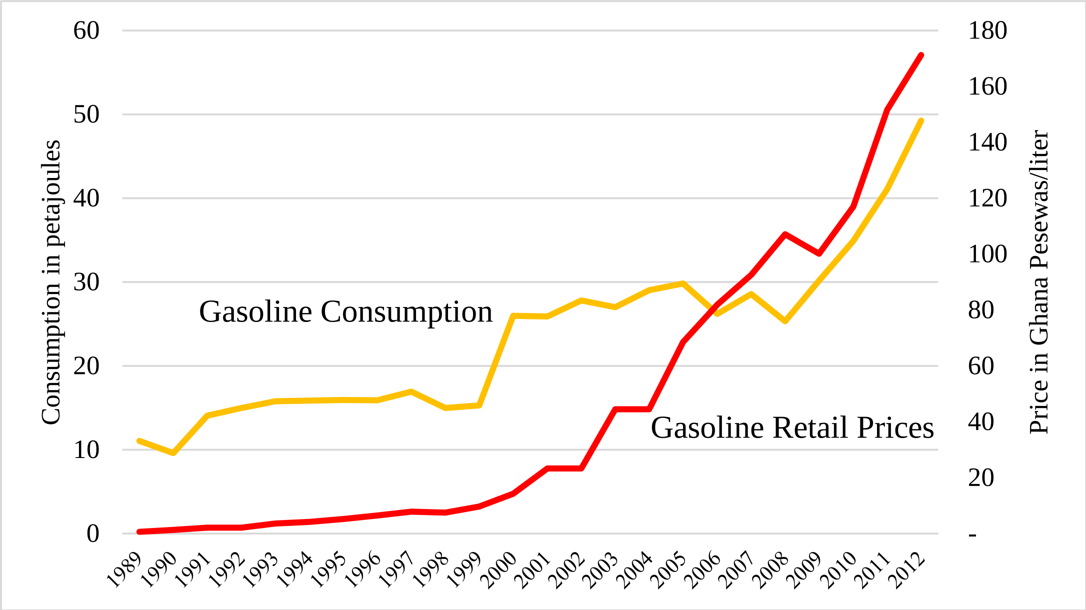


Figure 1.4 Annual Log-changes in Gasoline Consumption and Retail Prices in Ghana

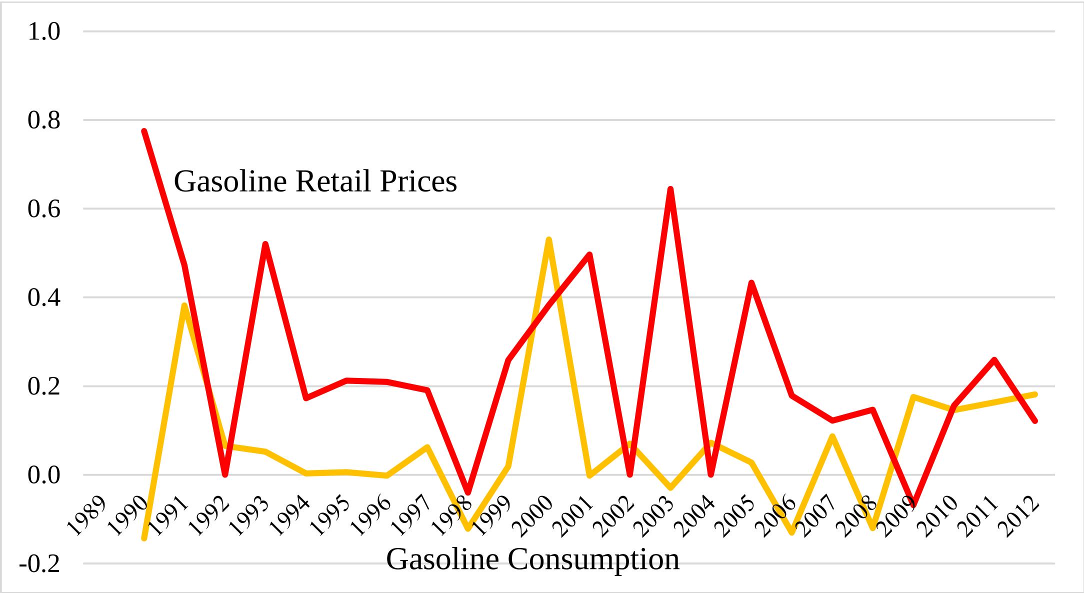


Figure 1.5 Trends in Diesel Consumption and Retail Prices in Ghana

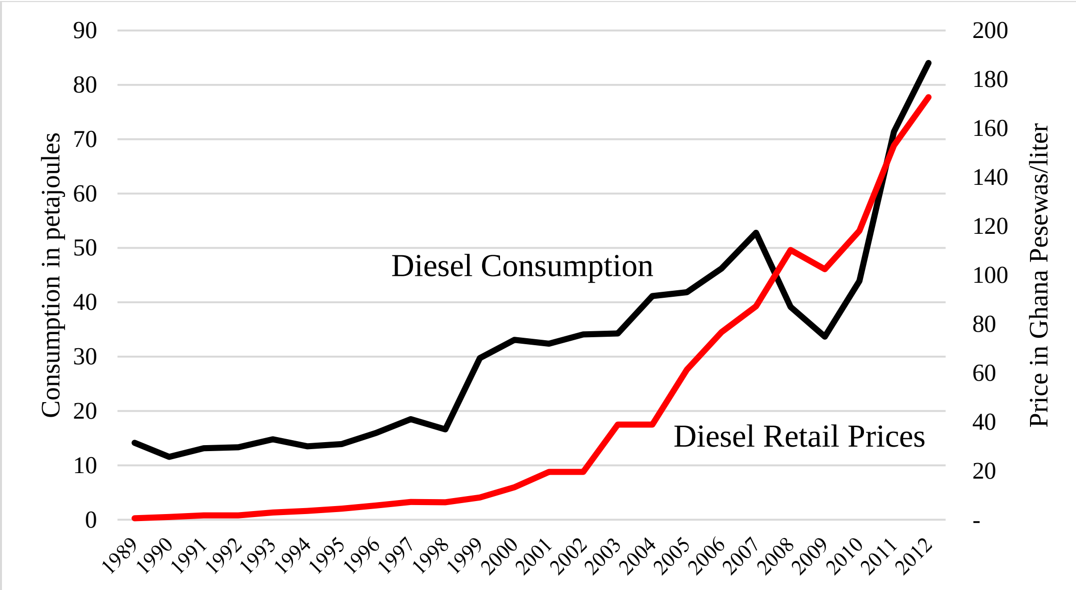


Figure 1.6 Annual Log-changes in Diesel Consumption and Retail Prices in Ghana

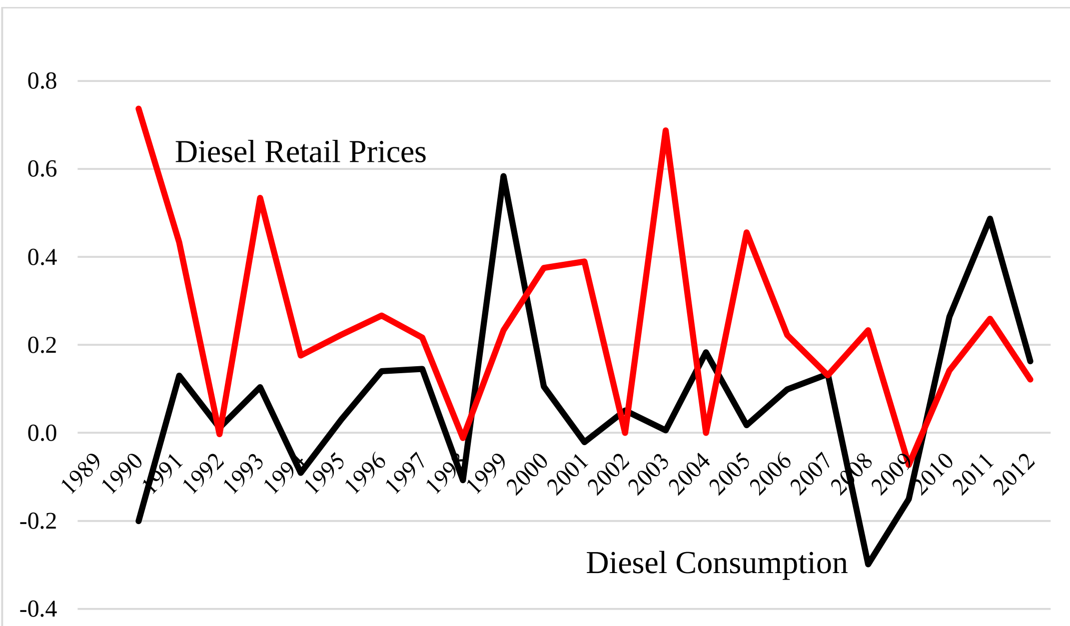


Figure 1.7 Trends in Kerosene Consumption and Retail Prices in Ghana

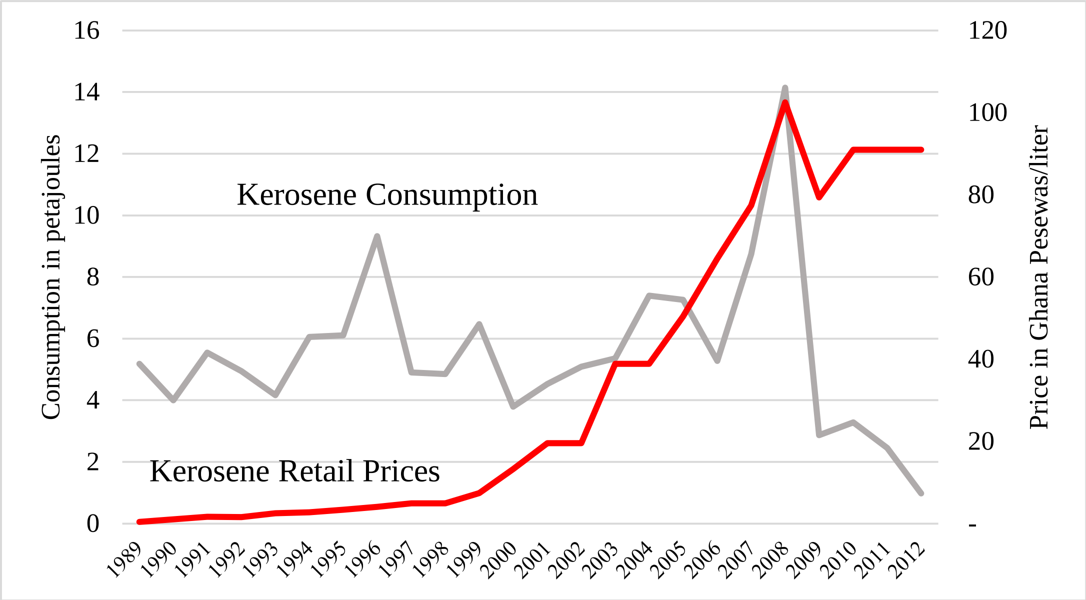


Figure 1.8 Annual Log-changes in Kerosene Consumption and Retail Prices in Ghana

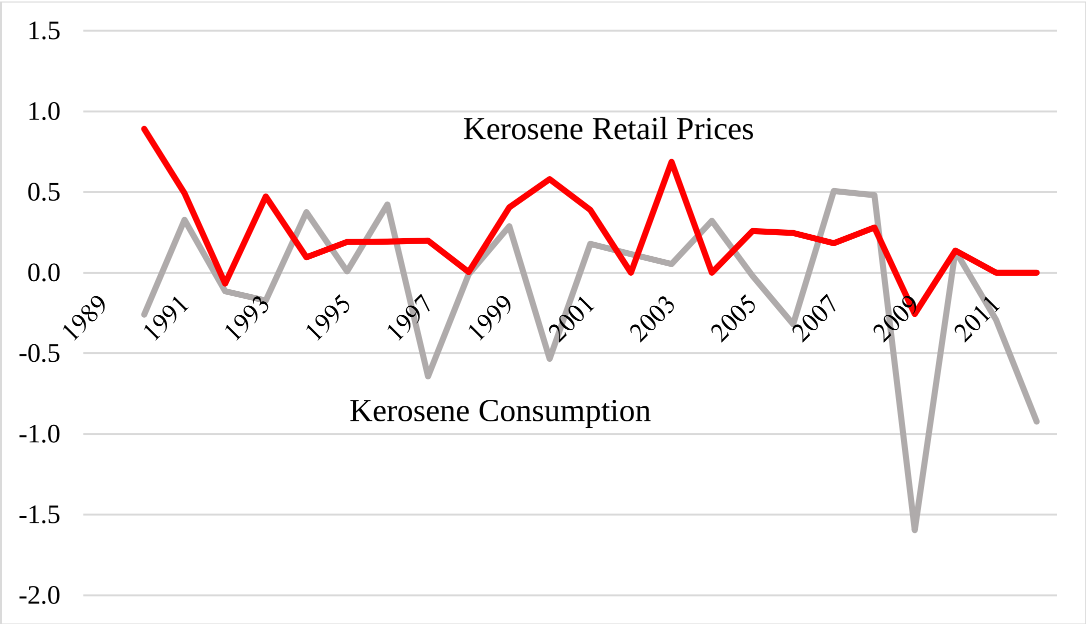


Figure 1.9 Trends in LPG Consumption and Retail Prices in Ghana

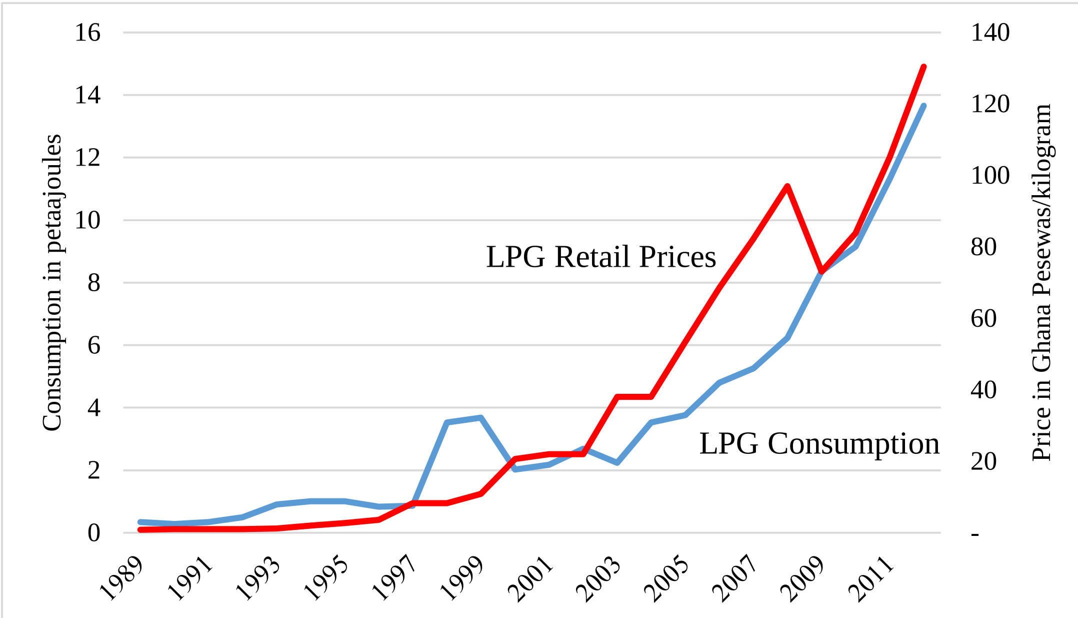
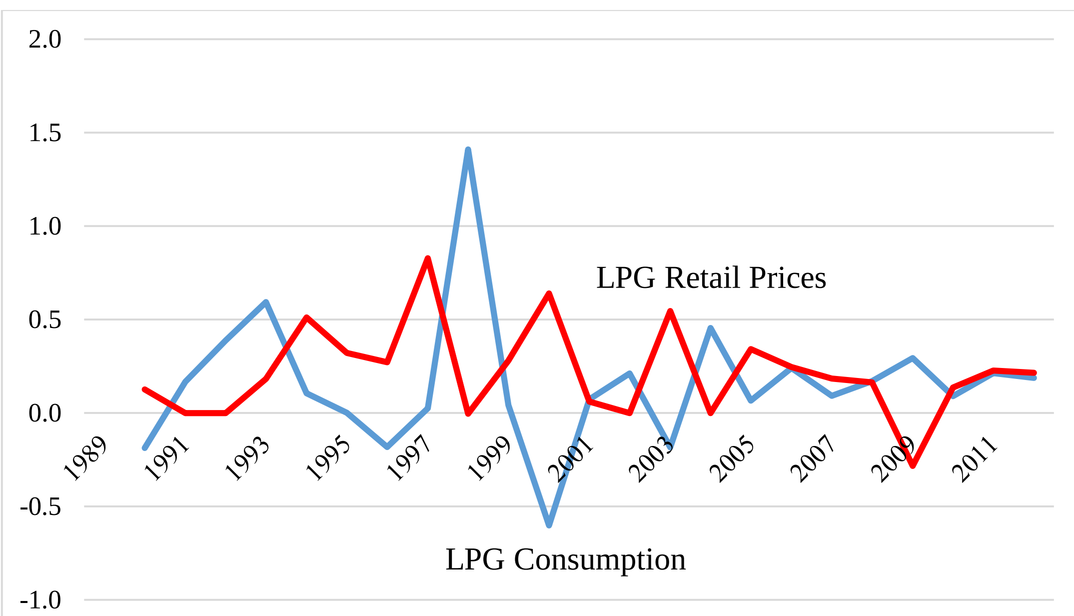


Figure 1.10 Annual Log-changes in LPG Consumption and Retail Prices in Ghana



1.3 Fuel Subsidies in Ghana

According to the Energy Center at the Kwame Nkrumah University of Science and Technology (KNUST), the government introduced the automatic price setting mechanism in 2001. The mechanism was designed to reduce the subsidy burden on government by adjusting domestic retail prices of refined petroleum products to reflect changes in international oil prices, and to relieve the Tema Oil Refinery (TOR) of its accumulating debts due to fuel subsidies over the years. However, there was pressure on government to abolish the automatic adjustment due to high global oil prices in 2002. In 2003, the mechanism was re-introduced and the adjustment resulted in about a 90% increase in fuel prices and an 8.5% decline in real income (KNUST).

The mechanism was abandoned in 2004 following public pressure and fuel subsidies amounted to 2.2% of GDP (Cooke et al, 2014). Fuel prices increased significantly in mid-2009, early 2011, 2012, and 2013 (Cooke et al, 2014). The removal of fuel subsidies largely occurred in February 2013 when prices of gasoline, diesel, kerosene, LPG, marine diesel, and residual fuel oil increased by 15% to 50%, with the exception of premix fuel which remained subsidized. Gradual increases occurred in 2013 which saw the price of gasoline increasing by almost 30% in total from Ghana Pesewas (GHp) 170.80 per liter at the beginning to the market rate of GHp 222 per liter later in the year (Cooke et al, 2014). On July 1, 2015, fuel prices for all refined petroleum products, except premix fuel and residual fuel oil, were abolished.

Prior to the removal of fuel price subsidies in July 2015, the National Petroleum Authority (NPA) negotiated with refined petroleum product importers, distributors, and marketers to determine the full-pass-through prices for the products, usually every two weeks. The full-pass-through price, or the price at which the full cost of the product is passed onto the consumer, constitutes international refined petroleum product price, the cost of shipment, margins for suppliers, distributors, and marketers, and taxes and levies. The full-pass-through price represents the marginal cost of fuel. The government provides fuel price subsidies to help lessen the impact of increases in international fuel prices on consumers. The retail price of fuel products in Ghana is the full-pass-through price minus the subsidy.

Occasionally, the government decides to maintain the existing retail prices of fuel when international fuel prices fall, leading to a net tax on fuel. By doing so, the government generates some revenue to defray the budgetary cost of providing fuel price subsidies. Figures 1.11 to 1.14 show the trends in retail prices, full-pass-through prices, and price subsidies in Ghana from 2009 to 2014. Since there is no explicit data on the amount of fuel price subsidies provided per unit of fuel, I calculate the amount of subsidy per unit of fuel as the positive difference between the full-pass-through and retail prices.

Figure 1.11 Gasoline Prices and Subsidies in Ghana, 2009-2014

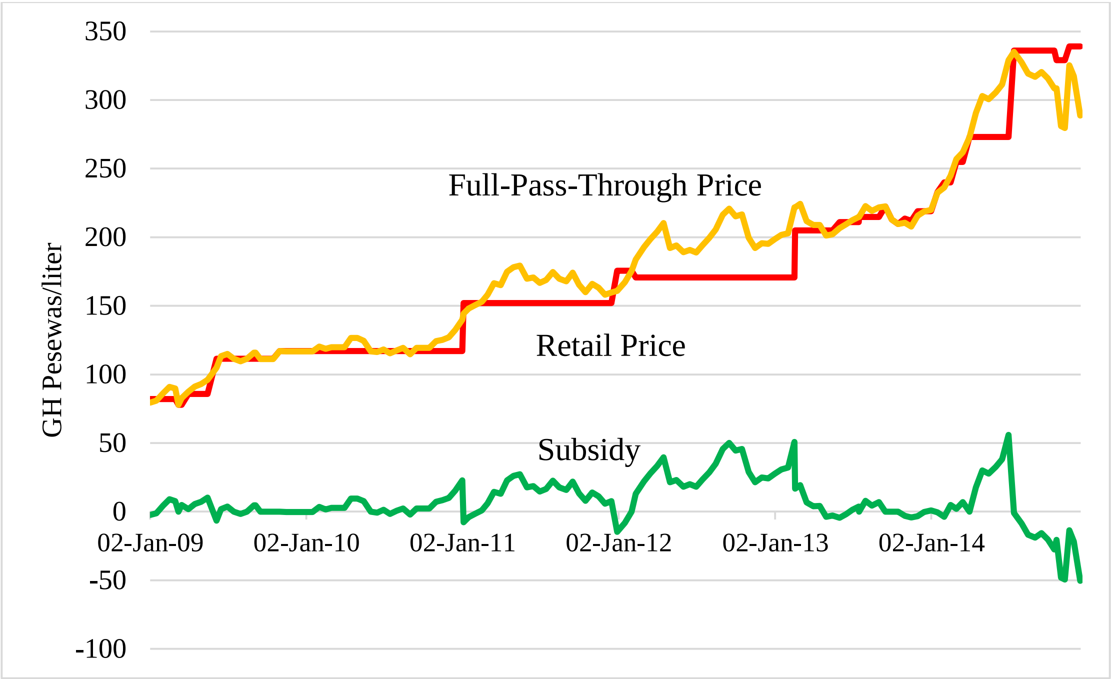


Figure 1.12 Diesel Prices and Subsidies in Ghana, 2009-2014

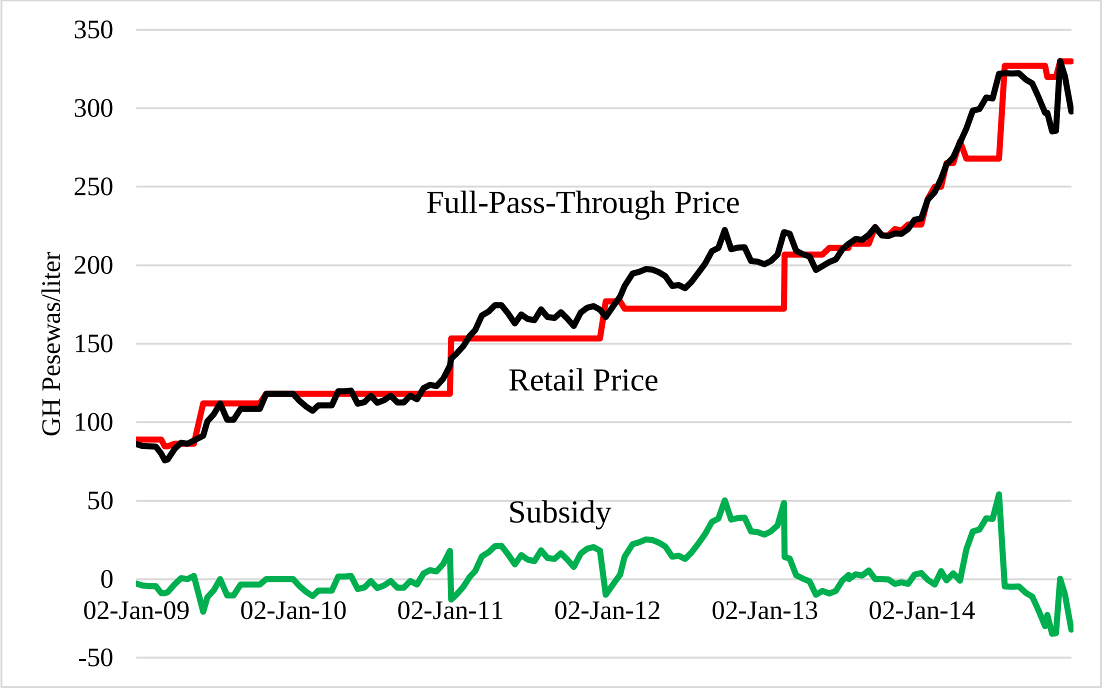


Figure 1.13 Kerosene Prices and Subsidies in Ghana, 2009-2014

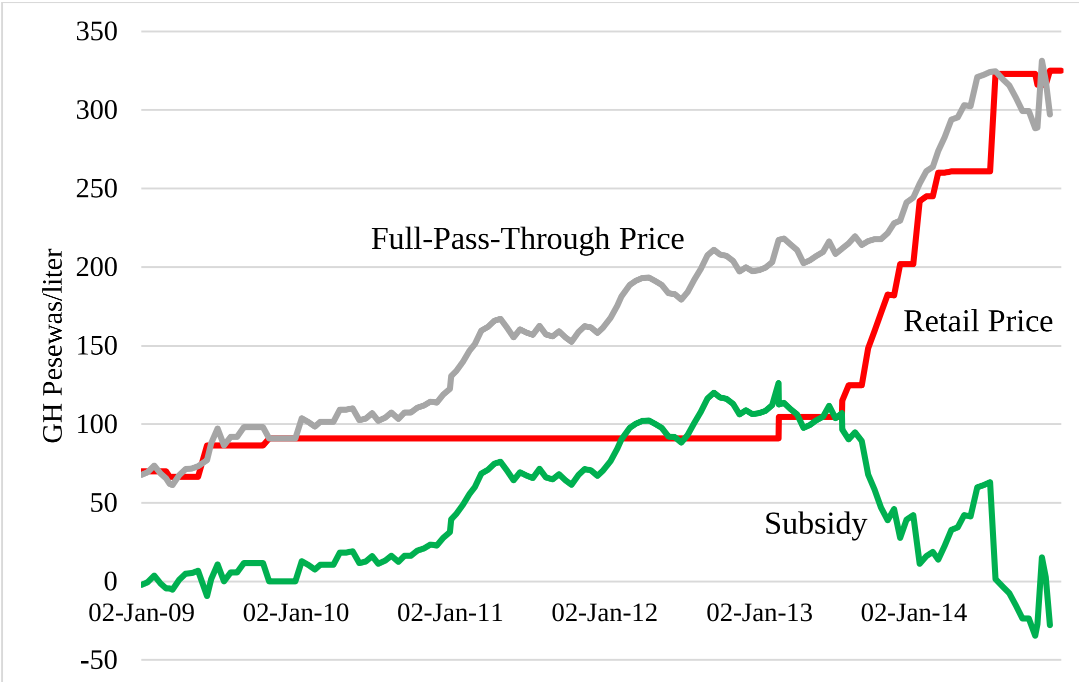
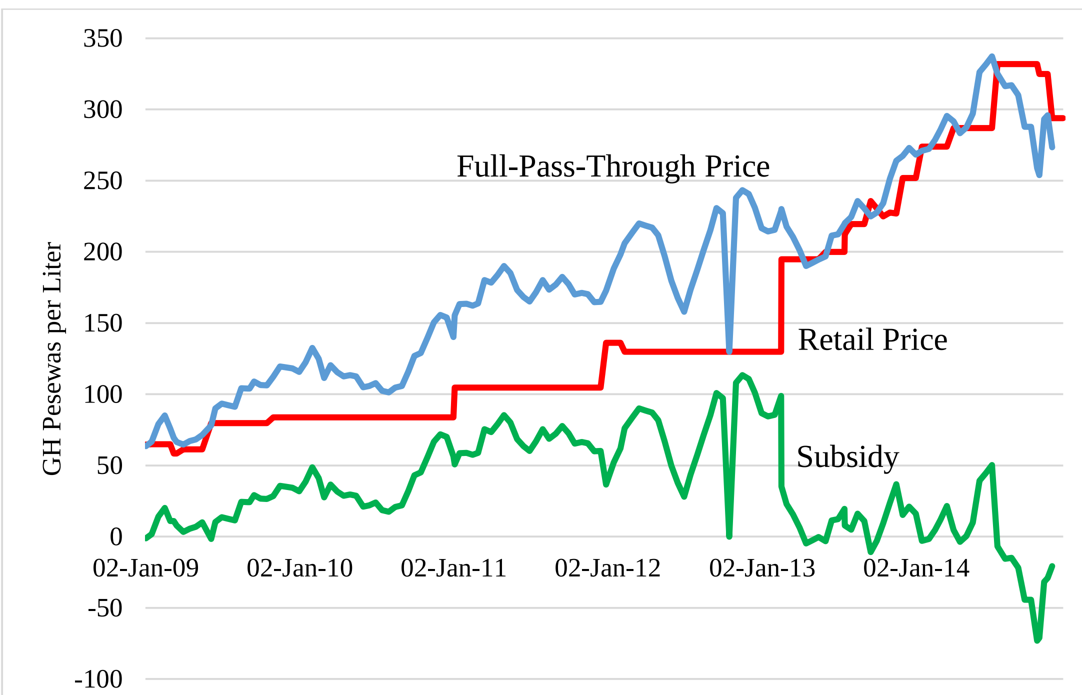


Figure 1.14 LPG Prices and Subsidies in Ghana, 2009-2014



High-income households benefit more from fuel subsidies since their consumption of fuel is the highest among income groups, hence fuel price subsidies have largely failed to meet distributional goals since they benefit the rich more than the poor (Cooke et al, 2014). The richest consumption quintile receives more than 44% of fuel subsidies for gasoline, kerosene, and LPG, while the poorest quintile receives less than 8% of these subsidies in Africa (Granado et al, 2010). In Ghana, the richest quintile of the population overall received GHS 15.86 per capita from fuel price subsidies, almost 78%, while the poorest received just GHS 2.23 per capita, less than 3%, in a year (Cooke et al, 2014). Looking at particular fuels, the richest quintile received about 92.8% of gasoline, 96.5% of diesel, and 85.5% of LPG subsidies, while the poorest quintile received less than 1% of subsidies for these fuels (Cooke et al, 2014). Although one might expect poor households to benefit most from kerosene subsidies, since poor households use a lot of kerosene, this is not the case. The poorest quintile received about 10.7% of kerosene subsidies while about 36.4% went to the richest quintile, as shown in Table 1.1 (Cooke et al, 2014).

Table 1.1 Distribution of Fuel Price Subsidies Across Income Groups in Ghana (%)

Subsidies	Income Quintile				
	1	2	3	4	5
Gasoline	0.90	1.35	1.62	3.35	92.78
Diesel	0.12	0.63	1.45	1.33	96.46
LPG	0.16	0.69	2.17	11.43	85.55
Kerosene	10.69	13.88	18.06	20.96	36.42
Total	2.97	4.14	5.83	9.27	77.80

1 - Poorest, 5 - Richest. Source: Cooke et al (2014).

Studies have also shown that the phasing-out of fuel subsidies and the scaling-up of social protection programs could be a cost-effective and more sustainable way of protecting the poor against fuel price increases, reducing income inequality and poverty in developing countries. A study by Cooke et al. (2014) revealed that expanding the cash transfer program (Livelihood Empowerment Against Poverty), which provides direct cash transfers to the poor, could entirely reverse the negative impact of fuel price increases arising from fuel subsidy reform on poor households.

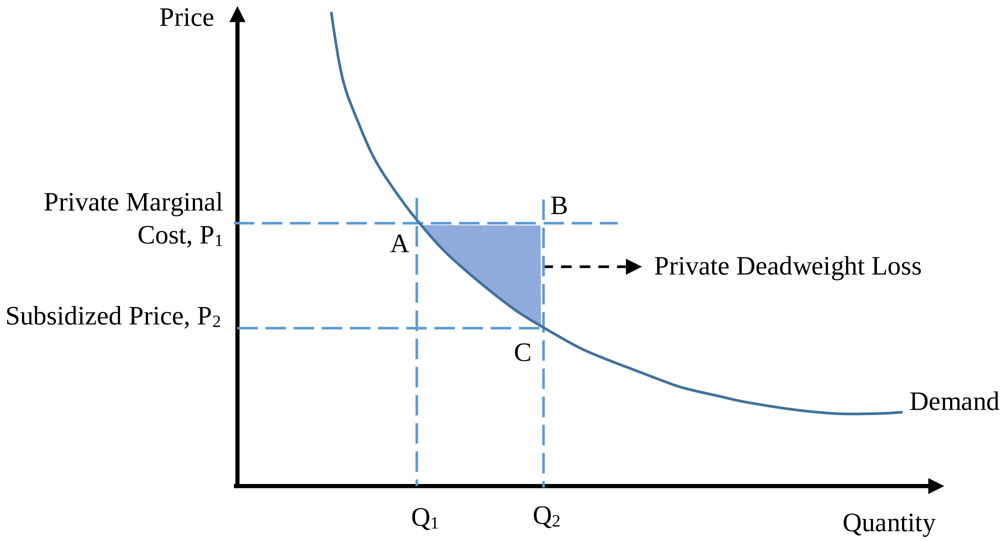
CHAPTER 2 - THEORY OF DEADWEIGHT LOSS

2.1 Introduction

Deadweight loss, or excess burden, is the loss of economic efficiency. Deadweight loss can occur in the market for a good or service when the marginal social cost of the good's production and consumption differs from the marginal social benefit. In other words, deadweight loss can occur when equilibrium is not Pareto optimal. Deadweight loss may arise as a result of taxes, subsidies, monopoly pricing, or externalities. Rational consumers are expected to increase consumption of fuel when the price is set below private marginal cost, as a result of a price subsidy. By consuming up to a point where marginal cost exceeds the consumers' marginal willingness-to-pay, deadweight loss is created in the market. Fuel subsidies create deadweight loss by reducing the equilibrium prices. Since fuel price subsidies are transfers from the government to consumers, the economic cost involved in providing such transfers is the deadweight loss created. Deadweight loss is then considered as an economic cost to society. According to Davis (2014), the total amount of deadweight loss created in a market depends on the elasticities of demand and supply. The more elastic demand and supply are, the larger the deadweight loss created by a price subsidy (Davis, 2014).

Figure 2.1 below illustrates a free market for a fuel product in a small open economy with a constant marginal cost. Producers sell at private marginal cost, P_1, and consumers are willing to buy Q_1, as they desire based on their demand schedule. When the government provides a price subsidy for the product, the price falls from P_1 to P_2, and consumers can now afford extra units of the product beyond the amount they are willing to purchase at private marginal cost. They increase consumption from Q_1 to Q_2, creating excess demand beyond the efficient level, Q_1. The area ABC is the deadweight loss created by the subsidy.

Figure 2.1 Private Deadweight Loss and Subsidy

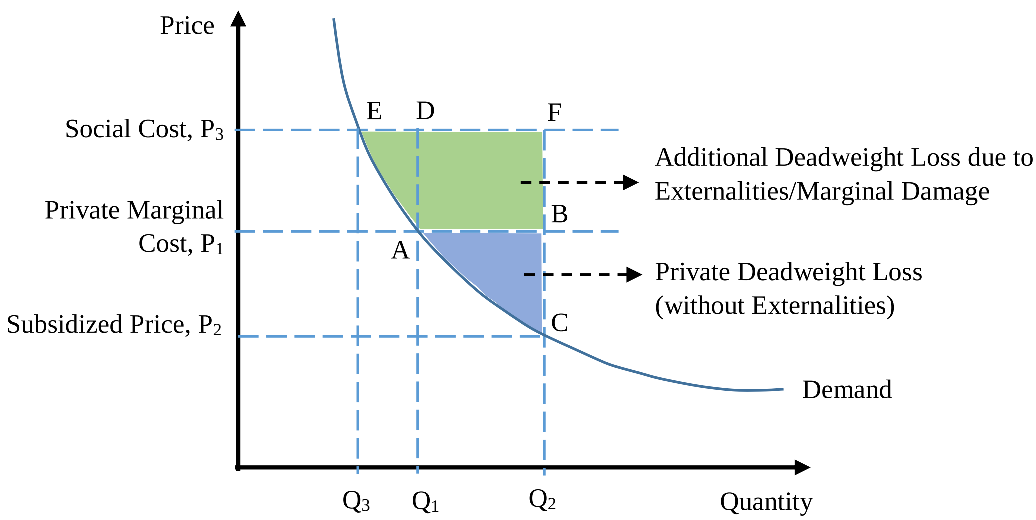


Following Davis (2014), I can estimate the private deadweight loss associated with a fuel price subsidy in a given year by first calculating the area of the rectangle P_1BCP_2 in Figure 2.1, and then subtracting off the area under the demand curve from P_2 to P_1. The resulting difference (area ABC), is the private deadweight loss caused the subsidy (Appendix 1).

2.2 Fuel Externalities

The consumption of refined petroleum products presents indirect damages to the consumers, the environment, and the economy as a whole. First of all, the exploration, production, storage, and transportation of crude oil, together with consumption of petroleum products downstream, impact negatively on the natural habitat of plants and animals both on land and at sea. Exhaust and pollutants from combustion engines and factories also contaminate the air with harmful gases, such as carbon dioxide, and particulates (i.e., dust), that contribute to climate change and result in poor health and respiratory consequences. In addition, the use of fuel is also associated with road accidents, which increase the toll of death and injuries, as well as noise pollution and road congestion. These indirect social costs are termed “externalities.” Figure 2.2 below illustrates the additional cost to society beyond private marginal cost. Social deadweight loss, or total efficiency cost, associated with the increase in fuel consumption as a result of subsidy is, however, not just the private deadweight loss, area ABC, but also includes the additional deadweight loss, area EABF, caused by externalities. Hence, the social deadweight loss is represented by area ECF.

Figure 2.2 Social Deadweight Loss and Subsidy



There are studies that estimate the size of externalities associated with the consumption of fuels such as gasoline and diesel. Such studies quantify and monetize these indirect costs that society incurs through the consumption of petroleum products. They estimate the marginal external damage of both local and global externalities, such as air pollution and the associated health risks, as well as climate change. These estimates also account for the cost of road accidents, injuries, traffic congestion, road maintenance, and noise pollution. One such study estimated the marginal external damages to be US$ 1.11 per gallon in the United States (Parry et al, 2007). Although estimating the externalities associated with fuel consumption in Ghana is important, it is not the primary focus of this study.

As economic agents, consumers of a product consider not only the price of the product, but also the prices of related products in making consumption decisions, especially in the long-run. Hence, a price subsidy provided for a product may influence not just the consumption of the product, but also related products. In the same manner, price subsidies provided for related products will also influence the consumption of the product in question. As a result, an estimate of deadweight loss will require a general equilibrium approach that accounts for the impact of cross-price effects of related products.

2.3 Harberger Formula and Deadweight Loss from Taxation

According to Hines Jr. (1999), Arnold C. Harberger proposed the triangular method of estimating deadweight loss, and applied the method to estimate excess burden, or deadweight loss, arising from income taxes in the United States. Deadweight loss triangles became known as ‘‘Harberger triangles’’ due to the broad influence of Harberger’s papers on subsequent research (Hines Jr., 1999). According to Goulder and Williams III (2003), the comprehensive Harberger formula, which is a linear approximation of excess burden, is given by:

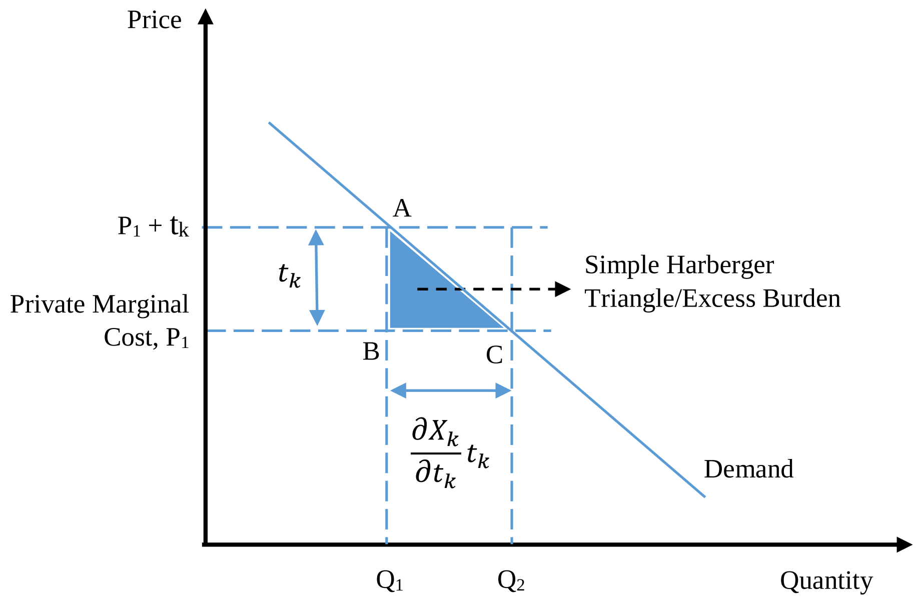
$$EB \approx -\frac{1}{2}\, t_k^2\, \frac{\partial X_k}{\partial t_k} - \sum_{i \neq k} t_i t_k \frac{\partial X_i}{\partial t_k} \;,$$

where EB is the excess burden or deadweight loss caused by the imposition of a tax on good k, X represents respective quantities demanded, i is a related good, and t is the tax. The term $-\frac{1}{2}\, t_k^2\, \frac{dX_k}{dt_k}$ represents the deadweight loss created by t_k in market k, and the term $\sum_{i \neq k} t_k t_i \frac{dX_i}{dt_k}$ represents the reduction in deadweight loss created by t_k in other related markets due to the presence of pre-existing taxes in these other markets. That is, for example, a tax on good k would not create as much deadweight loss as you might otherwise expect, if it reduces the deadweight loss due to a tax on a close substitute good i. Under the assumptions underlying the formula, the tax rate represents marginal distortionary cost or the discrepancy between marginal social value and marginal social cost (Goulder and Williams III 2003). Since it is often difficult to obtain all the cross-price effects for all possible related goods, researchers rarely use the comprehensive Harberger formula. Instead, the simple formula which ignores the cross-price effects is mostly used (Goulder and Williams III, 2003). The simple Harberger formula is written as:

$$EB \approx -\frac{1}{2}\, t_k^2\, \frac{\partial X_k}{\partial t_k}$$

The simple Harberger formula assumes that $\frac{dX_i}{dt_k} = 0$ or $t_i = 0$ for all $i \neq k$. Under the assumption of a constant marginal cost curve, I illustrate the simple Harberger triangle in Figure 2.3.

Figure 2.3 Simple Harberger Triangle



2.4 Adapting the Harberger Formula to Price Subsidies

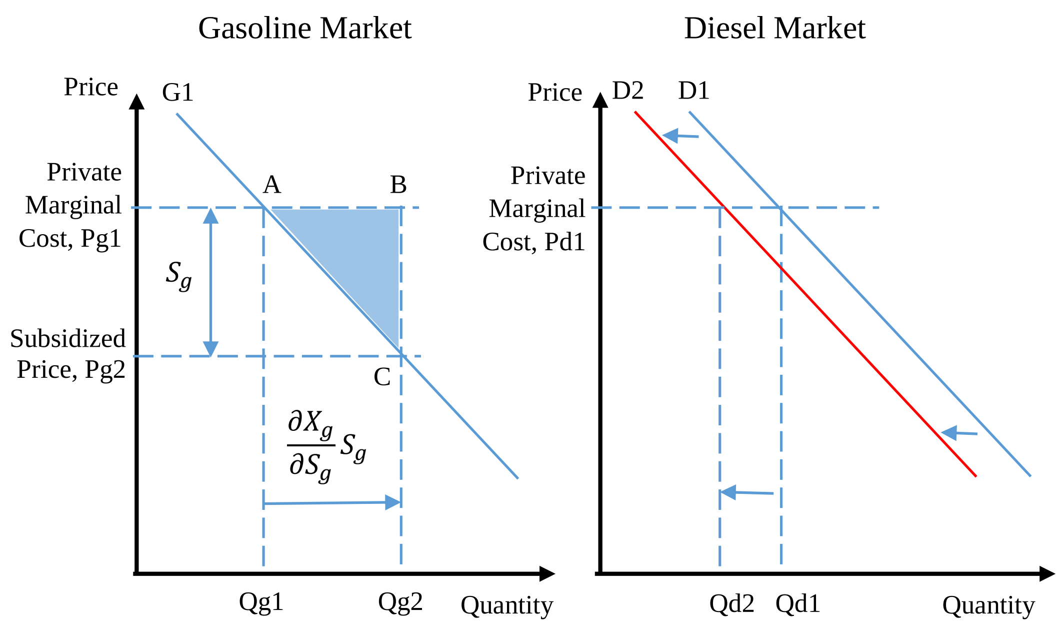
By adapting the comprehensive Harberger formula to fuel price subsidies, I derive estimates for the deadweight loss associated with gasoline and diesel price subsidies. In Scenario 1, a subsidy is provided for only one product. In Scenario 2, multiple subsidies are provided for gasoline and diesel in a sequential order (gasoline first, then diesel or vice versa). In Scenario 3, multiple subsidies are provided for gasoline and diesel simultaneously. For simplicity, I make the following assumptions; (1) consumers' demand for a particular fuel type is influenced purely by its price and the price of substitute fuel types holding other factor (such as income) constant, (2) consumers face no barrier to switch between fuels, (3) all consumers respond negatively to changes in own price and positively to changes in cross price at all times (since these are substitute goods), (4) consumers' responses to changes in taxes or subsidies are no different from their responses to changes in price arising from non-tax sources, and (5) constant marginal cost curves for gasoline and diesel supply, since Ghana is a small open economy where majority of petroleum products are imported and consumers take prices as given.

Scenario 1: A price subsidy is provided to gasoline consumers (Figure 2.4). The subsidy for gasoline will induce consumers to increase demand of gasoline from Qg1 to Qg2, while demand for diesel falls from Qd1 to Qd2 as the demand curve for diesel shifts inwards from D1 to D2. The subsidy creates a distortion in only the gasoline market. The deadweight loss (area ABC) can be estimated as:

$$DWL_G \approx \frac{1}{2} S_g^2 \frac{\partial X_g}{\partial S_g} \approx -\frac{1}{2} S_g^2 \frac{\partial X_g}{\partial P_g} \frac{P_g}{X_g} \frac{X_g}{P_g} \approx -\frac{1}{2} S_g^2 E_{gg} \frac{X_g}{P_g} ,$$

where X_g is quantity demanded for gasoline, and S_g is fuel price subsidy for gasoline, P_g is the price of gasoline, $\frac{\partial X_g}{\partial S_g} = -\frac{\partial X_g}{\partial P_g} > 0$, and $E_{gg} < 0$ is the own-price elasticity of gasoline demand. This formula is equivalent to the simple Harberger formula.

Figure 2.4 DWL of Gasoline Price Subsidy



Scenario 2: A price subsidy is provided first to the gasoline consumer, then to the diesel consumer (Figure 2.5). This scenario is equivalent to providing a diesel price subsidy in the presence of a pre-existing gasoline subsidy (continuing from Scenario 1). When a diesel price subsidy is introduced, a deadweight loss (area ABC) will be created in the diesel market, as consumption of diesel increases from Qd1 to Qd2. Since gasoline consumers will find diesel relatively cheaper, consumption of gasoline will decrease from Qg1 to Qg2 as the gasoline demand curve shifts inward from G1 to G2. The initial deadweight loss created by the pre-existing price subsidy for gasoline will be reduced by area EBCD.

Thus, I can extend the Harberger formula to estimate the total deadweight loss created by the sequential provision of gasoline and diesel price subsidies as:

$$DWL_{(G\ 1st,\ D\ 2nd)} \approx \frac{1}{2} S_g^2 \frac{\partial X_g}{\partial S_g} + \frac{1}{2} S_d^2 \frac{\partial X_d}{\partial S_d} + S_g S_d \frac{\partial X_g}{\partial S_d}$$

$$DWL_{(G\ 1st,\ D\ 2nd)} \approx -\frac{1}{2} S_g^2 E_{gg} \frac{X_g}{P_g} - \frac{1}{2} S_d^2 E_{dd} \frac{X_d}{P_d} - S_g S_d E_{gd} \frac{X_g}{P_d} ,$$

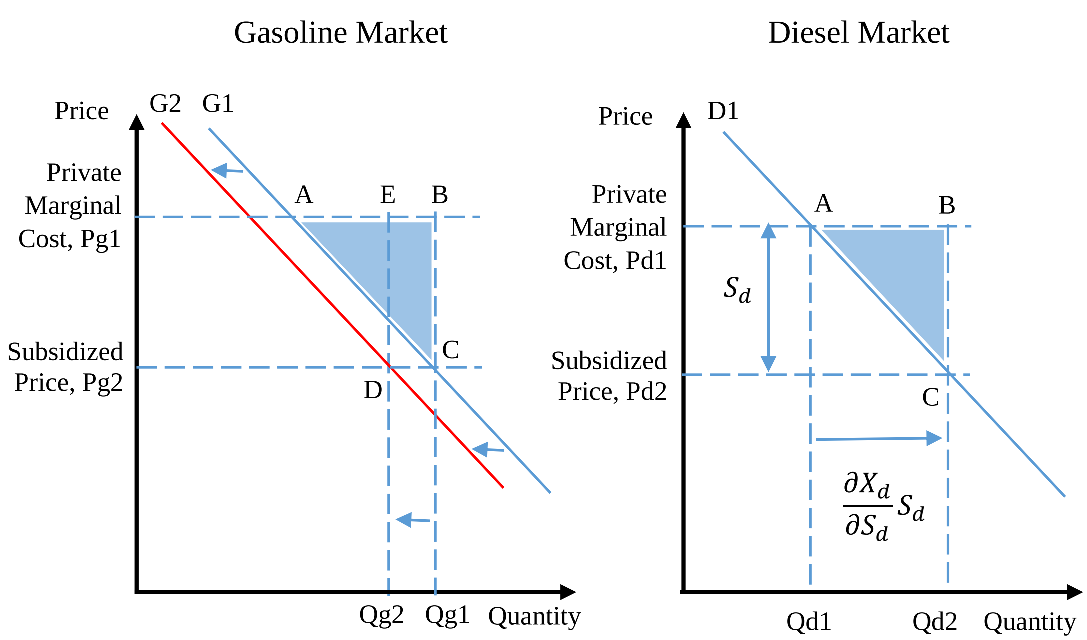
where S_d is diesel price subsidy, P_d is the price of diesel, X_d is quantity demanded for diesel, $\frac{\partial X_d}{\partial S_d} = -\frac{\partial X_d}{\partial P_d} > 0$, $\frac{\partial X_g}{\partial S_d} = -\frac{\partial X_g}{\partial P_d} < 0$, $\frac{1}{2} S_d^2 \frac{\partial X_d}{\partial S_d}$ is the incremental deadweight loss created by the diesel subsidy in the diesel market, $S_g S_d \frac{\partial X_g}{\partial S_d}$ represents the amount of reduction in the pre-existing deadweight loss in the gasoline market caused by the cross-price effect of the diesel subsidy, $E_{dd} < 0$ is own-price elasticity of diesel demand, and $E_{gd} > 0$ is the cross-price elasticity of gasoline demand. Alternatively, I can start with a diesel subsidy, then introduce a gasoline subsidy. In that case, the estimate for deadweight loss will be:

$$DWL_{(D\ 1st,\ G\ 2nd)} \approx \frac{1}{2} S_d^2 \frac{\partial X_d}{\partial S_d} + \frac{1}{2} S_g^2 \frac{\partial X_g}{\partial S_g} + S_d S_g \frac{\partial X_d}{\partial S_g}$$

$$DWL_{(D\ 1st,\ G\ 2nd)} \approx -\frac{1}{2} S_g^2 E_{dd} \frac{X_d}{P_d} - \frac{1}{2} S_d^2 E_{gg} \frac{X_g}{P_g} - S_d S_g E_{dg} \frac{X_d}{P_g} ,$$

where $\frac{\partial X_d}{\partial S_g} = -\frac{\partial X_d}{\partial P_g} < 0$, and $E_{dg} > 0$ is the cross-price elasticity of diesel demand. Since the sequential ordering of the provision of subsidies in Scenario 2 is different for $DWL_{(G\ 1st,\ \ D\ 2nd)}$ and $DWL_{(D\ 1st,\ \ G\ 2nd)}$, the estimates are not the same in general due to the path-dependence problem (Just, Hueth, and Schmitz, 2004).

Figure 2.5 DWL of Sequential Gasoline and Diesel Subsidies



Scenario 3: Gasoline and diesel price subsidies are provided simultaneously to consumers (Figure 2.6). The initial deadweight loss, area ABC, in each market will be created as prices fall and consumption increases. As consumers respond to cross-price effects between the two markets, however, the demand curves will shift inwards and consumers in each market will reduce consumption simultaneously. The reduction in quantity demanded of each product will cause a reduction in the initial deadweight loss from area ABC to area AED in each market. Following

Parry et al (2014), I calculate the net change in consumption in each market caused by the own-price and cross-price effects of the simultaneous subsidies. I then use the quantity changes and the subsidies in each market to estimate deadweight loss using the conventional (triangular) method. The total deadweight loss created in both markets by the simultaneous provision of gasoline and diesel price subsidies is approximated as:

$$DWL_{(G\&D)} \approx \frac{1}{2} S_g \left[\Delta X_g\right] + \frac{1}{2} S_d \left[\Delta X_d\right]$$

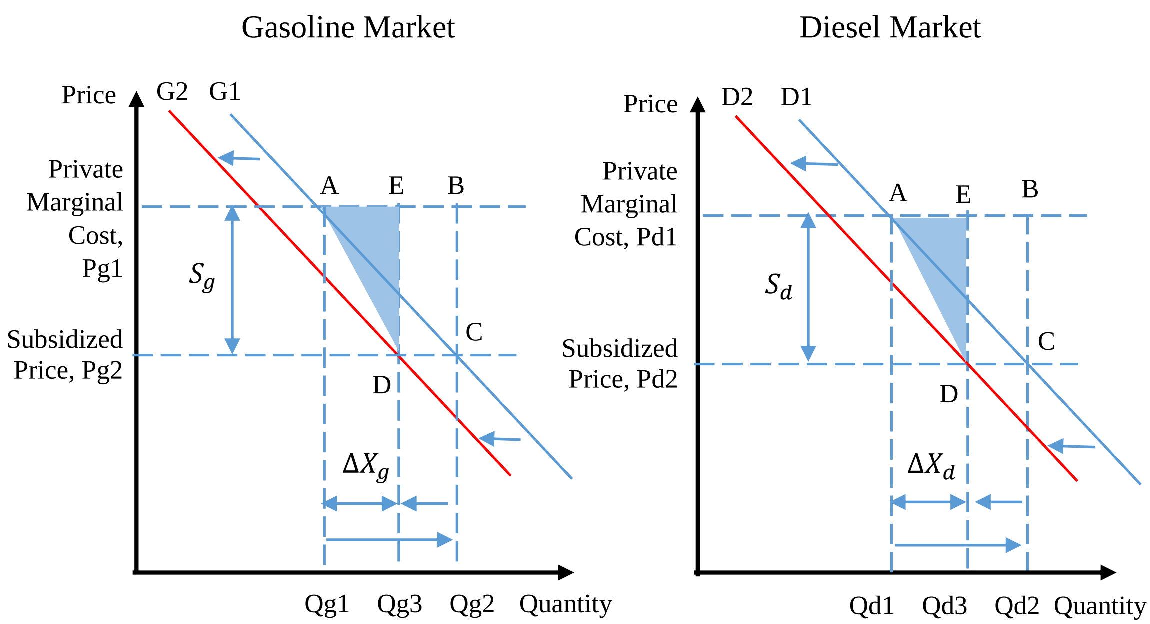
$$DWL_{(G\&D)} \approx \frac{1}{2} S_g \left[S_g \frac{\partial X_g}{\partial S_g} + S_d \frac{\partial X_g}{\partial S_d}\right] + \frac{1}{2} S_d \left[S_d \frac{\partial X_d}{\partial S_d} + S_g \frac{\partial X_d}{\partial S_g}\right]$$

$$DWL_{(G\&D)} \approx \frac{1}{2} S_g \left[- S_g E_{gg} \frac{X_g}{P_g} - S_d E_{gd} \frac{X_g}{P_d}\right] + \frac{1}{2} S_d \left[- S_d E_{dd} \frac{X_d}{P_d} - S_g E_{dg} \frac{X_d}{P_g}\right]$$

$$DWL_{(G\&D)} \approx \frac{1}{2} \left[- S_g^2 E_{gg} \frac{X_g}{P_g} - S_g S_d E_{gd} \frac{X_g}{P_d}\right] + \frac{1}{2} \left[- S_d^2 E_{dd} \frac{X_d}{P_d} - S_d S_g E_{dg} \frac{X_d}{P_g}\right],$$

where ΔX_g and ΔX_d are the net quantity changes in the gasoline and diesel markets, respectively, resulting from the provision of price subsidies for both products at the same time.

Figure 2.6 DWL of Simultaneous Gasoline and Diesel Subsidies



In Appendix 2, I show that the approximation for deadweight loss in Scenario 3 is equal to the average of the two estimates in Scenario 2.

$$DWL_{(G\&D)} = \frac{1}{2}\left[DWL_{(G\ 1st,\ D\ 2nd)} + DWL_{(D\ 1st,\ G\ 2nd)}\right]$$

All the extended formulas in Scenarios 2 and 3 are valid general equilibrium approximations for the deadweight loss associated with multiple price subsidies for substitute products.

CHAPTER 3 - FUEL DEMAND ELASTICITIES

3.1 Model Specification

I use two linear panel data models to estimate price and income elasticities of demand for gasoline and diesel in Africa. I specify quantity demanded as a function of the price of the fuel, the price of the substitute fuel, and income. I specify Model 1 in natural logs as:

$$Model\ 1: \quad lnQ_{it} = \alpha_0 + \alpha_{PF} lnPF_{it} + \alpha_{PS} lnPS_{it} + \alpha_I lnI_{it} + \delta_Y' Y_t^* + \delta_Y' \delta_C C_i^* + \mu_{it} \ ,$$

where Q_{it} is fuel consumption for country i in year t, PF_{it} is the real price of the fuel, PS_{it} is the real price of the substitute fuel, and I_{it} is real income. Y_t^* and C_i^* are vectors of year and country dummies. The terms $\alpha_0, \alpha_{PF}, \alpha_{PS}, \alpha_I, \delta_Y$, and δ_C are the coefficients and μ_{it} is the error term. I specify another model in natural logs, Model 2, which is the same as Model 1 but with time lags:

$$Model\ 2: \quad lnQ_{it} = \alpha_{00} + \alpha_{PF0} lnPF_{it} + \alpha_{PF1} lnPF_{it-1} + \alpha_{PS0} lnPS_{it} + \alpha_{PS1} lnPS_{it-1} + \alpha_{I0} lnI_{it} + \alpha_{I1} lnI_{it-1} + \delta_Y' Y_t^* + \delta_Y' \delta_C C_i^* + \theta_{it} \ ,$$

where $\alpha_{00}, \alpha_{PF0}, \alpha_{PF1}, \alpha_{PS0}, \alpha_{PS1}, \alpha_{I0}$, and α_{I1} are the coefficients and θ_{it} is the error term. For each fuel, I estimate both models to obtain their respective coefficients (α), which are the demand elasticities for own-price, cross-price, and income. In Model 1, the coefficients (α) are both the short-run and long-run estimates. In Model 2, the coefficients (α) for variables in time t are the short-run estimates, while the sum of the coefficients for variables in time t and $t-1$ are the long-run estimates. I estimate each demand model with fixed effects and first difference estimators using Stata (13.1).

3.2 Sources of Data

I create a panel consisting of annual data on twenty seven African countries (Appendix 3) spanning 1998 to 2010 with one year intervals. Data on gasoline and diesel consumption in kilotons of oil equivalent, nominal retail prices for gasoline and diesel in US$ per liter, real GDP in 2005 US$, consumer price index (CPI), and exchange rates were downloaded from The World Bank's online database. I use GDP as a proxy for income. I follow Liu (2004) to obtain real prices in 2010 US Dollars. I first convert US$ nominal prices into respective country currencies using equivalent rates in each year, then covert to real respective country currency values using each country's respective CPI. Finally, I convert back to 2010 US$ using 2010 US$ exchange rates. Data on kerosene and LPG consumption and prices are not available for most of the countries in the panel so these fuels are excluded from the analysis. Summary statistics for all the variables are shown in Appendix 3.

3.3 Endogeneity and Instrumental Variables

Although gasoline and diesel prices are sometimes found to be endogenous, I have reasons to expect prices to be exogenous in my model. Most of the African countries in my panel are small open economies. As a result, consumers in these countries take prices as given. According to data from EIA's online database, consumption of gasoline in Africa totaled 894 thousand barrels per day (bbl/d), while that of the United States reached 8,682 thousand bbl/d in 2012. The local currencies of most of the African countries, on average, depreciate against the US$ because as net importers, their demand for the US$ often exceeds supply (Appendix 4). Finally, fuel price subsidies are provided to consumers to minimize the effects of increases in international oil prices and exchange rates on domestic retail prices. Hence, domestic retail prices for petroleum products in Africa are less influenced by the interaction of demand and supply. With these characteristics in mind, I do not expect prices to be endogenous.

To explore this issue, I run tests to examine the endogeneity of prices in my model. Some studies use instruments such as the prices of related fuel products, regional dummy variables, and average fuel price in neighboring countries or locations [Dahl (1979), Manzan and Zerom (2010), Liu (2014)]. One potential instrument, given the nature of fuel pricing in Africa, is changes in fuel price subsidies, but such data are not available for most of the countries in my panel. Another good instrument is the average prices of fuel in neighboring countries. The average fuel price in neighboring countries is a valid and strong instrument since governments in African countries take into account fuel prices in neighboring countries when making pricing decisions to avoid fuel smuggling. Hence, I expect prices in neighboring countries to be correlated with local prices in each country (instrument relevance), but uncorrelated with fuel consumption residuals (instrument exogeneity).

I first test the instrument relevance assumption. I run regressions to test if the coefficient on the potential instrument is significantly different from zero (Appendix 5). The results show that the average price in neighboring countries is a statistically significant predictor of diesel price, but not so for gasoline price. I then use average fuel price in neighboring countries as an instrument to run endogeneity tests, and I am unable to reject the null hypothesis that gasoline and diesel prices are exogenous (Appendix 5).

3.4 Estimation and Results

I conduct a test for heteroskedasticity and autocorrelation for both models, and the results confirmed the presence of heteroskedasticity and autocorrelation in the error term (Appendix 6). Thus, I use clustered standard errors in my estimation to correct for heteroskedasticity and autocorrelation. Details of the estimation procedures are contained in Appendix 7. Table 3.1 shows results for the fixed effects and first difference estimates of Model 1.

Gasoline: The fixed effects estimates for the gasoline model are larger in magnitude than the first difference estimates, but both models yield the expected signs for all coefficients. For instance, in both the fixed effects and first difference models, the estimates for own-price elasticity (-0.34 and -0.13) are negative, while the estimates for cross-price elasticity (0.19 and 0.08) and income elasticity (0.44 and 0.16) are both positive respectively. Estimated standard errors are high, except that of the fixed effects estimate for the income elasticity. The fixed effects and first difference estimates for the income elasticity are significant at 1% and 5% respectively.

Diesel: All of the fixed effects estimates for the diesel model have the expected signs, but the first difference estimates all have the wrong signs. As Table 3.1 shows, the estimate for own-price elasticity (-0.22) is negative, while the estimates for cross-price elasticity (0.14) and income elasticity (0.19) are both positive for the fixed effects model. However, the own-price elasticity (0.05) estimate is positive, while the cross-price elasticity (-0.11) and income elasticity (-0.17) estimates are both negative for the first difference model. Also, all of the fixed effects estimates are larger in magnitude than the first difference estimates. However, standard errors for all of the estimates are high, and none of the estimates are statistically significant.

Table 3.1 Results of Model 1

	Fixed Effects		First Difference	
	Gasoline	Diesel	Gasoline	Diesel
Price of Gasoline	-0.34 *(0.36)*	0.14 *(0.50)*	- 0.13 *(0. 15)*	-0.11 *(0.13)*
Price of Diesel	0.19 *(0.28)*	-0.22 *(0.46)*	0.08 *(0.12)*	0.05 *(0.12)*
Income	0.44*** *(0.08)*	0.19 *(0.15)*	0.16** *(0.08)*	-0.17 *(0.26)*
Year Effects	Yes	Yes	Yes	Yes
R-squared	0.51	0.37	0.11	0.09
Observations	181	181	153	153

Clustered Standard Errors in parentheses.
Significance: ***1%, **5%, *10%.

Table 3.2 shows the estimation results for Model 2 using fixed effects and first difference estimators.

Gasoline: All of the fixed effects and first difference estimates have the expected signs. As Table 3.2 shows, all of the fixed effects estimates are larger in magnitude than the first difference estimates for both the short-run and long-run coefficients, and all of the long-run estimates are larger in magnitude than the short-run estimates, except the cross-price elasticity estimates. In both the fixed effects and first difference models, the short-run estimates for own-price elasticity (-0.24 and -0.15) are negative, while the short-run estimates for cross-price elasticity (0.10 and 0.10) and income elasticity (0.24 and 0.17) are both positive, respectively. The long-run estimates for own-price elasticity (-0.38 and -0.29) are negative, but the long-run estimates for cross-price elasticity (0.15 and 0.19) and income elasticity (0.48 and 0.36) are positive, in both the fixed effects and first difference models, respectively. The fixed effects and first difference estimates for both the short-run and long-run income elasticities have low standard errors and are statistically significant at 1% (Appendix 8). Conversely, the rest of the estimates have high standard errors and are not statistically significant.

Diesel: Most of the fixed effects estimates and few of the first difference estimates have the expected signs. Likewise, most of the fixed effects estimates are larger in magnitude than the first difference estimates. All of the fixed effects and first difference estimates, except the first difference short-run estimate for income, have high standard errors. Table 3.2 shows that the short-run estimates for income elasticity (0.22 and 0.16) are positive, and the long-run estimates for income elasticity (0.31 and 0.14) are also positive in both the fixed effects and first difference models, respectively. The first difference short-run and the fixed effects long-run estimates for income elasticity are statistically significant at 10% and 5%, respectively, but the rest of the estimates are not (Appendix 8).

Table 3.2 Results of Model 2

	Fixed Effects		First Difference	
	Gasoline	Diesel	Gasoline	Diesel
Price of Gasoline	-0.24	-0.01	-0.15	-0.09
	(0.34)	*(0.37)*	*(0.21)*	*(0.20)*
Lag, Price of Gasoline	-0.15	0.10	-0.13	0.08
	(0.24)	*(0.48)*	*(0.19)*	*(0.32)*
Price of Diesel	0.10	-0.11	0.10	0.04
	(0.26)	*(0.33)*	*(0.17)*	*(0.16)*
Lag, Price of Diesel	0.05	-0.14	0.09	-0.03
	(0.21)	*(0.53)*	*(0.17)*	*(0.32)*
Income	0.24***	0.22	0.17***	0.16*
	(0.08)	*(0.11)*	*(0.06)*	*(0.09)*
Lag, Income	0.24***	0.08	0.19***	-0.01
	(0.08)	*(0.09)*	*(0.07)*	*(0.09)*
Long-run, Price of Gasoline	-0.38	0.09	-0.29	-0.01
	[0.49]	*[0.91]*	*[0.47]*	*[0.98]*
Long-run, Price of Diesel	0.15	-0.26	0.19	0.01
	[0.73]	*[0.76]*	*[0.56]*	*[0.99]*
Long-run, Income	0.48	0.31	0.36	0.14
	[0.00]	*[0.03]*	*[0.00]*	*[0.26]*
Year Dummies	Yes	Yes	Yes	Yes
R-squared	0.51	0.34	0.18	0.05
Observations	154	154	127	127

Clustered Standard Errors in parentheses.
P-values for test of null hypothesis that long-run estimates are zero in square brackets.
Significance: ***1%, **5%, and *10%.

The fixed effects and first difference estimates for Models 1 and 2 are not substantially different for the gasoline model coefficients in terms of signs and statistical significance. But it is evident that in general the fixed effect estimator provides better estimates for the diesel model coefficients in Model 1 than the rest of the estimates in terms the signs. For the diesel model coefficients, all of the fixed effects estimates for Model 1 have the correct signs, but all of the first difference estimates for Model 1 have the wrong signs (Table 3.1). Also, some of the coefficient estimates in Model 2 have wrong signs for the diesel estimates (Table 3.2). For consistency, I prefer the fixed effects estimates to the first difference estimates, and Model 1 to Model 2, for the long-run gasoline and diesel demand elasticities.

My preferred long-run own-price, cross-price, and income elasticity estimates for gasoline demand (-0.34, 0.19, 0.44) and diesel demand (-0.22, 0.14. 0.19), respectively, are all inelastic. Although by themselves, all of my estimates, except income elasticity for gasoline demand, are not statistically significant, they are reasonable in terms of magnitude and sign if I compare them to other estimates in the literature (Table 3.3 and 3.4).

My estimates reveal that a 1% increase in the real price of gasoline will lead to a 0.34% reduction in gasoline consumption, and a 1% increase in the real price of diesel will lead to 0.22% reduction in diesel consumption in Africa, holding other factors constant. Since gasoline and diesel are substitutes, a 1% increase in the real price of diesel will induce a 0.19% increase in gasoline consumption, while a 1% increase in the real price of gasoline will cause a 0.14% increase in diesel consumption in Africa, all else equal. Also, a 1% increase in the real income of consumers will induce a 0.44% increase in gasoline consumption, while a 1% increase in the real income of consumers will induce a 0.19% increase in diesel consumption in Africa, all else equal. My income elasticity estimates confirm that gasoline and diesel are normal goods.

3.5 Comparing Elasticity Estimates

There is wide variation in the literature on estimates for fuel demand elasticities in different parts of the world. This is no surprise, however, as socioeconomic factors differ, and researchers adopt different estimation techniques to address specific knowledge gaps. Liu (2004) noted the discernible divergence among the estimates of energy demand elasticities from empirical studies as a result of the differences in modeling methodologies and data sets applied in these studies.

Nonetheless, since such estimates are expected to provide insights and inform energy policy, achieving realistic estimates should be a priority. One guiding principle should be the fact that, consumers in low-income economies have lower willingness-to-pay compared to consumers in the high-income economies, and hence the former should be more price responsive. As a region dominated by low-income economies, I expect fuel demand elasticities, on the average, to be more elastic in African countries, such as Ghana, than in high income countries like the United States.

My estimates for gasoline and diesel demand elasticities are not substantially different from other recent estimates (Table 3.3 and 3.4). I have not found any estimate for cross-price elasticity of demand for any type of petroleum product.

Dahl (2012) conducted a study that revealed that estimates for own-price elasticities of gasoline and diesel in African countries ranged from -0.09 to -0.33 and -0.13 to -0.46, respectively, while that of income ranged from 0.54 to 1.65 for gasoline and 1.19 to 1.46 for diesel. Using a structural time-series model, Abdullahi (2014) found long-run own-price elasticity estimates for gasoline demand (-0.23), diesel demand (-0.30), kerosene demand (-0.20), LPG demand (-0.58), and fuel oil demand (-0.18) in Nigeria to be inelastic. Mensah (2014) estimated long-run demand elasticities for LPG in Ghana. He reported long-run estimates using an autoregressive distributed lag model (-0.28, 0.45, 5.89) and a partial adjustment model (-0.28, 0.55, 5.62) for own-price, income, and rate-of-urbanization elasticities respectively. Boshoff (2012), in comparing own-price and income elasticity estimates for gasoline demand in South Africa, found using an autoregressive distributed lag model that elasticity estimates using short sample periods (-0.59 and 0.82) are higher than estimates using long sample periods (-0.44 and 0.67). Akinboade, Ziramba, and Kumo (2008) estimated own-price and income elasticities of -0.47 and 0.36, respectively, for gasoline demand in South Africa, also with an autoregressive distributed lag bounds co-integration approach. Gebreegziabher et al. (2010) estimated own price elasticity of demand for kerosene as -0.66 for Ethiopia using an almost-ideal demand system approach.

In Asia, Koshal et al. (1999) estimated a long-run own-price elasticity of demand for kerosene in Indonesia to be -0.17 with a time-series model. Lim et al. (2012) estimated -0.547 and 1.478 as long-run own-price and income elasticities, respectively, for diesel demand in Korea. Lin and Zeng (2013) estimated the intermediate-run own-price elasticity of gasoline demand (-0.497 to -0.196) and income elasticity (1.01 to 1.05) for China.

Finally, Liu (2014) estimated own-price and income elasticities of gasoline demand for various states in the United States. Her estimates range from -0.013 (Illinois) to -0.235 (West Virginia) for own-price elasticity, and 0.017 (Illinois) to 0.172 (West Virginia) for income elasticity, using a semi-parametric smooth coefficient model. In their study, Hughes, Knittel, and Sperling (2008) discuss evidence of a shift in the demand elasticity for gasoline in the United States as they estimate short-run own-price elasticities of -0.21 to -0.34 from 1975 to 1980, and -0.034 to -0.077 from 2001 to 2006 (Tables 3.3 and 3.4).

Table 3.3 Long-run Demand Elasticity Estimates for Gasoline and Diesel

Own-Price Elasticity		Income Elasticity			
Gasoline	Diesel	Gasoline	Diesel	Country /Region	Source
-0.34	-0.22	0.44	0.19	Africa	This study
-0.09 to -0.33	-0.13 to -0.46	0.54 to 1.65	1.19 to 1.46	Africa	Dahl, 2012
-0.23	-0.30			Nigeria	Abdullahi, 2014
-0.44		0.67		S. Africa	Boshoff, 2012
-0.47		0.36		S. Africa	Akinboade et al, 2008
-0.20 to -0.50[a]		1.01 to 1.05		China	Lin and Zeng, 2012
	-0.55		1.48	Korea	Lim et al, 2012
-0.01 to -0.24		0.02 to 0.17		USA	Liu, 2011
-0.03 to -0.08[b]				USA	Hughes et al, 2006

a. Intermediate-run. b. Short-run.

Table 3.4 Long-run Demand Elasticity Estimates for Kerosene and LPG

Own-Price Elasticity			
Kerosene	LPG	Country	Source
-0.20	-0.58	Nigeria	Abdullahi, 2014
	-0.28	Ghana	Mensah, 2014
-0.66		Ethiopia	Gebreegziabher et al, 2010
-0.17		Indonesia	Koshal et al, 1999

CHAPTER 4 - COST OF FUEL PRICE SUBSIDIES

4.1 Introduction

I use my long-run own-price and cross-price elasticity estimates for gasoline (-0.34 and 0.19) and diesel (-0.22 and 0.14) in Table 3.1, long-run own-price elasticity estimates for kerosene (-0.20) and LPG (-0.58) for Nigeria by Abdullahi (2014), and fuel consumption and price data from the National Petroleum Authority (NPA) to estimate the deadweight loss associated with fuel price subsidies in Ghana.

4.2 Simple Method

I calculate the deadweight loss associated with fuel price subsidies using the adapted simple Harberger formula, $DWL \approx \frac{1}{2} S_g^2 \frac{\partial x_g}{\partial s_g}$. The average subsidies per liter (or per kilogram for LPG) for gasoline, diesel, kerosene, and LPG during 2009 to 2014 are GHS 0.13, GHS 0.10, GHS 0.48, and GHS 0.37, respectively. Under the assumption that cross-price effects are insignificant, or zero, the cost of fuel price subsidies for gasoline, diesel, kerosene and LPG from 2009 to 2014 in each market are shown in Tables 4.1 to 4.4. The total deadweight loss, or economic cost, associated with subsidies for these fuels is GHS 109.45 million for the period 2009 to 2014, with an annual total cost of GHS 18.24 million for all four fuels. As the Tables below show, the annual economic costs of fuel price subsidies in Ghana are GHS 2.93 million for gasoline, GHS 1.47 million for diesel, GHS 2.03 million for kerosene, and GHS 11.81 million for LPG.

Table 4.1 Economic Cost of Gasoline Price Subsidies in Ghana

Year	Subsidy [a]	Quantity Consumed [b]	Deadweight Loss [c]
2009	0.17	929.47	4.51
2010	0.04	997.34	0.21
2011	0.13	1083.23	2.07
2012	0.27	1332.52	9.29
2013	0.08	1450.53	0.84
2014	0.09	1522.24	0.65
Average	*0.13*	*1219.22*	*2.93*

a. Ghana Cedis per liter. b. Million liters. c. Million Ghana Cedis.

Table 4.2 Economic Cost of Diesel Price Subsidies in Ghana

Year	Subsidy [a]	Quantity Consumed [b]	Deadweight Loss [c]
2009	0.00	1326.95	0.00
2010	0.03	1212.82	0.09
2011	0.12	1343.60	1.32
2012	0.25	1569.38	6.21
2013	0.06	1663.53	0.30
2014	0.12	1649.81	0.88
Average	*0.10*	*1461.02*	*1.47*

a. Ghana Cedis per liter. b. Million liters. c. Million Ghana Cedis.

Table 4.3 Economic Cost of Kerosene Price Subsidies in Ghana

Year	Subsidy [a]	Quantity Consumed [b]	Deadweight Loss [c]
2009	0.04	110.50	0.02
2010	0.15	61.09	0.15
2011	0.64	77.31	3.43
2012	1.01	56.61	6.39
2013	0.89	34.47	2.20
2014	0.18	11.50	0.01
Average	*0.48*	*58.58*	*2.03*

a. Ghana Cedis per liter. b. Million liters. c. Million Ghana Cedis.

Table 4.4 Economic Cost of LPG Price Subsidies in Ghana

Year	Subsidy [a]	Quantity Consumed [b]	Deadweight Loss [c]
2009	0.16	220.60	2.38
2010	0.36	177.19	8.15
2011	0.66	214.43	25.72
2012	0.74	268.49	32.39
2013	0.24	251.76	2.11
2014	0.07	237.25	0.13
Average	*0.37*	*228.29*	*11.81*

a. Ghana Cedis per kilogram. b. Million liters. c. Million Ghana Cedis.

4.3 General Equilibrium Method

Using the three general equilibrium formulas for estimating deadweight loss created by multiple fuel price subsidies in Scenarios 2 and 3 above, I calculate the economic cost of gasoline and diesel price subsidies in Ghana from 2009 to 2014. The results confirm that the approximation in Scenario 3 (simultaneous subsidies) is equal to the average of the two approximations in Scenario 2 (sequential subsidies). Hence, I show only one results (Scenario 3) in Table 4.5. The estimates show that accounting for cross-price effects under the general equilibrium approach reduces the cost of fuel price subsidies for gasoline and diesel almost by half. In particular, the total cost falls from GHS 26.38 million (US$ 15.40 million) to GHS 13.61 million (US$ 8.27 million) during 2009 to 2014, while the annual cost falls from GHS 4.40 million (US$ 2.57 million) to GHS 2.27 million (US$ 1.38 million).

Table 4.6 expresses the deadweight loss of the fuel price subsidy as a fraction of the government's total expenditure on fuel price subsidies. The ratio varies from a high of 2.81% in 2009 to a low of 0.19% in 2010. On average, the annual cost of the fuel price subsidy in Ghana is 0.8% of the subsidy expenditure.

Table 4.5 Economic Cost of Gasoline and Diesel Price Subsidies in Ghana

Year	Simple Method (mm GHS)	Gen. Equilibrium Method (mm GHS)	Ratio	Gen. Equilibrium Method (mm US$)
2009	4.51	4.47	0.99	3.17
2010	0.30	0.14	0.46	0.10
2011	3.39	1.42	0.42	0.94
2012	15.51	6.42	0.41	3.58
2013	1.14	0.54	0.47	0.28
2014	1.53	0.62	0.41	0.21
Average	*4.40*	*2.27*	*0.53*	*1.38*

Figures in million GHS and million US$.
Simple Method is from Tables 4.1 and 4.2.
General Equilibrium Method is Scenario 3.

Table 4.6 Economic Cost of Gasoline and Diesel Price Subsidies in Ghana

Year	Subsidy Cost (million GHS)	Subsidy Expenditure (million GHS)	Ratio
2009	4.47	159.00	2.81%
2010	0.14	72.14	0.19%
2011	1.42	298.42	0.48%
2012	6.42	744.52	0.86%
2013	0.54	217.84	0.25%
2014	0.62	327.91	0.19%
Average	*2.27*	*303.31*	*0.80%*

4.4 Sensitivity Analysis

To help understand the sensitivity of the deadweight loss created by the fuel price subsidy in Ghana to the assumed demand elasticities, Tables 4.7 and 4.8 show estimates of deadweight loss with different elasticities. I increase my own-price and cross-price elasticity estimates for gasoline (-0.34, 0.19) and diesel (-0.22, 0.14) by 50% in Table 4.7 and 100% in Table 4.8. The results below show that an increase in the size of the elasticities results in a proportional increase in the size of the deadweight loss. That is, my main estimate imply that the average cost of gasoline and diesel price subsidies is GHS 2.27 million (Table 4.6). The average cost increases by 50% to GHS 3.40 million (Table 4.7) and 100% to GHS 4.54 million (Table 4.8) when I increase the elasticity estimates by 50% and 100%, respectively.

Table 4.7 Economic Cost of Gasoline and Diesel Price Subsidies in Ghana

Year	Subsidy Cost (million GHS)	Subsidy Expenditure (million GHS)	Ratio
2009	6.70	159.00	4.21%
2010	0.21	72.14	0.29%
2011	2.13	298.42	0.71%
2012	9.64	744.52	1.29%
2013	0.81	217.84	0.37%
2014	0.93	327.91	0.28%
Average	*3.40*	*303.31*	*1.19%*

General Equilibrium Method is Scenario 3.
Own-price and cross-price elasticities for gasoline (-0.51, 0.29) and diesel (-0.33, 0.21).

Table 4.8 Economic Cost of Gasoline and Diesel Price Subsidies in Ghana

Year	Subsidy Cost (million GHS)	Subsidy Expenditure (million GHS)	Ratio
2009	8.93	159.00	5.62%
2010	0.28	72.14	0.38%
2011	2.84	298.42	0.95%
2012	12.85	744.52	1.73%
2013	1.08	217.84	0.50%
2014	1.24	327.91	0.38%
Average	*4.54*	*303.31*	*1.59%*

General Equilibrium Method is Scenario 3.
Own-price and cross-price elasticities for gasoline (-0.68, 0.38) and diesel (-0.44, 0.28).

CHAPTER 5 - CONCLUSION

I adapt the Harberger triangle for excess burden to approximate the size of the deadweight loss associated with fuel price subsidies for gasoline and diesel in Ghana from 2009 to 2014. I find that the deadweight loss (efficiency or economic cost) from energy subsidies are quite small due to inelastic energy demand. I also find that naively ignoring cross-price effects between energy markets nearly doubles the size of the deadweight loss associated with gasoline and diesel price subsidies in Ghana, all else equal. My preferred estimates imply, on average, that for every Ghana Cedi of government revenue spent on gasoline and diesel price subsidies, an efficiency cost of 0.8% is created. These findings indicate that subsidy reforms would be better motivated by their poor targeting of poor households and impact on debt-financing, rather than their efficiency losses.

Although my estimates for gasoline and diesel demand elasticities are not statistically significant, they are consistent with other estimates in the literature. In the future, it would be worthwhile to estimate the own-price and cross-price elasticities for all fuel types in Ghana. Such estimates are vital since they will help expand the general equilibrium analysis and estimation of deadweight loss to include other fuels, such as LPG, which is increasingly used as a transportation fuel in Ghana.

APPENDICES

Appendix 1 - Deadweight Loss Formula

Following Davis (2013), I can estimate the deadweight loss using a constant price elasticity demand function, $Q = \beta P^{\alpha}$. Q is the quantity of fuel consumed, P is the price of fuel, and α is the long-run price elasticity of demand, and β is a scale parameter. Deadweight loss (DWL) associated with a fuel price subsidy can be approximated as:

$$DWL \approx Q_2(P_1 - P_2) - \int_{P_2}^{P_1} \beta p^{\alpha} \, dp$$

$$\mathrm{DWL} \approx Q_2(P_1 - P_2) - \frac{\beta}{(1+\alpha)}(P_1^{1+\alpha} - P_2^{1+\alpha})$$

Appendix 2 - Proof of Deadweight Loss Formula

$$DWL_{(G\&D)} = \frac{1}{2}\left[DWL_{(G\ 1st,\ \ D\ 2nd)} + DWL_{(D\ 1st,\ \ G\ 2nd)}\right]$$

$$DWL_{(G\&D)} = \frac{1}{2}\left[\frac{1}{2}\,S_g^2\,\frac{\partial X_g}{\partial S_g} + \frac{1}{2}\,S_d^2\,\frac{\partial X_d}{\partial S_d} + S_g S_d\,\frac{\partial X_g}{\partial S_d}\right]$$

$$+\frac{1}{2}\left[\frac{1}{2}\,S_d^2\,\frac{\partial X_d}{\partial S_d} + \frac{1}{2}\,S_g^2\,\frac{\partial X_g}{\partial S_g} + S_d S_g\,\frac{\partial X_d}{\partial S_g}\right]$$

$$DWL_{(G\&D)} = \left[\frac{1}{4}\,S_g^2\,\frac{\partial X_g}{\partial S_g} + \frac{1}{4}\,S_d^2\,\frac{\partial X_d}{\partial S_d} + \frac{1}{2}\,S_g S_d\,\frac{\partial X_g}{\partial S_d}\right]$$

$$+\left[\frac{1}{4}\,S_d^2\,\frac{\partial X_d}{\partial S_d} + \frac{1}{4}\,S_g^2\,\frac{\partial X_g}{\partial S_g} + \frac{1}{2}\,S_d S_g\,\frac{\partial X_d}{\partial S_g}\right]$$

$$DWL_{(G\&D)} = (2)\frac{1}{4}\,S_g^2\,\frac{\partial X_g}{\partial S_g} + \frac{1}{2}\,S_g S_d\,\frac{\partial X_g}{\partial S_d} + (2)\frac{1}{4}\,S_d^2\,\frac{\partial X_d}{\partial S_d} + \frac{1}{2}\,S_d S_g\,\frac{\partial X_d}{\partial S_g}$$

$$DWL_{(G\&D)} \approx \frac{1}{2}\,S_g\left[S_g\frac{\partial X_g}{\partial S_g} + S_d\frac{\partial X_g}{\partial S_d}\right] + \frac{1}{2}\,S_d\left[S_d\frac{\partial X_d}{\partial S_d} + S_g\frac{\partial X_d}{\partial S_g}\right]$$

Appendix 3 - Countries and Summary Statistics

Table 3.5 African Countries by Region

Northern	Western	Eastern	Southern	Central
Algeria	Benin	Eritrea	Botswana	Angola
Egypt	Côte d'Ivoire	Ethiopia	Namibia	Cameroon
Libya	Ghana	Kenya	South Africa	Congo
Morocco	Nigeria	Mozambique		Congo, DR
Sudan	Senegal	Tanzania		Gabon
Tunisia	Togo	Zambia		
		Zimbabwe		

Table 3.6 Summary Statistics of Variables

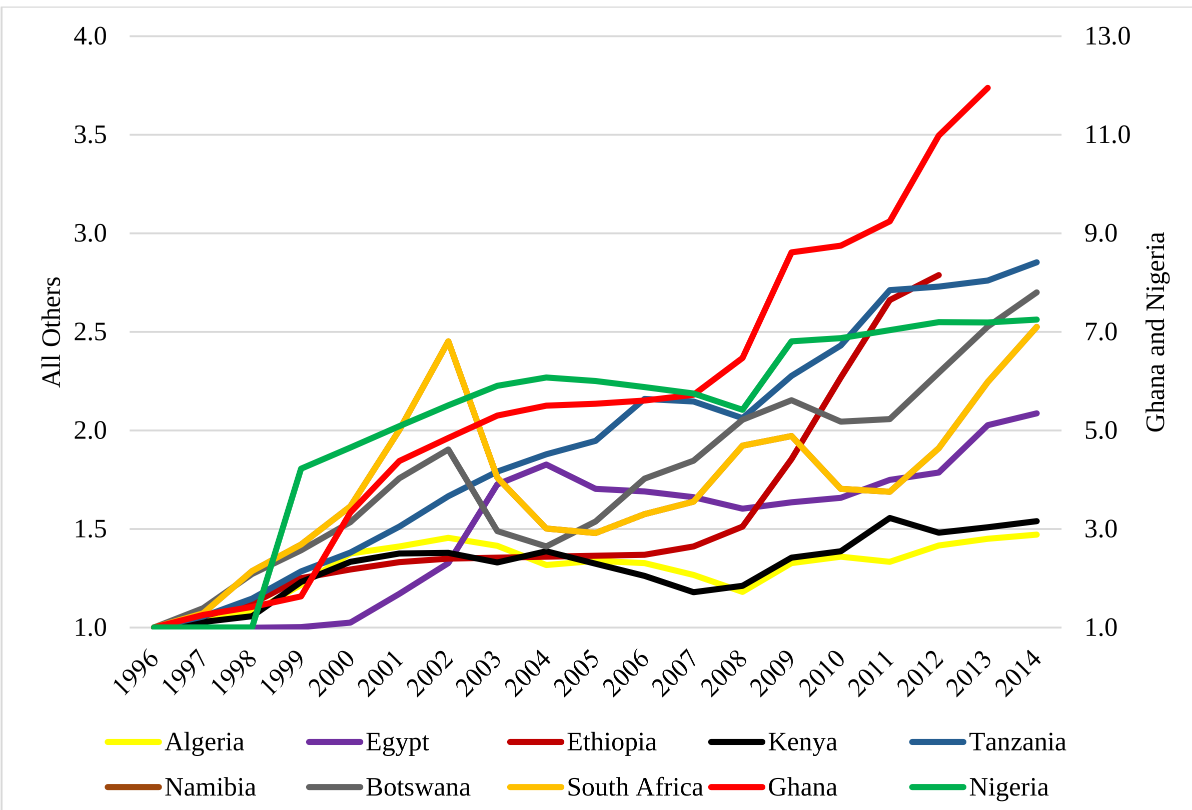
Variables	Obs.	Mean	Std. Dev.	Min.	Max.
Gasoline consumption [1]	188	985.35	1898.03	5.00	8155.00
Diesel consumption [1]	188	1041.21	1582.12	11.00	6557.00
Real price of gasoline [2]	183	0.67	0.39	0.02	2.28
Average real price of gasoline in three neighboring countries [2]	189	0.59	0.27	0.16	1.37
Real price of diesel [2]	183	0.55	0.34	0.02	1.43
Average real price of diesel in three neighboring countries [2]	189	0.50	0.27	0.12	1.20
Real GDP (Billion 2005 US$)	184	32.19	52.45	0.57	348.39

1. Kilotons of oil equivalent. 2. 2010 US$ per liter.

Appendix 4 - Exchange Rates

The graph below exhibits an upward trend in exchange rates in local currency to US$ for ten African countries. The graph shows that, for the period 1996 to 2014, the local currencies of the countries depreciated, on average, against the US$.

Figure 3.1 Exchange Rates in Selected African Countries



Note: Exchange rates have been indexed with 1996 as the base year (1.0).

Appendix 5 - Test for Endogeneity of Prices

Table 3.7 Description of Variables in Model

Variables	Description of variables
lngas	Log of gasoline consumption
lndiz	Log of diesel consumption
lnpg	Log of real price of gasoline
lnpgiv	Log of real average price of gasoline in neighboring countries
lnpd	Log of real price of diesel
lnpdiv	Log of real average price of diesel in neighboring countries
lngdp	Log of real GDP

To test the instrument relevance assumption for the instrument variable (IV) of average price in three neighboring countries, I run the following regressions. For each fuel, I run two regressions: (1) price against IV, and (2) price against all exogenous variables including the IV. The results of the regressions are shown in Figures 3.2 to 3.5 below, and indicate that the average price of fuel in neighboring countries is a statistically significant predictor of the price of diesel, but not so for the price of gasoline.

Figure 3.2 Instrument Relevance Test for Gasoline Price (1)

```
. xtreg lnpg lnpgiv _Iyear_* , i(cid) fe cluster(country)

Fixed-effects (within) regression               Number of obs      =       183
Group variable: cid                             Number of groups   =        27

R-sq:  within  = 0.5499                         Obs per group: min =         4
       between = 0.0030                                        avg =       6.8
       overall = 0.2017                                        max =         7

                                                F(7,26)            =     25.16
corr(u_i, Xb)  = -0.0403                        Prob > F           =    0.0000

                               (Std. Err. adjusted for 27 clusters in country)
------------------------------------------------------------------------------
             |               Robust
        lnpg |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
      lnpgiv |   .3650231   .1685603     2.17   0.040     .0185424    .7115038
  _Iyear_2002 |   .0156624   .0847396     0.18   0.855    -.1585223    .1898471
  _Iyear_2003 |  -.1034247    .111987    -0.92   0.364    -.3336172    .1267678
  _Iyear_2004 |   .2255327   .1294504     1.74   0.093    -.0405564    .4916219
  _Iyear_2005 |   .3275618   .1702893     1.92   0.065    -.0224729    .6775964
  _Iyear_2006 |   .4011091   .1809868     2.22   0.036     .0290854    .7731329
  _Iyear_2007 |   .4567951   .1804982     2.53   0.018     .0857756    .8278145
       _cons |  -.5784581   .2019015    -2.87   0.008    -.9934726   -.1634436
-------------+----------------------------------------------------------------
     sigma_u |  .56866858
     sigma_e |  .32923862
         rho |  .74895187   (fraction of variance due to u_i)
```

Figure 3.3 Instrument Relevance Test for Gasoline Price (2)

```
. xtreg lnpg lnpgiv lnpd lngdp _Iyear_* , i(cid) fe cluster(country)

Fixed-effects (within) regression               Number of obs      =       182
Group variable: cid                             Number of groups   =        27

R-sq:  within  = 0.9353                         Obs per group: min =         4
       between = 0.8716                                        avg =       6.7
       overall = 0.8919                                        max =         7

                                                F(9,26)            =     86.44
corr(u_i, Xb)  = -0.2331                        Prob > F           =    0.0000

                              (Std. Err. adjusted for 27 clusters in country)
------------------------------------------------------------------------------
             |               Robust
        lnpg |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
      lnpgiv |  -.0556608   .0671312    -0.83   0.415    -.1936509    .0823293
        lnpd |   .9234335   .0803681    11.49   0.000     .7582346    1.088632
       lngdp |  -.0071393   .0406071    -0.18   0.862    -.0906083    .0763297
 _Iyear_2002 |  -.0220596   .0212289    -1.04   0.308    -.0656962    .0215769
 _Iyear_2003 |   -.056955   .0262452    -2.17   0.039    -.1109029   -.0030072
 _Iyear_2004 |  -.0084007   .0337442    -0.25   0.805    -.0777629    .0609615
 _Iyear_2005 |  -.0028915     .05347    -0.05   0.957    -.1128007    .1070176
 _Iyear_2006 |  -.0609489   .0525133    -1.16   0.256    -.1688914    .0469937
 _Iyear_2007 |  -.0352356   .0627502    -0.56   0.579    -.1642204    .0937492
       _cons |   .1854215   .1447048     1.28   0.211    -.1120235    .4828665
-------------+----------------------------------------------------------------
     sigma_u |  .21242382
     sigma_e |  .12604443
         rho |  .73960141   (fraction of variance due to u_i)
------------------------------------------------------------------------------
```

Figure 3.4 Instrument Relevance Test for Diesel Price (1)

```
. xtreg lnpd lnpdiv _Iyear_* , i(cid) fe cluster(country)

Fixed-effects (within) regression               Number of obs      =       183
Group variable: cid                             Number of groups   =        27

R-sq:  within  = 0.6281                         Obs per group: min =         4
       between = 0.1422                                        avg =       6.8
       overall = 0.3152                                        max =         7

                                                F(7,26)            =     23.03
corr(u_i, Xb)  = 0.0370                         Prob > F           =    0.0000

                                 (Std. Err. adjusted for 27 clusters in country)
------------------------------------------------------------------------------
             |               Robust
        lnpd |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
      lnpdiv |    .497549   .1640819     3.03   0.005     .1602739    .8348242
  _Iyear_2002 |   .0336486   .0849458     0.40   0.695    -.1409599    .2082571
  _Iyear_2003 |  -.0614234   .1056537    -0.58   0.566    -.2785978    .1557509
  _Iyear_2004 |    .214377   .1174456     1.83   0.079    -.0270359    .4557898
  _Iyear_2005 |   .2855451   .1743181     1.64   0.113    -.0727709    .6438612
  _Iyear_2006 |   .3940862   .1900766     2.07   0.048     .0033781    .7847943
  _Iyear_2007 |   .4387063   .1906724     2.30   0.030     .0467736     .830639
       _cons |  -.6300679   .2318676    -2.72   0.012    -1.106679   -.1534572
-------------+----------------------------------------------------------------
     sigma_u |  .59378169
     sigma_e |  .32881937
         rho |  .76530836   (fraction of variance due to u_i)
------------------------------------------------------------------------------
```

Figure 3.5 Instrument Relevance Test for Diesel Price (2)

```
. xtreg lnpd lnpdiv lnpg lngdp _Iyear_* , i(cid) fe cluster(country)

Fixed-effects (within) regression               Number of obs      =       182
Group variable: cid                             Number of groups   =        27

R-sq:  within  = 0.9488                         Obs per group: min =         4
       between = 0.8540                                        avg =       6.7
       overall = 0.8806                                        max =         7

                                                F(9,26)            =    127.52
corr(u_i, Xb)  = 0.2507                         Prob > F           =    0.0000

                              (Std. Err. adjusted for 27 clusters in country)
------------------------------------------------------------------------------
             |               Robust
        lnpd |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
      lnpdiv |    .119714   .0635636     1.88   0.071    -.0109428    .2503709
        lnpg |   .8889504   .0595136    14.94   0.000     .7666184    1.011282
       lngdp |   .0769711   .0359481     2.14   0.042     .0030787    .1508636
 _Iyear_2002 |   .0318009   .0230349     1.38   0.179    -.0155481    .0791499
 _Iyear_2003 |   .0372935   .0224015     1.66   0.108    -.0087535    .0833405
 _Iyear_2004 |   .0279254   .0313856     0.89   0.382    -.0365886    .0924394
 _Iyear_2005 |   .0174267   .0582236     0.30   0.767    -.1022536    .1371069
 _Iyear_2006 |   .0689242   .0676306     1.02   0.318    -.0700925    .2079408
 _Iyear_2007 |   .0519026    .074129     0.70   0.490    -.1004718     .204277
       _cons |  -.4376912   .1228796    -3.56   0.001    -.6902738   -.1851085
-------------+----------------------------------------------------------------
     sigma_u |  .26281687
     sigma_e |  .12326225
         rho |  .81969559   (fraction of variance due to u_i)
------------------------------------------------------------------------------
```

For each model, I run 2SLS IV regressions with average fuel price in neighboring countries as instrument for local price. I then run the Durbin and Wu-Hausman procedures to test if gasoline and diesel prices are endogenous. The results below show that prices are not endogenous (i.e., I am unable to reject the null hypothesis that the prices are exogenous).

1. Test for Endogenous Gasoline Price in Gasoline Model

ivregress 2sls lngas lnpd lngdp _Iyear_* _Icountry_* (lnpg=lnpgiv), cluster(country)

estat endogenous

Tests of endogeneity

Ho: variables are exogenous

Robust regression F(1,26) = .185633 (p = 0.6701)

(Adjusted for 27 clusters in country)

2. Test for Endogenous Diesel Price in Gasoline Model

ivregress 2sls lngas lnpg lngdp _Iyear_* _Icountry_* (lnpd=lnpdiv), cluster(country)

estat endogenous

Tests of endogeneity

Ho: variables are exogenous

Robust regression F(1,26) = .101343 (p = 0.7528)

(Adjusted for 27 clusters in country)

3. Test for Endogenous Gasoline price in Diesel Model

ivregress 2sls lndiz lnpd lngdp _Iyear_* _Icountry_* (lnpg=lnpgiv), cluster(country)

estat endogenous

Tests of endogeneity

Ho: variables are exogenous

Robust regression F(1,26) = 1.35525 (p = 0.2549)

(Adjusted for 27 clusters in country)

4. Test for Endogenous Diesel Price in Diesel Model

ivregress 2sls lndiz lnpg lngdp _Iyear_* _Icountry_* (lnpd=lnpdiv), cluster(country)

estat endogenous

Tests of endogeneity

Ho: variables are exogenous

Robust regression F(1,26) = 1.09551 (p = 0.3049)

(Adjusted for 27 clusters in country)

Appendix 6 - Tests for Heteroskedasticity and Autocorrelation

1. Test for Heteroskedasticity in Gasoline Model

reg lngas lnpg lnpd lngdp _Iyear_* _Icountry_*

hettest

Breusch-Pagan / Cook-Weisberg test for heteroskedasticity

Ho: Constant variance

Variables: fitted values of lngas

chi2(1) = 20.55

Prob > chi2 = 0.0000

2. Test for Heteroskedasticity in Diesel Model

reg lndiz lnpg lnpd lngdp _Iyear_* _Icountry_*

hettest

Breusch-Pagan / Cook-Weisberg test for heteroskedasticity

Ho: Constant variance

Variables: fitted values of lndiz

chi2(1) = 27.00

Prob > chi2 = 0.0000

<u>3. Test for first-order Autocorrelation in Gasoline Model</u>

xtserial lngas lnpg lnpd lngdp _Iyear_* _Icountry_*

Wooldridge test for autocorrelation in panel data

H0: no first-order autocorrelation

F(1, 26) = 5.570

Prob > F = 0.0261

<u>4. Test for first-order Autocorrelation in Diesel Model</u>

xtserial lndiz lnpg lnpd lngdp _Iyear_* _Icountry_*

Wooldridge test for autocorrelation in panel data

H0: no first-order autocorrelation

F(1, 26) = 35.057

Prob > F = 0.0000

Appendix 7 - Stata Outputs for Model Estimation

Figure 3.6 Fixed Effects Results for Gasoline Model (1)

xtreg lngas lnpg lnpd lngdp _Iyear_* , i(cid) fe cluster(country)

```
. xtreg lngas lnpg lnpd lngdp _Iyear_* , i(cid) fe cluster(country)

Fixed-effects (within) regression               Number of obs      =       181
Group variable: cid                             Number of groups   =        27

R-sq:  within  = 0.5147                         Obs per group: min =         4
       between = 0.8340                                        avg =       6.7
       overall = 0.7837                                        max =         7

                                                F(9,26)            =      8.14
corr(u_i, Xb)  = 0.7317                         Prob > F           =    0.0000

                              (Std. Err. adjusted for 27 clusters in country)
------------------------------------------------------------------------------
             |               Robust
       lngas |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
        lnpg |  -.3424084   .3618941    -0.95   0.353    -1.086292    .4014755
        lnpd |   .1899513   .2832068     0.67   0.508    -.3921886    .7720912
       lngdp |   .4387981    .084218     5.21   0.000     .2656855    .6119107
 _Iyear_2002 |   .0690197   .0632078     1.09   0.285    -.0609059    .1989453
 _Iyear_2003 |   .1401488   .0611587     2.29   0.030     .0144354    .2658622
 _Iyear_2004 |   .0979615   .0861655     1.14   0.266    -.0791543    .2750772
 _Iyear_2005 |   .0192903   .1069395     0.18   0.858    -.2005269    .2391076
 _Iyear_2006 |   .0299895   .1290707     0.23   0.818    -.2353192    .2952982
 _Iyear_2007 |   .1623786   .1406139     1.15   0.259    -.1266573    .4514146
       _cons |   4.465983   .2429382    18.38   0.000     3.966616    4.965349
-------------+----------------------------------------------------------------
     sigma_u |  .99625697
     sigma_e |  .23793543
         rho |  .94603847   (fraction of variance due to u_i)
------------------------------------------------------------------------------
```

Figure 3.7 Fixed Effects Results for Diesel Model (1)

xtreg lndiz lnpg lnpd lngdp _Iyear_* , i(cid) fe cluster(country)

```
. xtreg lndiz lnpg lnpd lngdp _Iyear_* , i(cid) fe cluster(country)

Fixed-effects (within) regression               Number of obs      =       181
Group variable: cid                             Number of groups   =        27

R-sq:  within  = 0.3676                         Obs per group: min =         4
       between = 0.8564                                        avg =       6.7
       overall = 0.6067                                        max =         7

                                                F(9,26)            =      7.62
corr(u_i, Xb)  = 0.6599                         Prob > F           =    0.0000

                              (Std. Err. adjusted for 27 clusters in country)
------------------------------------------------------------------------------
             |               Robust
       lndiz |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
        lnpg |   .1357205   .4972459     0.27   0.787    -.8863831    1.157824
        lnpd |  -.2204741   .4623017    -0.48   0.637    -1.170749    .7298007
       lngdp |   .1925496   .1490707     1.29   0.208    -.1138695    .4989688
 _Iyear_2002 |   .2859532   .1306411     2.19   0.038     .0174165    .5544898
 _Iyear_2003 |   .3685589   .1191474     3.09   0.005      .123648    .6134698
 _Iyear_2004 |   .4622945   .1575288     2.93   0.007     .1384894    .7860995
 _Iyear_2005 |   .4997443   .1962031     2.55   0.017      .096443    .9030456
 _Iyear_2006 |   .5646392   .2484952     2.27   0.032       .05385    1.075428
 _Iyear_2007 |   .6761595   .2425808     2.79   0.010     .1775275    1.174791
       _cons |   5.073305   .3800106    13.35   0.000     4.292182    5.854428
-------------+----------------------------------------------------------------
     sigma_u |  1.0583681
     sigma_e |  .35040709
         rho |  .90121301   (fraction of variance due to u_i)
------------------------------------------------------------------------------
```

Figure 3.8 First Difference Results for Gasoline Model (1)

reg D.lngas D.lnpg D.lnpd D.lngdp _Iyear_* , cluster(country)

```
. reg D.lngas D.lnpg D.lnpd D.lngdp _Iyear_* ,  cluster(country)
note: _Iyear_2003 omitted because of collinearity

Linear regression                                      Number of obs =     153
                                                       F(  8,    26) =    1.67
                                                       Prob > F      =  0.1525
                                                       R-squared     =  0.1050
                                                       Root MSE      =  .22548

                              (Std. Err. adjusted for 27 clusters in country)
```

D.lngas	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
lnpg						
D1.	-.1300445	.1505804	-0.86	0.396	-.4395671	.179478
lnpd						
D1.	.0779377	.1236345	0.63	0.534	-.1761966	.3320719
lngdp						
D1.	.1579106	.0762684	2.07	0.048	.0011387	.3146825
_Iyear_2002	-.068993	.075418	-0.91	0.369	-.2240169	.0860309
_Iyear_2003	0	(omitted)				
_Iyear_2004	-.1098557	.087635	-1.25	0.221	-.289992	.0702805
_Iyear_2005	-.126701	.066222	-1.91	0.067	-.2628223	.0094203
_Iyear_2006	-.0304564	.0583436	-0.52	0.606	-.1503834	.0894705
_Iyear_2007	.0337211	.0625198	0.54	0.594	-.0947901	.1622324
_cons	.1144547	.0389608	2.94	0.007	.0343696	.1945398

Figure 3.9 First Difference Results for Diesel Model (1)

reg D.lndiz D.lnpg D.lnpd D.lngdp _Iyear_* , cluster(country)

```
. reg D.lndiz D.lnpg D.lnpd D.lngdp _Iyear_* ,  cluster(country)
note: _Iyear_2003 omitted because of collinearity

Linear regression                                      Number of obs =     153
                                                       F(  8,    26) =    0.68
                                                       Prob > F      =  0.7028
                                                       R-squared     =  0.0898
                                                       Root MSE      =   .3132

                              (Std. Err. adjusted for 27 clusters in country)
```

D.lndiz	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
lnpg						
D1.	-.1135039	.1337915	-0.85	0.404	-.3885163	.1615085
lnpd						
D1.	.0508155	.1205385	0.42	0.677	-.1969549	.298586
lngdp						
D1.	-.1694234	.2584477	-0.66	0.518	-.7006702	.3618233
_Iyear_2002	.1620487	.1050307	1.54	0.135	-.0538451	.3779424
_Iyear_2003	0	(omitted)				
_Iyear_2004	.0997323	.0878691	1.14	0.267	-.0808853	.2803499
_Iyear_2005	.0292752	.0631494	0.46	0.647	-.1005302	.1590807
_Iyear_2006	.0347664	.0834384	0.42	0.680	-.1367438	.2062766
_Iyear_2007	.0276808	.0743577	0.37	0.713	-.1251636	.1805252
_cons	.1030549	.0668659	1.54	0.135	-.0343899	.2404997

Figure 3.10 Fixed Effects Results for Gasoline Model (2)

xtreg lngas lnpg l.lnpg lnpd l.lnpd lngdp l.lngdp _Iyear_* , i(cid) fe cluster(country)

```
. xtreg lngas lnpg l.lnpg lnpd l.lnpd lngdp l.lngdp _Iyear_* , i(cid) fe cluster(country)
note: _Iyear_2007 omitted because of collinearity

Fixed-effects (within) regression               Number of obs      =       154
Group variable: cid                             Number of groups   =        27

R-sq:  within  = 0.5118                         Obs per group: min =         3
       between = 0.8412                                        avg =       5.7
       overall = 0.8128                                        max =         6

                                                F(11,26)           =     10.97
corr(u_i, Xb)  = 0.7366                         Prob > F           =    0.0000

                               (Std. Err. adjusted for 27 clusters in country)
------------------------------------------------------------------------------
             |               Robust
       lngas |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
        lnpg |
         --. |  -.2387444   .3409392    -0.70   0.490    -.9395551    .4620662
         L1. |  -.1462063   .2391606    -0.61   0.546    -.6378079    .3453953
             |
        lnpd |
         --. |   .1038813   .2614929     0.40   0.694     -.433625    .6413877
         L1. |   .0500093   .2114166     0.24   0.815    -.3845638    .4845824
             |
       lngdp |
         --. |    .244214   .0809171     3.02   0.006     .0778865    .4105415
         L1. |   .2396826   .0828907     2.89   0.008     .0692983     .410067
             |
 _Iyear_2002 |  -.1385544   .1251473    -1.11   0.278    -.3957984    .1186895
 _Iyear_2003 |  -.0362152   .1125989    -0.32   0.750    -.2676655    .1952351
 _Iyear_2004 |  -.0521881   .0793487    -0.66   0.517    -.2152917    .1109155
 _Iyear_2005 |  -.1096767   .0555353    -1.97   0.059    -.2238312    .0044777
 _Iyear_2006 |  -.0962959   .0315238    -3.05   0.005    -.1610941   -.0314978
 _Iyear_2007 |          0  (omitted)
       _cons |   4.478516   .2956018    15.15   0.000     3.870898    5.086134
-------------+----------------------------------------------------------------
     sigma_u |  .94065404
     sigma_e |   .2225291
         rho |   .9470014   (fraction of variance due to u_i)
```

Figure 3.11 Fixed Effects Results for Diesel Model (2)

xtreg lndiz lnpg l.lnpg lnpd l.lnpd lngdp l.lngdp _Iyear_* , i(cid) fe cluster(country)

```
. xtreg lndiz lnpg l.lnpg lnpd l.lnpd lngdp l.lngdp _Iyear_* , i(cid) fe cluster(country)
note: _Iyear_2007 omitted because of collinearity

Fixed-effects (within) regression               Number of obs      =       154
Group variable: cid                             Number of groups   =        27

R-sq:  within  = 0.3366                         Obs per group: min =         3
       between = 0.8510                                        avg =       5.7
       overall = 0.7843                                        max =         6

                                                F(11,26)           =      4.88
corr(u_i, Xb)  = 0.7788                         Prob > F           =    0.0004

                               (Std. Err. adjusted for 27 clusters in country)
------------------------------------------------------------------------------
             |               Robust
       lndiz |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
        lnpg |
         --. |  -.0099903   .3652419    -0.03   0.978    -.7607559    .7407752
         L1. |    .100313   .4837935     0.21   0.837    -.8941389    1.094765
             |
        lnpd |
         --. |  -.1144984   .3282244    -0.35   0.730    -.7891734    .5601765
         L1. |  -.1419619   .5310556    -0.27   0.791    -1.233562    .9496386
             |
       lngdp |
         --. |   .2221113   .1131637     1.96   0.060       -.0105    .4547226
         L1. |    .083945   .0948228     0.89   0.384    -.1109661    .2788561
             |
 _Iyear_2002 |  -.3305579   .1548259    -2.14   0.042    -.6488071   -.0123087
 _Iyear_2003 |  -.2854155   .1526087    -1.87   0.073    -.5991073    .0282762
 _Iyear_2004 |  -.1609511   .1229771    -1.31   0.202    -.4137342     .091832
 _Iyear_2005 |  -.1398841   .0707434    -1.98   0.059    -.2852993    .0055311
 _Iyear_2006 |  -.1008843   .0431498    -2.34   0.027    -.1895801   -.0121886
 _Iyear_2007 |          0  (omitted)
       _cons |    5.37789   .5108279    10.53   0.000     4.327868    6.427911
-------------+----------------------------------------------------------------
     sigma_u |  .91375565
     sigma_e |  .29273614
         rho |    .906919   (fraction of variance due to u_i)
```

Figure 3.12 First Difference Results for Gasoline Model (2)

reg D.lngas D.lnpg D.L.lnpg D.lnpd D.L.lnpd D.lngdp D.L.lngdp _Iyear_* , cluster(country)

```
. reg D.lngas D.lnpg D.L.lnpg  D.lnpd D.L.lnpd D.lngdp D.L.lngdp _Iyear_* , cluster(country)
note: _Iyear_2002 omitted because of collinearity
note: _Iyear_2005 omitted because of collinearity

Linear regression                                      Number of obs =     127
                                                       F( 10,     26) =    4.27
                                                       Prob > F      =  0.0014
                                                       R-squared     =  0.1751
                                                       Root MSE      =  .21181

                               (Std. Err. adjusted for 27 clusters in country)
------------------------------------------------------------------------------
             |               Robust
     D.lngas |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
        lnpg |
         D1. |  -.1503498   .2108682    -0.71   0.482    -.5837957     .283096
         LD. |  -.1349164   .1921129    -0.70   0.489    -.5298101    .2599772
             |
        lnpd |
         D1. |   .0997203   .1724703     0.58   0.568    -.2547975    .4542381
         LD. |   .0928117   .1718294     0.54   0.594    -.2603886     .446012
             |
       lngdp |
         D1. |   .1675643   .0585972     2.86   0.008     .0471161    .2880125
         LD. |   .1897767   .0657722     2.89   0.008       .05458    .3249734
             |
 _Iyear_2002 |          0  (omitted)
 _Iyear_2003 |   .1959233    .064565     3.03   0.005     .0632081    .3286385
 _Iyear_2004 |   .0311449   .0791865     0.39   0.697    -.1316253    .1939151
 _Iyear_2005 |          0  (omitted)
 _Iyear_2006 |   .0933233   .0654005     1.43   0.165    -.0411094    .2277561
 _Iyear_2007 |   .1614743   .0780811     2.07   0.049     .0009762    .3219723
       _cons |  -.0634827   .0649418    -0.98   0.337    -.1969726    .0700072
------------------------------------------------------------------------------
```

Figure 3.13 First Difference Results for Diesel Model (2)

reg D.lndiz D.lnpg D.L.lnpg D.lnpd D.L.lnpd D.lngdp D.L.lngdp _Iyear_* , cluster(country)

```
. reg D.lndiz D.lnpg D.L.lnpg  D.lnpd D.L.lnpd D.lngdp D.L.lngdp _Iyear_* , cluster(country)
note: _Iyear_2002 omitted because of collinearity
note: _Iyear_2005 omitted because of collinearity

Linear regression                                      Number of obs =     127
                                                       F( 10,     26) =    4.30
                                                       Prob > F      =  0.0013
                                                       R-squared     =  0.0525
                                                       Root MSE      =  .25739

                                  (Std. Err. adjusted for 27 clusters in country)
```

D.lndiz	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
lnpg						
D1.	-.0948609	.2017194	-0.47	0.642	-.509501	.3197791
LD.	.0822419	.3203738	0.26	0.799	-.576296	.7407798
lnpd						
D1.	.0368235	.1629853	0.23	0.823	-.2981975	.3718446
LD.	-.0282785	.3202435	-0.09	0.930	-.6865483	.6299914
lngdp						
D1.	.1587765	.089478	1.77	0.088	-.0251482	.3427011
LD.	-.0141965	.0918107	-0.15	0.878	-.2029161	.174523
_Iyear_2002	0	(omitted)				
_Iyear_2003	.0531084	.0634519	0.84	0.410	-.0773189	.1835356
_Iyear_2004	.0898741	.0484029	1.86	0.075	-.0096193	.1893676
_Iyear_2005	0	(omitted)				
_Iyear_2006	.0337296	.0638957	0.53	0.602	-.0976098	.165069
_Iyear_2007	.0777774	.0649244	1.20	0.242	-.0556767	.2112315
_cons	.0130548	.047353	0.28	0.785	-.0842806	.1103902

Appendix 8 - Test for the Significance of Long-Run Coefficients

A. Test for Significance of Long-run Fixed Effects Coefficients for Gasoline Model (2)

xtreg lngas lnpg l.lnpg lnpd l.lnpd lngdp l.lngdp _Iyear_* , i(cid) fe cluster(country)

1. Long-run own-price coefficient:

test lnpg+l.lnpg=0

(1) lnpg + L.lnpg = 0

F(1, 26) = 0.49

Prob > F = 0.4922

2. Long-run cross-price coefficient:

test lnpd+l.lnpd=0

(1) lnpd + L.lnpd = 0

F(1, 26) = 0.12

Prob > F = 0.7280

3. Long-run income coefficient:

test lngdp+l.lngdp=0

(1) lngdp + L.lngdp = 0

F(1, 26) = 27.05

Prob > F = 0.0000

B. Test for Significance of Long-run Fixed Effects Coefficients for Diesel Model (2)

```
xtreg lndiz lnpg l.lnpg lnpd l.lnpd lngdp l.lngdp _Iyear_* , i(cid) fe cluster(country)
```

4. Long-run cross-price coefficient:

```
test lnpg+l.lnpg=0

 ( 1)  lnpg + L.lnpg = 0

       F(  1,    26) =    0.01

            Prob > F =    0.9123
```

5. Long-run own-price coefficient:

```
test lnpd+l.lnpd=0

( 1)  lnpd + L.lnpd = 0

       F(  1,    26) =    0.10

            Prob > F =    0.7572
```

6. Long-run income coefficient:

```
test lngdp+l.lngdp=0

 ( 1)  lngdp + L.lngdp = 0

       F(  1,    26) =    5.05

            Prob > F =    0.0334
```

C. Test for Significance of Long-run First Difference Coefficients for Gasoline Model (2)

reg D.lngas D.lnpg D.L.lnpg D.lnpd D.L.lnpd D.lngdp D.L.lngdp _Iyear_* , cluster(country)

7. Long-run own-price coefficient:

test d.lnpg+d.l.lnpg=0

(1) D.lnpg + LD.lnpg = 0

F(1,   26) =   0.54

Prob > F =   0.4679

8. Long-run cross-price coefficient:

test d.lnpd+d.l.lnpd=0

(1) D.lnpd + LD.lnpd = 0

F(1,   26) =   0.34

Prob > F =   0.5642

9. Long-run income coefficient:

test d.lngdp+d.l.lngdp=0

(1) D.lngdp + LD.lngdp = 0

F(1,   26) =   20.02

Prob > F =   0.0001

D. Test for Significance of Long-run First Difference Coefficients for Diesel Model (2)

reg D.lndiz D.lnpg D.L.lnpg D.lnpd D.L.lnpd D.lngdp D.L.lngdp _Iyear_* , cluster(country)

10. Long-run cross-price coefficient:

test d.lnpg+d.l.lnpg=0

(1) D.lnpg + LD.lnpg = 0

F(1,   26) =   0.00

Prob > F =   0.9797

11. Long-run own-price coefficient:

test d.lnpd+d.l.lnpd=0

(1) D.lnpd + LD.lnpd = 0

F(1,   26) =   0.00

Prob > F =   0.9850

12. Long-run income coefficient:

test d.lngdp+d.l.lngdp=0

(1) D.lngdp + LD.lngdp = 0

F(1,   26) =   1.35

Prob > F =   0.2560

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