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Ackah, Ishmael

University of Portsmouth, UK

26 September 2014

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Ishmael Ackah

PhD Student, Department of Economics, Portsmouth Business School, University of Portsmouth, Winston Churchill Avenue PO1 2UP, UK. Email: ackish85@yahoo.com

Abstract

The study investigates the effect of economic and non-economic factors on natural gas demand in Ghana at the aggregate and disaggregates levels. The structural time series model is employed as it has the ability of capturing exogenous non-economic factors. The findings suggest that both economic and non-economic factors influence natural gas demand. It further reveal that different sectors respond differently to these factors. The study recommends that policies such as natural gas price subsidies should be customised for different sectors to obtain optimal results.

1. Background

Due to supply security and environmental concerns, global natural gas demand is increasing at a rate above average primary energy demand (Ruester and Neumann, 2008). The increase in global natural gas consumption has been attributed to many factors. Firstly, gas is cleaner than coal to burn and cheaper than petroleum. For instance, natural gas possesses some attractive characteristics like the limited carbon emissions, operational flexibility and efficiency (Akkurt *et al*., 2010). Moreover, natural gas is the cleanest and most hydrogen-rich of all the hydrocarbon energy sources, and it has high energy conversion efficiencies for power generation (Economides and Wood, 2009).

Figure 1 shows that, global consumption of natural gas has increased from 1729 million tons of oil equivalent to 2653 million tons of oil equivalent (BP, 2010).

The global demand for natural gas is in the process of dramatic changes, such as the globalisation of the gas market (Huntington, 2009), rising shares of LNG trade and spot contracts (IEA, 2008) and the increase in the in the prospect of unconventional gas supply. The increase in the demand may be driven by many other factors. In Bangladesh, the Government is encouraging the use of compressed natural gas as a transportation fuel (Wadud *et al*., 2011). In other cases, the demand has been due to advances in technology such as the use of gas fired combined cycle gas turbine power plants for electricity generation.

Natural gas consumption has grown substantially in recent years in Africa, stimulated by increased economic activity, large investments in new infrastructure and domestic price

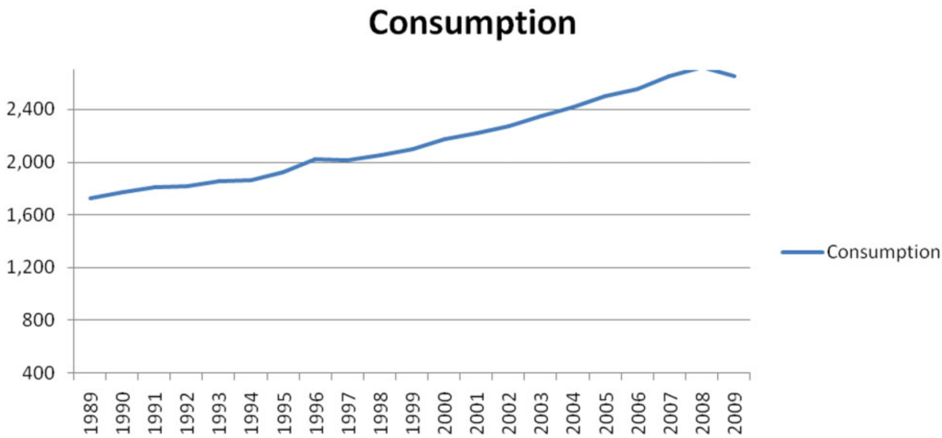

Figure 1 Global natural gas consumption.
Source: BP, 2010

subsidies (Eggoh *et al*., 2011). Ghana uses natural gas mainly as a fuel for cooking, transport and industry (Kemausuor *et al*., 2011). Ghana's forest cover has dwindled from 8.13 million hectares at the beginning of the last century to 1.6 million hectares today (Ghana Energy Commission, 2010). According to the UN Food and Agriculture Organization 2009, the rate of deforestation in Ghana is 3 per cent per year. In order to solve the deforestation problem, the government of Ghana launched a National LPG programme in 1990 to encourage the use of LPG as an alternative to charcoal and firewood for cooking to reduce deforestation and help to achieve the climate change goal of the Government (UNDP, 2004). The policy among other things supported natural gas consumption through price subsidies that encouraged households to buy. Again, the opening of the natural gas and cylinder distribution and retail markets to the private sector helped industry and households in rural areas especially to have access to gas. Finally, the use of gas in power production especially by the Asogli power plant boosted natural gas consumption. This policy led to an exponential increase in the demand for natural gas. **Figure 2** shows that, the total final consumption of natural gas in Ghana was 6 Ktoe in 1989. However, the final natural gas consumption in 2009 was 221 Ktoe. This has been driven by both residential demand and industry demand. For instance, natural gas consumption in Ghana's industry sector has increased by 52.6 per cent per annum from 1989 to 2009. Figure 2 shows the natural gas demand at the aggregate level, residential sector and the industrial sector of Ghana between 1989 and 2009.

For regions such as sub-Saharan Africa, the investments necessary to produce the required increase in all forms of commercial energy are major compared with traditional

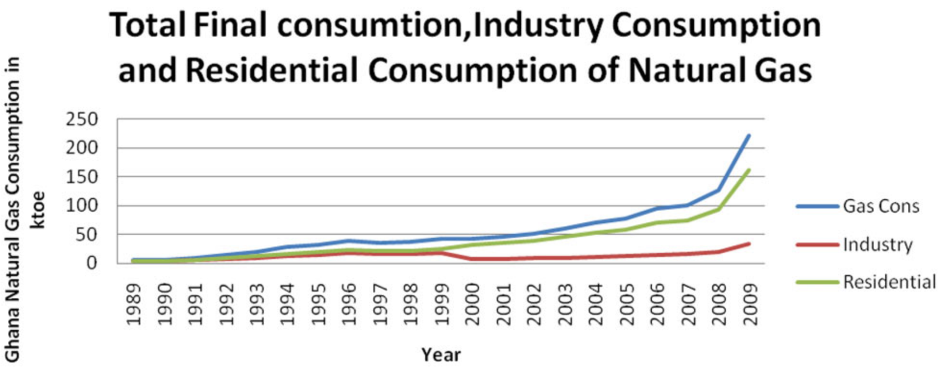

Figure 2 Natural gas consumption in Ghana.
Source: IEA, 2011

gross capital formation in society and net capital inflows (De Vita *et al*., 2006). Over-investments in energy infrastructure and investments made long before they are needed, represent costly drains on scarce resources under-investments, or investments made too late, can also carry significant economic costs. With a significant potential for energy demand growth in the developing world, but an equally great uncertainty over the time and magnitude of this growth, providing information that may decrease this uncertainty should prove valuable to policy makers. Therefore, the knowledge of current demand patterns, the factors that affect demand and future possible trend demand will be a valuable asset for both planning and for investment decisions such as production, refinery and storage (Abdel-Aal, 2008).

Although, as far as is known, there is no study on gas demand and forecasting in Ghana, efforts have been made to model the demand for other sources of energy especially electricity. Previous attempts have been made to model aggregate electricity demand and investigate the long-run equilibrium relationship and short-run causal relationship between electricity consumption and economic growth in Ghana (Adom, 2011). Again, existing energy studies in Ghana concentrate only on the aggregate level or a specific sector and not both aggregate and the sectors. In addition, the overwhelming majority of studies that have tested for geographical-based differences in elasticities have found that consumers in different regions respond differently to changes in the determinants of natural gas demand (Dagher, 2012).This means that, elasticities of natural gas studies in other developing countries cannot be used as a proxy in Ghana.

Recently, Ghana started commercial oil production. The government has been exploring how the associated gas discovered with the oil will be developed and commercialised. Because these decisions require huge investments, knowledge of the natural gas market will help the natural gas policy design. The purpose of this study is to examine the effect of economic and non-economic factors to natural gas demand in Ghana. In addition, the Structural Time Series Model (STSM) and the Underlying Energy Demand Trend (UEDT), which have the advantage to capture the changes in ‘taste’, energy saving technical progress and efficiency (Hunt *et al*., 2003) have not been applied to energy studies in Ghana. In addition, due to long lead time and large amount of money needed to build natural gas facilities, identifying the factors that influence demand will be an added advantage.

2. Literature review

The oil price hikes of the 1970s and 1980s led to an increase in the number of energy demand studies, a trend that has been to some extent revitalised by the emergence of worries about the emissions of greenhouse gases from the combustion of fossil fuels. In addition, environmental concerns and concerns about possibility of oil peaking have intensified studies on natural gas demand. Therefore, various studies of natural gas demand have been undertaken using various estimation methods and have obtained different elasticities. The purpose of this section is to evaluate the methods that have been used to estimate natural gas demand and assess the application of econometric models to energy studies in Ghana. The Literature Review is divided into three sections. These are: studies on natural gas demand at the national, regional or global level, natural gas demand at the residential level, and industry level, and energy studies in Ghana. The focus of the literature is narrowed to studies based on the economic concept of natural gas demand instead of the technical qualities of natural gas such as transportation and storage.

2.1. Natural gas demand at the national level

The empirical literature on the relationship between natural gas consumption and economic factors at the aggregate level has employed a variety of econometric approaches. Liu (1983) analyses US aggregate as well as regional natural gas consumption across sectors over the period 1960–1978 using both ordinary least squares (OLS) and two-stage least squares. Liu finds that own price, income and a dummy variable for the oil embargo of the 1970s are statistically significant, whereas real electricity prices and oil prices are statistically insignificant. The own-price elasticity estimate is −0.490, and the income elasticity estimate is 0.553. However, it has been argued that the OLS suffers from the problem of multicollinearity (Vinod, 1978). Another shortcoming of their study was that it did not differentiate between the long-run and short-run price and income elasticities. This study seeks to overcome both shortcomings by employing the

STSM to estimate both the short-run and long-run price and income elasticities for natural gas demand in Ghana.

Estrada and Fugleberg (1989) adopted a model based on translog functions to investigate the price responsiveness of natural gas demand for West Germany and France and found estimated price elasticities varying between −0.75 and −0.82 for West Germany and from −0.61 to −0.76 for France. However, Blackorby *et al*. (1977), suggests that the translog does not provide a good approximation of a wide range of observations and are inflexible in providing second-order approximation. To overcome these weaknesses, Lu *et al*. (1979) suggest that the sample size is increased when using the translog functions. Again, an economic variable such as income was not considered in their study. This study considers the effect of income on natural gas demand in addition to price over a period of 20 years and included variables such as income, final household expenditure and industry variable added in addition to gas price to assess their impact on natural gas demand in Ghana.

Eltony (1996) explores the structure of the demand for natural gas in Kuwait using two econometric models: Partial Adjustment Model (PAM) and Error Correction Model (ECM). The results from PAM indicated that demand for natural gas is inelastic with respect to both price and income for both the short and long run. Based upon ECM, the estimates of short- and long-run price elasticities are −0.17 and −0.34, respectively, indicating an inelastic demand. The income elasticity of demand for ECM model is 0.45 in the short run and 0.82 in the long run, suggesting that the response of natural gas consumption to changes in income is higher in the long run than short run.

Most of the above studies have concentrated on the developed economies. In order to estimate natural gas demand from a developing economy, Wadud *et al*. (2011) develops a dynamic econometric model to understand the natural gas demand in Bangladesh, in the national level, the power and the industrial sectors. The demand model shows large long-run income elasticity around 1.5 for aggregate demand for natural gas but a short-run income elasticity of 0.33. Forecasts into the future also show a larger demand in the future than predicted by various national and multilateral organisations. Price response was statistically not different from zero, indicating that prices are possibly too low and that there is a large suppressed demand for natural gas in the country. For the power sector, the short-run income elasticity is 0.58, whereas the long-run income elasticity is 6.3. The estimated short and long-run income elasticities for the industrial sector is 0.76 and 1.76, respectively. **Table 1** shows a summary of natural gas demand elasticities.

This confirms Dagher's (2012) assertion that there are widely divergent estimates that the various surveys conducted to date have reported no firm consensus on price and income elasticities. This implies that there is a need to model natural gas demand in Ghana as using elasticity estimates from others studies for Ghana may not reflect the true picture.

Table 1 Summary of natural gas studies at the National level

Author	Short-run price elasticity	Long-run price elasticity	Short-run income elasticity	Long-run income elasticity
Taylor (1975)	0 to −0.38	0 to −3.85	0.01 to 1	−0.29 to 3.11
Bohi (1981)	0.09 to −0.50	0.33 to −2.42	−0.03 to 0.05	0.02 to 2.18
Eltony (1996)	−0.17	−0.34	0.45	0.82
Wadud *et al*. (2011)	Na	Na	Na	1.5

It can be deduced from the above literature summary that elasticities of various natural gas demand studies have been varied.

2.2. Residential and industry natural gas demand

The pioneering work of Houthakker (1951) on the British urban electricity consumption perhaps initiated the econometric investigation of residential energy demand in a formal way. Since then, and as with other applications, a wide variety of applications of the econometric approach to the residential sector has appeared in the literature. According to Bohi and Zimmerman (1984) and Madlener (1996), more studies have been done on this sector than any other area. Balestra and Nerlove (1966) pool annual data from 1950 to 1962 for 36 states to estimate a dynamic model of residential natural gas demand as a function of real natural gas prices, real per capita income and total population. The results indicate that time-invariant regional effects account for roughly 75 per cent of the total residual variance for residential natural gas demand, with the estimated long-run price and income elasticities of −0.63 and 0.62, respectively. However, this study did not consider the effect of energy-saving technical efficiency or the effect of other exogenous variables on natural gas demand. Such an omission may lead to misleading price and income elasticities.

Grady (1986) utilises pooled data from 1968 to 1978 for all 50 US states, grouped into five categories based on natural gas availability, to estimate residential natural gas demand using an error component model. The results indicate that only own price and heating degree days are statistically significant, whereas prices for electricity and fuel oil, income and the ratio of households using natural gas relative to total households are statistically insignificant. Moreover, Grady reports the average short-run and long-run own-price elasticity estimates across the five categories of states as −0.1 and −0.4, respectively.

Lin *et al*. (1987) examines the demand for residential natural gas for the four US census regions and the nine sub-census regions over the 1960–1983 period. Within a reduced-form dynamic model of residential natural gas demand, Lin *et al*. employ the error components seemingly unrelated regression procedure to find that, based on the average elasticity estimates across regions, the own-price elasticity estimate is −0.15 in the short run and −1.215 in the long run. The average income elasticity estimate is 0.11 in the short run and 0.57 in the long run. Furthermore, he found that the respective own price, income and cross price elasticity estimates and adjustment speeds to the desired level of residential natural gas consumption vary across regions.

Payne *et al*. (2011) estimates the demand for residential natural gas in the state of Illinois using an autoregressive distributed lag (ARDL) bounds testing approach based on annual data from 1970 to 2007. The ARDL bounds testing approach reveals a long-run equilibrium relationship between natural gas consumption per capita and real residential natural gas prices, real personal disposable income per capita, real residential electricity prices, real fuel oil prices and heating degree days. The short-run own-price elasticity is −0.26, whereas the short-run elasticity for heating degree is 0.63. In the long-run residential natural gas consumption is price inelastic, as a 1 per cent increase in real residential natural gas prices decreases residential natural gas consumption by 0.264 per cent. A 1 per cent increase in real residential electricity prices increases residential natural gas consumption by 0.123 per cent, whereas a 1 per cent increase in heating degree days increases residential natural gas consumption by 0.626 per cent. The results from the corresponding ECM indicate that only real residential natural gas prices and heating degree days are statistically significant. While the long-run elasticity estimates are larger than the short-run elasticity estimates, both the short-run and long-run elasticity estimates are less than one in absolute terms.

In conclusion, the above summary of residential and industrial natural gas demand studies suggest that there are varied elasticities of natural gas demand. In addition, efforts have not been made to capture energy-saving efficiency or the effect of other exogenous on natural gas demand studies in the residential and industrial sector. This studies attempts to model the effect of price, income, household final expenditure industrial value added (IVA) and 'exogenous factors' on the natural gas demand in Ghana.

2.3. Energy demand in Ghana and sub-Saharan Africa

There are few econometric studies on energy demand in Ghana. Most these studies are limited to the causality between electricity demand or energy demand and income.

Esso (2010) investigates the long run and the causality relationship between energy consumption and economic growth for seven sub-Saharan African countries during the period 1970–2007. Using the Gregory and Hansen (1996) testing approach to threshold cointegration, the findings suggest that energy consumption is cointegrated with economic growth in Cameroon, Cote d'Ivoire, Ghana, Nigeria and South Africa. Moreover, this test suggests that economic growth has a significant positive long-run impact on energy consumption in these countries before 1988, and this effect becomes negative after

1988 in Ghana and South Africa. The demand for energy in Ghana and South Africa is income inelastic in the long run. This may be due to the introduction of Structural Adjustment Programme in Ghana and the preparation of South Africa for their independence that were characterised by industrialisation and urbanisation. Furthermore, causality tests suggest bidirectional causality between energy consumption and real GDP in Cote d'Ivoire and unidirectional causality running from real GDP to energy usage in the case of Congo and Ghana. This study does not consider the effect of other economic factors. In addition, the finding is ambiguous as it is not known whether the cointegration between energy consumption and economic growth is in the short run, long run or both.

Adom (2011) estimates the electricity-economic growth nexus in Ghana and its implications for energy conservation measures and environmental policy. The Toda and Yomamoto Granger Causality test is used to carry out the test of causality between electricity consumption and economic growth from 1971 to 2008. The results obtained revealed that there exists a unidirectional causality running from economic growth to electricity consumption. Thus, data on Ghana support the growth-led-energy hypothesis. These findings differ from Esso's (2010) findings that suggest that economic growth has negative effect on energy consumption in Ghana after 1988. The differences may be due to the nature of data, estimation method and the time frame for the estimation. The results on the energy studies on Ghana are therefore not conclusive. Therefore, this study uses the STSM to assess the effect of income and other economic factors on natural gas demand in Ghana. **Table 2** shows the summary of findings on the relationship energy consumption and growth in Ghana and Africa.

Table 2 Summary of energy studies on Ghana and Sub-Saharan Africa

Author	Period	Country	Method	Causality Relationship
Adom (2011)	1971–2008	Ghana	Toda and Yomamoto Granger Causality test	$Y \rightarrow EC$
Twerefo *et al.* (2008)	1975–2006	Ghana	Vector error correction model granger causality	$Y \rightarrow EC$
Wolde-Rufael (2006)	1971–2001	Algeria, Congo, Egypt, Ghana, Ivory coast	Toda and Yomamoto granger causality test	$Y \rightarrow EC$

Table 2 shows summary of selected studies on energy demand in Ghana and sub-Saharan Africa.
Notes: $\rightarrow$, $\leftrightarrow$ and ---- represent, respectively, unidirectional causality, bidirectional causality and no causality.
EC = energy consumption; GDP(Y) = real gross domestic product.

To sum up, the findings on energy studies in Ghana have been varied. While some part of the literature indicates appositive relationship between economic growth and energy consumption, other parts of the literature reports otherwise. One thing though runs through all the literature. That is, both price and income have some effect on energy consumption. It has also been found that urbanisation and industry value added have significant effect on energy consumption both in the short and long run.

Most of the studies on natural gas demand occurred in the developed economy. Again, most of the elasticities reported for these studies were less than unitary. However, a study conducted by Wadud *et al*. (2011) on Bangladesh gas demand reported higher elasticities. This indicates a higher responsiveness of natural gas to changes in price and income in developing countries that developed. In addition, all the studies failed to capture the effect of exogenous factors on natural gas demand. This could be one of the reasons for the differences in the elasticities. Moreover, most of the estimation methods used in earlier studies such as the OLS have proven to be inadequate in recent times.

3. The model

Hunt *et al*. (2003) argues that energy-saving technical progress and a range of other exogenous factors (distinct from income and price) can have potential impact on energy demand. These factors include environmental pressures and regulations; energy efficiency standards; substitution of labour, capital or raw materials for energy inputs; and general changes in tastes that could lead to a more *or* less energy intensive situation. Hence there is a need for a broader concept to capture not only energy saving technical progress in an energy demand function but also other unobservable factors that might produce energy efficiency. The concept of the UEDT is therefore used as, arguably, it acts as a proxy, not only for energy saving technical progress and improved energy efficiency, but also for the change in the 'tastes' outlined above (Hunt *et al*., 2003). The STSM developed by Harvey (1989 and 1997, for example) allows for the UEDT to be modelled in a stochastic fashion hence it may vary over time (both positively and negatively) if supported by the data and is therefore a particularly useful and convenient tool in these circumstances. The UEDT/STSM has been found to be a superior approach to one that uses a deterministic trend to try and capture technical progress and moreover the elasticity estimates and the shapes of the UEDTs are robust to different lengths and frequencies of data (Dimitropoulos *et al*., 2005).

Chapter three provides an overview of how the STSM/UEDT is used to model natural gas demand in the residential, industrial and aggregate level for Ghana.

In addition, the role of technological change and its effect on energy demand has not been investigated in energy studies in Ghana. Therefore, one of the aims in this study here is to overcome some of the shortcomings of previous studies by attempting to identify key structural changes in natural gas demand in Ghana by using the UEDT and STSM.

Natural gas consumption results from demand for energy services such as cooking, heating and industrial production. In other words, it is a derived demand; hence, the factors that influence these services play an important role in the demand for natural gas. In industry and households alike, natural gas is used as an input into a productive process. That is, be it an industrial process or to produce heat in homes and the 'production function' is largely determined by the level and nature of the capital appliance stock. Hence the demand for natural gas is equally influenced by both the quantity and quality or efficiency of the capital and appliance stock. It is therefore important to reflect this in any estimated natural gas function.

Additionally, Hunt *et al*. (2003) argues that that technical progress is not the only exogenous factor that influences energy demand. Therefore, factors such as consumer tastes, change in regulations, change in economic structure, change in lifestyles and values might all play an important role in driving natural gas demand. In the absence of appropriate data to capture all the different exogenous effects, a stochastic UEDT is included in the natural gas demand specification estimated in line with recent research (Harvey and Koopman, 1993; Hunt and Ninomiya, 2003; Hunt *et al*., 2003). To achieve this, the STSM is utilised, given that it allows for the impact of unobserved components in a time series model to be a captured by a stochastic trend (Harvey, 1989).

The STSM decomposes time series into explanatory variables, a stochastic trend and an irregular component. As additional observations are included, the parameters and unobserved components of the model are estimated by using recursive filtering smoothing process (Kalman, 1960) and maximum likelihood.

A framework similar to the methodology of Dilaver and Hunt (2011) is used to estimate natural gas demand in Ghana. Three models are estimated for the industrial, residential and whole economy.

3.1. The model for aggregate natural gas demand

$$GN = f(YN, PN, POP, UEDTN) \quad (1)$$

Where

GN is the total gas demand of Ghana
YN is the income/GPD per capita of Ghana

PN is the real natural gas prices of Ghana
POP is the population of Ghana
UEDTN is the Underlying Energy Demand Trend for Aggregate Natural Gas Demand in Ghana.

3.2. Model for industrial demand

$$GI = f\left(YI, PI, POP, IVA, UEDTI\right) \tag{2}$$

Where

GI is the industry gas demand of Ghana
YI is the income/GPD per capita of Ghana
PI is the real natural gas prices of Ghana
POP is the population of Ghana
IVA is industry's contribution to Ghana's GDP
UEDTI is the Underlying Energy Demand Trend for Industrial Natural Gas Demand.

3.3. Model for residential demand

$$GR = f\left(YR, PR, POP, HE, UEDTR\right) \tag{3}$$

Where

GR is the residential gas demand of Ghana
YR is the income/GPD per capita of Ghana
POP is the total population of Ghana
PR is the real natural gas prices of Ghana
HE is the ratio of total final household expenditure to GDP of Ghana
UEDTR is the Underlying Energy Demand Trend for Residential Natural Gas Demand in Ghana.

From equations (1), (2) and (3), a general dynamic autoregressive distributed lag specification is estimated as follows:

$$A(L)ent = B(L)\,yn_t + C(L)\,pn_t + D(L)\,pop + UEDTn_t + \varepsilon_t \tag{4}$$

$$K(L)ei_t = M(L)\,yi_t + N(L)\,pi_t + O(L)iva_t + P(L)\,pop + UEDT_t + \varepsilon t \tag{5}$$

$$U(L)er_t = V(L)\,\mathrm{yr_t} + W(L)\,\mathrm{pr_t} + X(L)he_t + Y(L)\,pop + UEDTt + \varepsilon_t \tag{6}$$

Where ε is the irregular component of the schocastic trend, $A(L)$ = is the polynomial lag operator $1 - \lambda 1L - \lambda 2L^2 - \lambda 3L^3 - \lambda 4L^4$, $B(L)$ is the polynomial lag operator $1 + \alpha 1L + \alpha 2L^2 + \alpha 3L^3 + \alpha 4L^4$ and $C(L)$ is the polynomial lag operator defined as

$1 + \varphi 1L + \varphi 2L^2 + \varphi 3L^3 + \varphi 4L^4$, $D(L)$ is a polynomial lag operator defined as $1 + \delta 1L + \delta 2L^2 + \delta 3L^3 + \delta 4L^4$, $E(L)$ is polynomial lag operator defined as $1 + \theta 1L + \theta 2L^2 + \theta 3L^3 + \theta 4L^4$.

In order to estimate elasticities, the following mathematical functions are performed on the polynomial lag operators at the aggregate level.

Let $AL = \delta$ and $BL = \hat{\Phi}$, $CL = \hat{\Psi}$, $A(L) = \delta$

$$\frac{\hat{\Phi}}{1 - \hat{\delta}1 - \hat{\delta}2 + \hat{\delta}3 + \delta 4} = \text{the long-run income elasticity of aggregate gas demand}$$

$$\frac{\hat{\Psi}}{1 - \hat{\delta}1 - \hat{\delta}2 + \hat{\delta}3 + \delta 4} = \text{the long-run price elasticity of aggregate gas demand}$$

For the industrial sector, Lets $K(L) = \delta$, $M(L) = \lambda$, $N(L) = \rho$, $K(L) = \delta$ and $O(L) = \zeta$

$$\frac{\lambda}{1 - \hat{\delta}1 + \delta 2 + \delta 3 + \delta 4} = \text{the long-run income elasticity}$$

$$\frac{\rho}{1 - \hat{\delta}1 + \delta 2 + \delta 3 + \delta 4} = \text{the long-run price elasticity}$$

$$\frac{\zeta}{1 - \hat{\delta}1 + \delta 2 + \delta 3 + \delta 4} = \text{long-run elasticity of the industry value added.}$$

For the residential sector, let $V(L) = \theta$, $W(L) = \gamma$, $U(L) = \delta$ and $X(L) = \alpha$

$$\frac{\gamma}{1 - \hat{\delta}1 + \delta 2 + \delta 3 + \delta 4} = \text{long-run price elasticity for the residential sector}$$

$$\frac{\theta}{1 - \delta 1 + \delta 2 + \delta 3 + \delta 4} = \text{long-run income elasticity for the residential sector}$$

$$\frac{\alpha}{1 - \hat{\delta}1 + \delta 2 + \delta 3 + \delta 4} = \text{long-run elasticity of final household expenditure}$$

3.4. The UEDT

The UEDT is stochastic and can be estimated by the STSM.

$$\mu t = \mu t - 1 + \beta t - 1 + \eta t : \eta t \sim NID(0)$$

$$\beta t = \beta t - 1 + \varepsilon t : \varepsilon t \sim ND(0)$$

μt is the level while βt is the slope of the UEDT.

ηt and εt are mutually uncorrelated with zero means and variances $\hat{\delta}^{\varepsilon^2}$ and $\hat{\delta}^{\eta^2}$, respectively. The disturbance terms ηt and μt determine the shape of the stochastic trend component. The UEDT can be formulated as:

$$\text{UEDT} = \mu t + \text{irregular intervention} + \text{level intervention} + \text{slope intervention}.$$

According to Dilaver and Hunt (2011), the purpose of including the slope and/or level interventions is to ensure that normality of the auxiliary residuals is maintained. In addition, the interventions provide useful information about the model. The equations are to be estimated by maximum likelihood and Kalman filter. Insignificant variables are eliminated and interventions added to maintain the normality of the residuals and to ensure appropriate diagnostic test are passed to obtain the preferred model.

3.5. Data

Annual data from 1989 to 2009 on aggregate, residential and industrial natural gas demand was obtained from the IEA. Data on GDP, household final expenditure (HE) and IVA in current international prices were obtained from the World Bank. Data on Ghana's population was obtained from the World Bank. Real natural gas prices were obtained from the Ghana Petroleum Authority.

4. Estimated results

The STSM is employed to examine the behaviour of the UEDT. Three models were estimated for aggregate, residential and industrial natural gas demand in Ghana. All the models were estimated using four lags. The various trend components of the STSM such as local trend model, smooth trend mode, and a local level model with drift and local trend model without drift were examined to select a suitable model for the study. Dummy variables are introduced in 2000 and 1993 for the aggregate and in 2000 for the Industry natural gas demand and 1993, 1999 and 2000 for the residential natural gas demand. This is due to the large outliers found in the residuals graphics for the selected periods. In addition, the use of the dummy variables improved the normality and the serial correlation test for the study. The preferred model is selected based on the statistical criteria as suggested by Hunt *et al*. (2003) such as goodness of fit, prediction error variance, serial correlation and normality test. The results of the preferred model are shown in the Tables below.

4.1. The estimated results and test for national natural gas demand in Ghana

Sample: 1989–2009 Dependent variable: en

Table 3 Estimated coefficients of explanatory variables at the aggregate level

Variable	Coefficient	*t*-Value	[*P*-value]
ynt-1	0.38369	6.41620	[0.00002]
pn	−0.35680	−4.13061	[0.00118]
ent-1	0.80330	15.29489	[0.00000]
Irr 2000	−1.06046	−11.70150	[0.00000]
Slp1993	−0.15658	−2.71364	[0.01773]
Component	Estimate	q ratio	
Irregular	0.00643804	(1.000)	
Level	0.000000	(0.0000)	
Slope	0.000000	(0.0000)	

4.2. Long-run price elasticity aggregate for natural gas demand

$$\hat{\varepsilon}_{pn}{}^{LR} = \frac{\hat{\Psi}}{1 - \hat{\delta}1 - \hat{\delta}2 + \delta 3}$$

$$\hat{\varepsilon}_{pn}{}^{LR} = \frac{-0.35680}{1 - 0.80330}$$

$$\hat{\varepsilon}_{pn}{}^{LR} = -1.81$$

4.3. Long-run income elasticity for aggregate natural gas demand

$$\hat{\varepsilon}_{yn}{}^{LR} = \frac{\hat{\Phi}1 + \hat{\Phi}2 + \hat{\Phi}3 + \hat{\Phi}4}{1 - \hat{\delta}1 - \hat{\delta}2 + \delta 3}$$

$$\hat{\varepsilon}_{yn}{}^{LR} = \frac{0.38369}{1 - 0.80330}$$

$$\hat{\varepsilon}_{yn}{}^{LR} = 1.95$$

The results suggest that all coefficient including the irregular intervention are significant at 5 per cent. The model passed all the standard diagnostic test such as residual graphic test, auxiliary residual test and the predictive test as shown in **Table 3**. There was no indication of heteroskedasticity, serial correlation or non-normality. The short-run income elasticity is 0.38. This means, a 1 per cent increase in income leads to

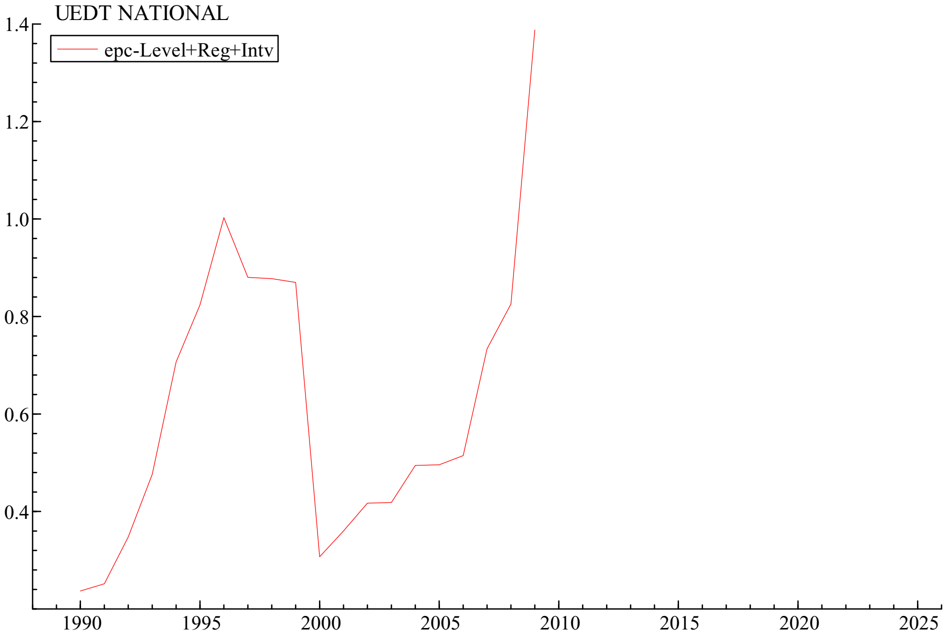

Figure 3 UEDT national.

0.38 per cent increase in natural gas demand at the national level. The short run price elasticity is −0.36.It means that a 1 per cent increase in price leads to a decrease of 0.36 per cent in natural gas demand in Ghana. The long-run elasticity estimates are higher than the short-run elasticity estimates as natural gas consumers have the opportunity to adjust appliance stock and their demand in the long run. The estimated long-run income elasticity is 1.95. This is similar to long-run elasticities reported in natural gas demand literature in both developing and developed countries. For instance Taylor (1975) finds long-run income elasticity to be between −0.29 and 3.11 and long-run price elasticity to be from 0 to −3.85, whereas Wadud *et al*., (2011) finds long-run income elasticity to be 1.5. In relation to electricity demand in Ghana, Adom (2011) finds long run income elasticity of 1.6.

Figure 3 shows the UEDT for the aggregate natural gas demand. The shape that estimated UEDT shows a decrease and increase over the estimation period. This UEDT would appear to reflect the occasional natural gas shortage in Ghana. Because natural gas shortage seems to follow a predictable trend in Ghana, consumers have learned to plan their demand to suit the irregular supply. An irregular intervention in 2000 and slope interventions in 1993 were required in order to maintain the normality of residuals and auxiliary residuals. The interventions appear to reflect the impact of natural gas shortage on the behaviour of consumers. Natural gas demand usage 'behaviour' and energy intensity increased from 1989 to 1995 as shown by the upward slope of the UEDT curve over this period. It started decreasing in 1996, which is an election year. Then, there is sharp decrease from 1998 until it reached the lowest point in 2000, another election year indicating a decreasing in energy intensity. Between 2001 and 2009, natural gas usage behaviour and energy intensity have been increasing with some dynamic trends. There was a slight decrease in 2004 and 2008. This probably reflects the way consumers adjust their behaviour to natural gas shortages especially during election years. However, the shape of the UEDT is different to the shape of the estimated UEDT of Hunt *et al*. (2003) and Dimitropoulos *et al*. (2005).

4.4 Residential natural gas demand in Ghana

Sample 1989–2009
Dependent variable: er

Table 4 Estimated Coefficients of explanatory variables at the residential level

Variable	Coefficient	t-Value	[*P*-value]
yr	0.47548	7.50370	[0.00001]
pr	−0.47411	−6.48570	[0.00005]
ert-1	0.094438	17.29969	[0.00000]
het_1	1.35499	2.33504	[0.03952]
Outlier 2000(1)	−0.97877	−9.52511	[0.00000]
Level break 1999(1)	0.15216	1.82006	0.09604]
Slope break 1993(1	−0.17949	−4.11626	[0.00171]
Level		0.70880	
Slope		0.16761	

4.5. Long-run price elasticity of the residential sector

$$\hat{\varepsilon}_{pr}{}^{LR} = \frac{\gamma}{1-\hat{\delta}1}$$

$$\hat{\varepsilon}_{pr}{}^{LR} = \frac{-0.47411}{1-0.094438}$$

$$\hat{\varepsilon}_{pr}{}^{LR} = -0.52$$

4.6. Long-run income elasticity of the residential sector

$$\hat{\varepsilon}_{yr}{}^{LR} = \frac{\theta}{1-\hat{\delta}1}$$

$$\hat{\varepsilon}_{yr}{}^{LR} = \frac{0.47548}{1-0.094438}$$

$$\hat{\varepsilon}_{yr}{}^{LR} = 0.53$$

4.7. Long-run elasticity of household final expenditure

$$\hat{\varepsilon}_{he}{}^{LR} = \frac{\alpha}{1-\hat{\delta}1}$$

$$\hat{\varepsilon}_{he}{}^{LR} = \frac{1.35499}{1-0.094438}$$

$$\hat{\varepsilon}_{he}{}^{LR} = 1.50$$

This study finds a short-run residential income elasticity of 0.48 as reported in **Table 4**. This means that residential demand is more responsive to income changes than the national natural gas demand. A 1 per cent increase in income leads to 0.48 per cent increase in natural gas demand in the residential sector. The short-run price elasticity is −0.47 per cent. This implies that a 1 per cent increase in price leads to 0.47 per cent decrease in energy demand. Residential demand is more price elastic than the national natural gas demand. The short-run elasticity of the ratio of final household expenditure to the GDP (he) is 1.4 per cent. The model passed all standard diagnostic tests, and no sign of non-normality, auto-correlation was observed. All estimated variables were significant at 5 per cent confidence level except the level break in 1999, which was significant at 10 per cent level. The estimated long-run income elasticity is 0.53. This on a lower side compared with Balestra and Nerlove (1966) and Lin *et al*. (1987), who found long-run income elasticity for residential natural gas demand to be 0.62 and 0.57, respectively. These higher figures may be due to the failure of these studies to capture the UEDT. The long-run price elasticity is −0.52. However, the long-run elasticity for household final expenditure is 1.50. This means that, in the residential sector, changes in final household expenditure has more effect on natural gas demand than changes in income and price in the long run.

Figure 4 shows the UEDT for the residential sector. The UEDT has been negative from 1989 until 2009. The negative UEDT probably suggest high retail prices of natural

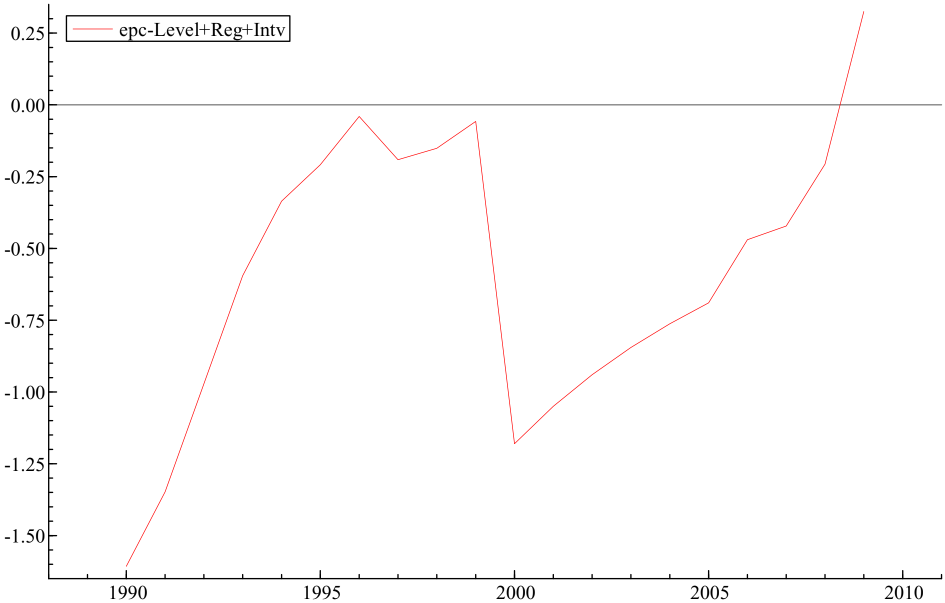

Figure 4 UEDT residential.

gas created by 'artificial shortages'. It could be due consumers' preference for charcoal as a cooking fuel and periodic unavailability of natural gas. The UEDT is non-linear and shows a decreasing and a decreasing with some irregular trend.

4.8. Industrial gas demand in Ghana

Long-run price elasticity of industrial sector

$$\hat{\varepsilon}_{pi}^{LR} = \frac{\rho}{1-\hat{\delta}1}$$

$$\hat{\varepsilon}_{pi}^{LR} = \frac{-0.41022}{1-0.93411}$$

$$\hat{\varepsilon}_{pi}^{LR} = -6.23$$

Table 5 Estimated coefficients of explanatory variables at the industrial level

Variable	Coefficient	t-Value	[*P*-value]
y	0.25470	2.99524	[0.01117]
p	−0.41022	−4.90445	[0.00036]
et-1	0.93411	21.02778	[0.00000]
Ivayt-2	−0.45257	−2.62059	[0.02236]
Irr 2000	−0.93360	−9.68348	[0.00000]
Level		−0.45220	
Slope		0.01841	

Long-run income elasticity of the industrial sector

$$\hat{\varepsilon}_{yi}{}^{LR} = \frac{\lambda}{1-\hat{\delta}1}$$

$$\hat{\varepsilon}_{yi}{}^{LR} = \frac{0.25470}{1-0.93411}$$

$$\hat{\varepsilon}_{yi}{}^{LR} = 3.7$$

Long-run elasticity of industry value added

$$\hat{\varepsilon}_{iva}{}^{LR} = \frac{\zeta}{1-\hat{\delta}1}$$

$$\hat{\varepsilon}_{iva}{}^{LR} = \frac{-0.45257}{1-0.93411}$$

$$\hat{\varepsilon}_{iva}{}^{LR} = -6.87$$

The variables passed all diagnostic tests, and no non-normality, heteroskedasticity and serial correlation was observed. **Table 5** shows the elasticities of the industrial sector of Ghana. The short-run income elasticity is 0.25. This is lower than both the residential and national elasticities. This may be due to the fixed nature of natural gas appliance used in the industrial sector. A 1 per cent change in income leads to 0.25 per cent increase in natural gas demand in the industrial sector. The short-run price elasticity is −0.41 indicating that an increase in price by 1 per cent will lead to a fall in natural demand by 0.41 per cent. It is also observed that an increase in industrial output reduces natural gas consumption of the preceding 2 years. This may be due to efficiency improvement or technological advancement. The short-run elasticity for IVA was −0.45.

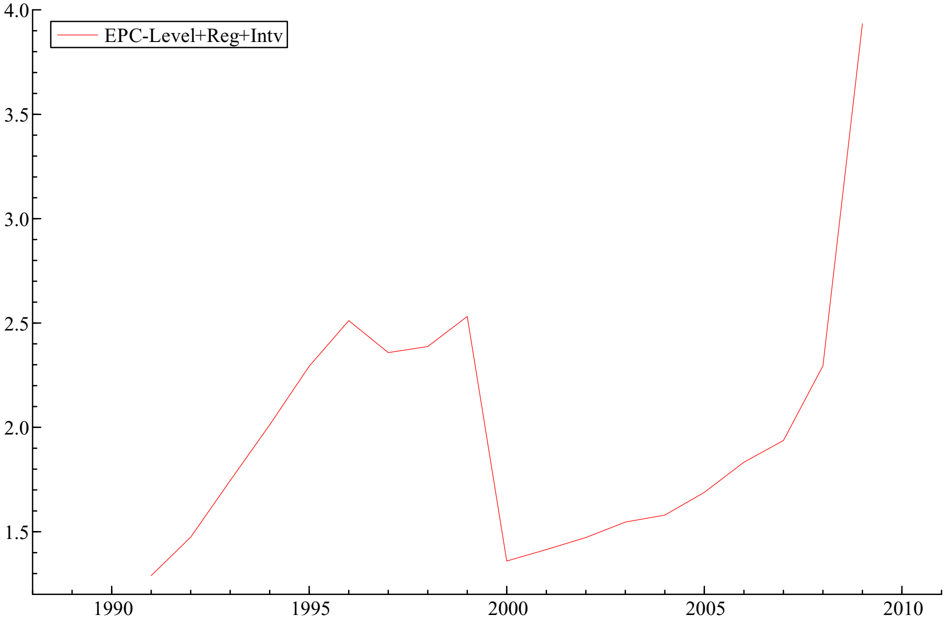

Figure 5 Industrial UEDT.

The long-run income and price elasticity is 3.7 and −6.3, respectively. This may be due to the high substitutability between natural gas and electricity in the industrial sector. The long-run income elasticity for IVA is –6.87. Because natural gas supply fluctuate in Ghana, an increase of 1 per cent in industrial output will lead to a decrease of 6.87 per cent in natural gas demand. Industry may demand more of electricity, which has a reliable supply to sustain the increase in output.

Figure 5 shows the UEDT for the industrial sector of Ghana. The shape of the UEDT is similar to the UEDT of Ghana's residential sector. The UEDT follows an irregular trend. The trend may be due to initial efforts by the Government to encourage domestic consumption of natural gas more than the industrial usage and high substitutability of natural gas and electricity in the industrial sector. It may also reflect the occasional natural gas shortage in Ghana.

5. Conclusion

5.1. Summary of findings

Due to environmental concerns and energy security, natural gas has become the fuel of choice. It has therefore become one of the fastest consuming fuels in the world.

In Ghana, the Government launched a natural gas consumption programme to encourage the use of natural gas in the residential areas to prevent reliance on charcoal for cooking. In addition to this, associated natural gas was discovered in Ghana in 2008. Efforts are been made by the Government to build gas infrastructure and establish the local natural gas market. Knowledge of the demand of natural gas will serve as a valuable asset for planning and execution of national natural gas project and programmes.

The purpose of the study is to model and forecast natural gas demand in Ghana. Different models are estimated for the aggregate, industrial and residential. The STSM is used for the estimation. This is due the ability of the STSM to capture the UEDT and relative advantage to capture energy-saving technical change and structural breaks.

The estimated short-run price elasticity for the aggregate natural gas demand is −0.36, whereas the short-run income elasticity is 0.38. The long-run price and income elasticities are −1.81 and 1.95, respectively. The short-run elasticities for the residential sector are −0.47 for price and 0.48 for income. The income elasticity is relatively lower for the industrial sector than for the aggregate and residential sectors. For the residential sector, the long-run price elasticity is −0.52, wherease the long-run income elasticity is 0.53. The long-run elasticity for final household consumption is 1.50.

The short-run price elasticity for the industrial sector was −0.41 while the short-run income elasticity is 0.25 while the short-run elasticity for industry value added is −0.45. The long-run price and income elasticities are −6. 23 and 3.7, respectively. The long-run elasticity for industry value added is −6.87.

The UEDT for the aggregate, residential and industrial sector shows stochastic but increasing and decreasing periods. However, there is a significant structural change in 2000 for all the three sectors. This might reflect energy conservation programmes embarked by the Energy Commission. It may also be due to the general shortage of natural gas on the domestic market and the fall of cocoa prices on the international market that affect Ghana's exchange rate.

In Ghana, there are no study that measures the effect of price, income, industrial output and household final expenditure on natural gas demand. Nonetheless, Adom (2011) found income elasticity of 0.84 per cent when they studied aggregate electricity demand of Ghana. There exist other studies on Ghana that concentrate on testing the electricity consumption-economic growth hypothesis such as Adom (2011); Wolde-Rufael (2006); and Twerefo *et al.* (2008). The major revelation from these studies is that economic growth significantly causes or leads to electricity consumption. The findings of this study support earlier findings. However, the low income elasticity may be due to the inclusion of interventions to capture structural breaks and the UEDT.

5.2. Policy implications and recommendations

These findings have policy implications for Ghana. The government already provides subsidy to encourage natural gas consumption. However, the study has revealed that income changes induce more response in industrial sector than in the residential sector. Again, there is high response in the residential to changes in price than the industrial sector. These findings suggest policies such as subsidy can be made separately for the residential and industrial sector instead of a uniform national gas subsidy as they respond to gas price and income changes differently. In addition, industrial output and household final expenditure were found to have significant effect on natural gas consumption. These variables are therefore recommended to be included in future energy demand studies in Ghana.

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