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Ghanaian energy economy: Inter-production factors and energy substitution

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ABSTRACT

Industries in Ghana depend highly on petroleum to fuel their operations which has brought immerse environmental threat from greenhouse emission gas (GHG). This study tried to investigate potential substitutability of factor inputs and fuel inputs among capital, labor, petroleum and electricity in Ghana by adopting the translog production and cost function approach. We used Ridge regression technique to estimate the parameters after our data show possibility of multicollinearity. Our result shows that, all inputs are substitutes with their relative technological progress also showing evidence of convergence. This suggests that, redirecting resources into the improvement of technology towards cleaner energy production like electricity will be a success over time and this will mean that the fueling of the economy will be done in a cleaner environment and mitigating mitigate CO_2 emissions as well. The improvement of electricity production and the promotion of its use require government policies that will enable industries to adjust to the switch from one input to the other through capital subsidies and tax rebates. Also, energy-labor and capital-energy being substitutes in our findings suggest that, removal of all energy subsidies will reduce the use of energy and increase capital and labor intensiveness. Input switch by industries will promote merger of smaller firms with bigger firms that have cost advantage during the switch period and requires a clear government merger control policies.

In a nutshell, our findings provide an insight into policies to promote the use of renewable energy, energy intensity and merger policies.

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1. Introduction

All socio economic activities in Ghana are propelled by energy which promotes commercial and industrial activities with the aim of delivering basic social services. Indeed, energy is an important contributor to Ghana's economy and provides not only an immerse contribution to the gross domestic product (GDP) of Ghana but also provides vital support to some key sectors of the economy which includes transportation, agriculture, health, education, tourism, fiscal revenue, food security, regional development and employment.

Notwithstanding the dominance of petroleum products in the Ghanaian energy mix, currently driven by the discovery of oil in commercial quantities, poses serious environmental concerns. For instance, the energy consumption mix in the industrial sector in 2010 was estimated to be about 85% petroleum products and electricity accounting for only 15% (Source; UN report on Ghana 2010) [1]. This has led to an increase in the level of energy-related CO_2 emissions (see Fig. 1). The amount of CO_2 emissions increased from 2.227 million tons in 1980 to 9.005 in 2011 representing 304.4%. (Source; international energy statistics, US Energy Information Administration EIA) [2]. Since 2005, average CO_2 emission growth rate from petroleum has been about 5.2% p.a. (Source; EIA) which has called for an urgency to control energy related emissions. Given the continuous growth of the Ghanaian economy (ADB 2013) [3], coupled with the increase in petroleum and electricity use (from 3,800,000billion British Thermal Unit (BTU) and 14,027.47 billion BTU respectively, in 1987, to 129,000,000 billion BTU and 28,740.873 BTU in 2012 representing 3294.7% and 104.8% increase respectively) (EIA), the rate of CO_2 emissions is expected to further increase. Though Ghana's emission contribution to global warming is less than the international standards, the country could be proportionately affected should climate change continue looking at the indicators of Ghana.

Numerous efforts by interest groups calling for emissions control have not been very successful. In Ghana there have been various policies enacted to control some of the emission issues and also to switch to a cleaner energy to fuel the economy (see in Table 1). Though all these policies are in place, some have actually not been implemented with others in the process of implementation.

The success of initiating these policies will largely depend on the extent of the amount of substitutability going on between different factors of production and fuel types. Inter-fuel substitution, sustainability of energy and other factors of production are greatly influenced by the effects of output growth and changing fuel prices on the demand for energy. These issues have generated numerous debates and have drawn a large attention to the number of energy demand studies with the greater number of these research studies focusing on developed economies.

Carrying out this research study on Ghana is very timely and significant for various reasons. First, due to the increasing demand for energy inputs and classical factor as the economy grows and expands; there is the need to match future demand forecast with the necessary future supply. In matching these future demand and supply forecasts, much attention should be given to both energy consumption and the level of inter-fuel and inter-factor substitution possibilities over time. To be precise, results of future forecasts for energy demand are more reliable when the demand models consider elasticity of substitution taking place over time. Second, to construct computable general equilibrium (CGE) model for Ghana's energy economy, the previous estimate could be of importance. There is a slight variation between general CGE models and CGE models that focus on energy. While the general one uses production function through constant elasticity of substitution (CES) forms where output is made up of (CES) combination of energy and non-

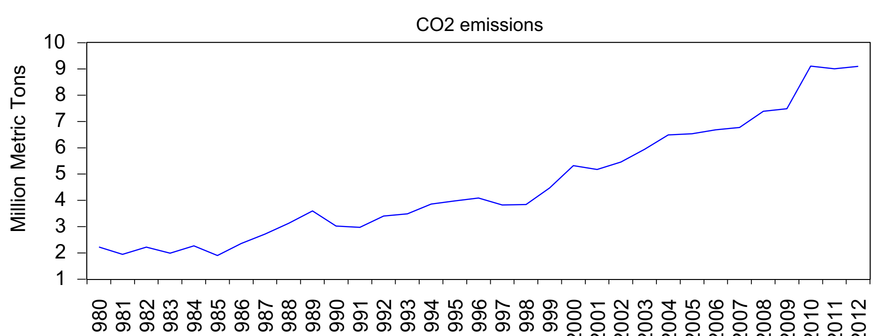

Fig. 1. CO_2 emissions from petroleum consumption in Ghana (Million Metric Tons) Source US EIA database.

Table 1
Policies put in place by government to promote the use and development of cleaner energy sources. (Source: Ghana energy commission and UNDP).

Year	Policy
1990	National LPG program (instituting a pricing scheme called uniform petroleum price fund where taxes on gasoline sales are used to cross subsidize LPG and also offering incentives for sales of LPG at locations more than 200 km from the Tema oil refinery)
1999	Renewable energy service program – RESPRO (direct investment into energy infrastructure for solar and solar photovoltaic).
1998	Renewable energy tax and duty exemption program (duty free and tax relief for all renewable energy inputs and equipment and tax relief for renewable energy investments).
2005	National renewable energy policy (accelerating the development and utilization of renewable energy so as to achieve 10% penetration of electricity and supplementing petroleum supply from biodiesel).
2006	Strategic national energy plan – SNEP (supporting strategic plans for multiple renewable energy sources)
2007	Ghana energy development and access project – GEDAP (providing grants, subsidies tax reliefs and economic instrument for private investment into wind, solar and solar photovoltaic projects).
2007	National electrification scheme – NES (promoting research and development with financial incentives for wind, solar generation for electricity)
2010	Ghana national energy policy (promoting hydropower, solar, geothermal, and biofuel for transportation and electricity generation)
2011	Renewable energy act – Act 2011, act 832 (provide physical incentives and regulatory framework to encourage private sector investment into renewable energy projects)

energy inputs such that there may be inter-substitution of different energy forms taking into account energy and factor substitution, the former only takes the trend of total energy consumption input into account. With the consideration of energy and factor substitution, the modeler can look into other issues related to energy policies like; price hike, taxes, price regulation and subsidies on the economy. Third, there is the need for urgent CO_2 emission control due to the increasing trend of greenhouse emission figures (see Fig. 1) in Ghana and this has called for the use of cleaner fuel. Ghana in the past years has enacted some public policies with the aim of reducing greenhouse emissions by 15% in 2020 which can be seen in the white paper named vision 2020 and also improve energy efficiency by 25% in the same year by the energy sector. The success of these policies will largely depend on policy makers having firsthand information on which energy sources are close substitutes to enable them access the possibilities of an alternative cleaner energy source for example to petroleum.

Finally, there has not been any literature on the use of inter-factor and inter-fuel elasticities of substitution on Ghana. This study is one of the kinds that will fill the literature vacuum regarding estimation of substitutability and elasticity of factor inputs and energy inputs in Ghana with an ideal dataset and appropriate econometric methods. The remaining of the paper is structured as follows: the second part introduces a brief literature Review. The third part introduces the description of dataset and how it was processed. The fourth part describes the model framework and the estimation procedures. The fifth part presents the empirical results and discussion and the sixth part presents the conclusion of the article and some policy discussions.

2. Overview of existing literature

A sizeable number of research works has been carried out with different econometric models in assessing the substitutability and elasticities among various inputs using a range of data sets by researchers. Among the empirical methods used, transcendental logarithmic (translog) cost function has been the most used partly due to its flexibility of the specification to satisfy the desired properties of production and cost function and partly due to the tractable methodology and the model itself being easy to understand. One of the first such studies to be conducted was by Pindyck [4]. He estimated the inter-factor substitution across 10 developed countries and his estimate shows possibility of substitution between capital and energy since these parameters have positive relation in his study. This energy-capital substitutability hypothesis was widely supported by a number of research works which includes Griffin [5]; Truong [6]; Thompson and Taylor [7]; Christopoulos [8]; Lin and Wesseh [9]; Koetse et al. [10]; Wesseh et al. [11]; Lin and Xie [12]. In contrast to the earlier hypothesis, a number of researches refute this hypothesis and sided with Berndt and wood [13] who concluded that energy and capital complement one another in US manufacturing sector. Notable research works that supported his position include Anderson [14], Fuss [15] and Prywes [16]. To ascertain the possibility of substitutability among different fuels, Shankar and Pacarri [17] went a step ahead to analyze not only the substitutability among factor inputs but also energy inputs in the industrial energy demand pattern of India. Their estimated result shows the parameters to be low among different fuels indicating less substitutability or possible complementarity among fuels with oil and coal showing the highest substitutability possibility in most industries especially in the steel industry. Substitutability between electricity and coal was also found to be less.

There have been other studies which adopted the translog cost function method and notable among them are Hall [18]; Bataille [19]; Nkomo and Goldstein [20]; Jones [21]; Considine [22]; Adeyemo et al. [23]; Penphamussak and Wangsapai [24] and Ma et al. [25]. There have also been other methods used in the estimation of substitutability and elasticities of factor and energy inputs which can be cited in the research study of Serletis et al. [26]; Smyth et al. [27]; Bjornel and Jensen [28]; Chakir and Thomas [29] and Serletis and Timilsina [30]. In fact, from evidence, the results from existing literatures on the study show that the substitutability and complementarity of various inputs are mixed.

To get the true value of elasticity and the factors that affect the elasticity estimates, an intuitive review of 47 research works on substitutability and elasticity among factor inputs and fuel inputs was carried out by Stern [31]. He attributed the variance in estimated results among the studies to differences in data sets used by various studies (e.g. time series, pooled and cross section data), the methodology used in each work (e.g. regional, sectorial and national level), sample size of data used in various studies and the economic indicators of the country on which the research is carried out. Stern's analysis found a high level of substitutability among coal, electricity, oil and gas in the industrial sector. His elasticity of substitution estimates among this energy inputs are not different from one statistically. Smyth et al. [27] criticize Sterns analysis sighting out datedness of the 47 works he analyzed since two-third of the data used in these works was before 1990. There have been very few studies that have examined inter-factor and inter-fuel substitution in developing countries. One of such studies is Serletis and Timilsina [30]. He examined the entire fuel substitution in six high income countries, five middle income countries and four low income countries. He found out that, inter-fuel substitution possibilities between coal, oil, gas, and electricity were consistently below unity. These evidence of inter-fuel substitution potential in high income countries compared to middle and low income countries were in the industrial and transport sectors. The only observation on inter-factor and inter-fuel substitution in developing countries on national level is Wesseh et al. [11]. He observed the inter-fuel substitution on Liberia economy and concluded that there is a potential inter-fuel and inter-factor substitution possibility between petroleum and electricity and between capital and labor. With the literature presented above, there is clear evidence that there has not been much attention paid to low income developing countries on the national level like Ghana irrespective of high threat of pollution from the fuel type used looking at the country's indicators. Undertaking such research on Ghana will fill not only the vacuum on inter-factor and inter-fuel substitution research but also provide meaningful policies which is crucial for Ghana's environmental threat from energy use and poverty reduction which is in line with Ghana's energy development and access project (GEDAP).

In addition to the above studies which have attempted to evaluate the level of CO_2 emissions reduction potentials by means of energy and factor substitution, other studies have taken different approaches. For instance, there are studies emphasizing energy efficiency and consideration of the rebound effect as one effective way to reduce CO_2 emissions. Some of these studies include Wang et al. (a) [32]; Wang et al. (b) [33]; Wang et al. [34]; Wang and Yang [35]; Bentzen [36]; Jin [37]; Sorrel and Dimitropoulos [38]; Bin and Zhonghua [39]; Blesl et al. [40]; and Zhang et al. [41].

3. Data description

Dataset used in this paper includes critical observations on yearly total petroleum consumption, electricity consumption, labor, output and gross capital formation in Ghana over the period 1980–2012. We carried out several transformations on the dataset

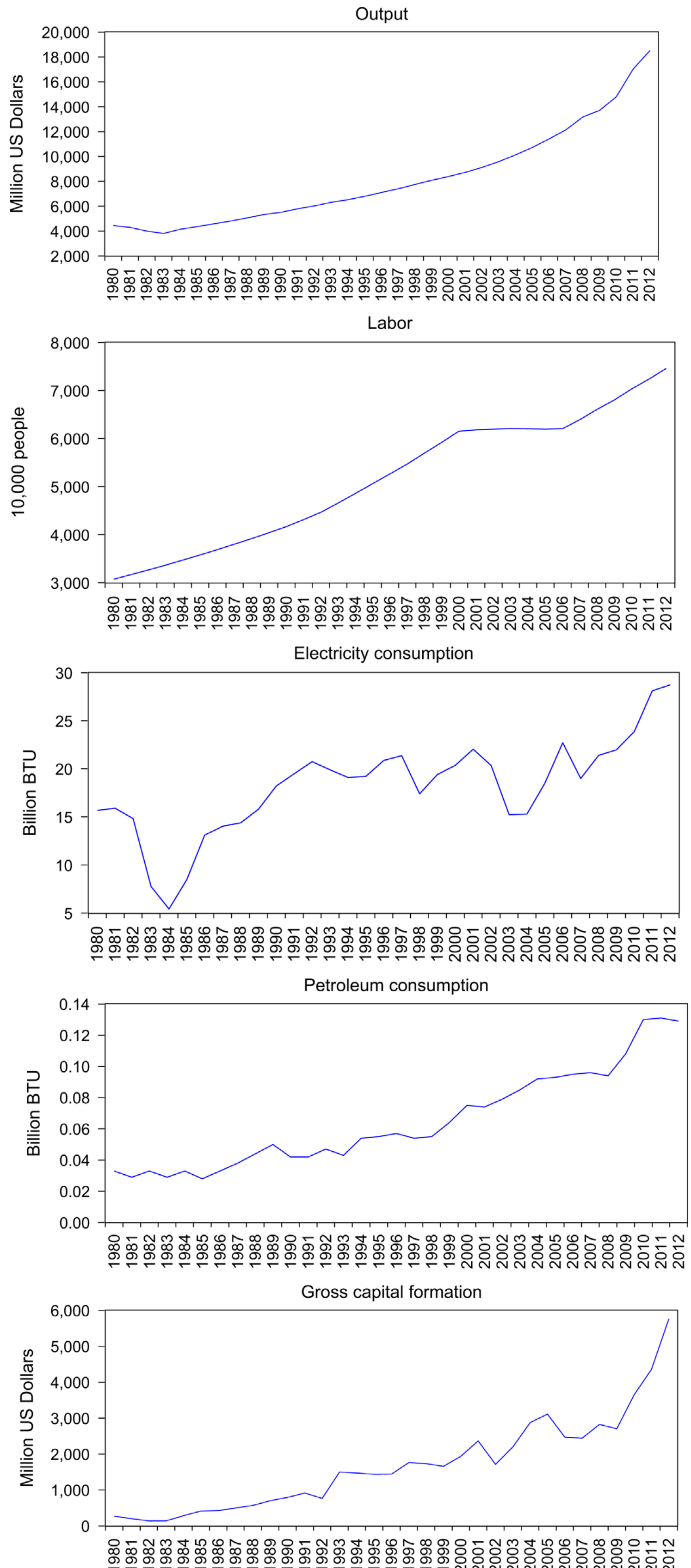

Fig. 2. Plot of variables 1980–2012.

to avoid spurious result of inter-fuel and inter-factor elasticities of substitution analysis. Output and capital stock was calculated at constant price (2005usd) to eliminate the impact of inflation. Due to stability and improvement of the statistical properties of the data, all variables were transformed into logarithmic form to suit the operation of the variance (as one of the box–cox transformation). Data on electricity and petroleum consumptions are from US Energy Information Administration (EIA) database [2]. We used the British thermal unit (BTU) as the standard of measurement for energy inputs. BTU is the total amount of heat energy required to raise the temperature of one pound of water by one degree F. This is the standard measurement used to state the amount of energy that a fuel has as well as the amount of output of any heat generating device. Data on output, labor and gross capital formation are from the world development indicators databank (WDI) [42]. We used real GDP constant (2005usd) to represent output in this paper. To get the labor estimate for this paper, we calculated employment to population ratio multiplied by the active population. Gross capital formation used in this paper consists of outlays on the accumulations to fixed assets of the economy with the addition of net changes in the level of inventories. Fixed assets include the construction of commercial and industrial buildings, private residential dwellings, hospitals, schools, offices, railways, roads, improvements on lands (fences, ditches, drains and so on); purchase of machinery and equipment. Adopting the 1993 national account system, we considered the net acquisition of valuables as capital formation which includes inventories (stock of goods held by firms to meet unexpected future fluctuations in production or sales and work in progress). Since WDI does not provide data on capital stock, this variable was derived by using the perpetual inventory method of calculation at constant prices (2000=100) as follows:

$$K_t = K_{t-1}(1-\delta) + I_t \tag{1}$$

Where K_t is the current capital stock, K_{t-1} is the capital stock of the previews year, δ is the capital depreciation rate and I_t is the capital investment in the current year. Based on World Bank total wealth estimate, depreciation rate of capital stock is taken to be 5% and per capital wealth estimate for 124 countries including Ghana, we compute capital stock using the following equation:

$$K_0 = I_0/(g+\delta) \tag{2}$$

Here, K_0 is the initial capital stock, I_0 is the initial capital investment, δ is the capital depreciation rate and g represents the average growth rate of capital investment over the period of the study. Fig. 2 shows the plotted graphs of variables over the period employed in the study. Pictorial look of the plotted graphs seems to confirm the likelihood of correlation among the independent variables thus suggests the need to test for correlation among the predictor variables.

4. Model framework and estimation procedure

We explained the methodology employed in our research and the procedure of extracting elasticities of substitution. As mentioned in Section 1 of this paper, the most used approach in the energy economics literature of estimating energy demand elasticities has been the translog cost function which requires data on output prices (e.g. Energy prices, wages and rent). The difficulty in getting these data over the sample period has compelled us to adopt approach used by Smyth et al. This approach employed a linear translog production and cost function to investigate the degree of inter-factor and inter-fuel substitution between petroleum, electricity, labor and capital in Ghana during the period 1980–2012.

4.1. Model framework

Translog production function is a second order Taylor series approximation describing the relationship between output and input services from several different productive factors can be expressed in the form as follows:

$$\ln Y_t = \ln_{a_0} + \sum_i a_i \ln X_{it} + \frac{1}{2}\sum_i\sum_j a_{ij} \ln X_{it} \ln X_{jt} \tag{3}$$

Where Y_t denotes output at time t, a_0 signifies the state of technical knowledge, X_{it} and X_{jt} represents inputs i and j, respectively at time t, a_i and a_{ij} are technologically determined parameters. The primary assumption here is that for Ghana, there exists a twice differentiable aggregate translog production function relating gross output to capital, labor, petroleum, and electricity inputs. In Pavelescu's [43] paper, the use of this functional form permits the avoidance of imposition of assumptions such as perfect competition or perfect substitution among inputs. The existence of quadratic terms also allows for nonlinear relationship between the output and inputs. These characteristics make translog production function attractive to researchers due to its flexibility compared to other functional forms. Given our energy inputs, the translog production function for Ghana can be specified as follows:

$$\begin{aligned}\ln \Upsilon_t = {} & a_0 + a_K \ln K_t + a_L \ln L_t + a_P \ln P_t + a_E \ln E_t + a_{KL} \ln K_t \ln L_t \\ & + a_{KP} \ln K_t \ln P_t + a_{KE} \ln K_t \ln E_t \\ & + a_{LP} \ln L_t \ln P_t + a_{LE} \ln L_t \ln E_t + a_{PE} \ln P_t \ln E_t \\ & + a_{KK}(\ln K_t)^2 + a_{LL}(\ln L_t)^2 + a_{PP}(\ln P_t)^2 + a_{EE}(\ln E_t)^2\end{aligned} \tag{4}$$

In the above expression, Υ_t represents output of the Ghanaian economy while K_t, L_t, P_t and E_t are inputs of capital, labor, petroleum and electricity respectively. a is the input of the parameters to be estimated while t is the time index.

Characterizing the economic region of a linear homogeneous production function, the output elasticity (η_{it}) of the ith input from Eq. (3) can be computed as:

$\eta_{it} = \frac{\partial \ln \Upsilon_t}{\partial \ln X_{it}} = a_i + \sum_j a_{ij} \ln X_{jt} \triangleright 0$(5)

Hence the output elasticity for capital stock becomes:

$$\eta_{Kt} = \frac{d \ln \Upsilon_t}{d \ln K_t} = a_K + a_{KL} \ln L_t + a_{KP} lP_t + a_{KE} \ln E_t + 2a_{KK} \ln K_t \triangleright 0 \tag{6}$$

The output elasticity for labor becomes:

$$\eta_{Lt} = \frac{d \ln \Upsilon_t}{d \ln L_t} = a_L + a_{LK} \ln K_t + a_{LP} \ln P_t + a_{LE} \ln E_t + 2a_{LL} \ln L_t \triangleright 0 \tag{7}$$

The output elasticity for petroleum becomes:

$$\eta_{Pt} = \frac{d \ln \Upsilon_t}{d \ln P_t} = a_P + a_{PK} \ln K_t + a_{PL} \ln L_t + a_{PE} \ln E_t + 2a_{PP} \ln P_t \triangleright 0 \tag{8}$$

The output elasticity for electricity becomes:

$$\eta_{Et} = \frac{d \ln \Upsilon_t}{d \ln E_t} = a_E + a_{EK} \ln K_t + a_{EL} \ln L_t + a_{EP} \ln P_t + 2a_{EE} \ln E_t \triangleright 0 \tag{9}$$

The output elasticities are expected to vary across the sample since these are functions of energy consumption per period of time. The elasticity of substitution between two energy or factor inputs can be calculated as:

$$\sigma_{ij} = \frac{\%\Delta(X_{it}/X_{jt})}{\%\Delta(P_{jt}/P_{it})} \tag{10}$$

With the assumption that firms in Ghanaian economy are cost minimization agents, Eq. (10) can be re-written as:

$$\sigma_{ij} = \frac{\%\Delta(X_{it}/X_{jt})}{\%\Delta(MP_{jt}/MP_{\text{it}})} = \left(\frac{d(X_{it}/X_{jt})}{d(MP_{jt}/MP_{it})}\right)\left(\frac{MP_{jt}/MP_{it}}{X_{it}/X_{jt}}\right) \tag{11}$$

From Eq. (11) the final formula we used in calculating the substitution elasticities between inputs i and j in our study is:

$$\sigma_{ij} = \left[1 + \frac{-a_{ij} + (\eta_i/\eta_j)a_{jj}}{-\eta_i + \eta_j}\right]^{-1} \tag{12}$$

The substitution elasticity between capital, labor, petroleum and electricity in Ghana can be written as:

$$\sigma_{KL} = \left[\frac{1 + -a_{KL} + (\eta_K/\eta_L)a_{LL}}{-\eta_K + \eta_L}\right]^{-1} \tag{13}$$

$$\sigma_{KP} = \left[1 + \frac{-a_{KP} + (\eta_K/\eta_P)a_{PP}}{-\eta_K + \eta_P}\right]^{-1} \tag{14}$$

$$\sigma_{KE} = \left[1 + \frac{-a_{KE} + (\eta_K/\eta_E)a_{EE}}{-\eta_K + \eta_E}\right]^{-1} \tag{15}$$

$$\sigma_{LP} = \left[1 + \frac{-a_{LP} + (\eta_L/\eta_P)a_{PP}}{-\eta_L + \eta_P}\right]^{-1} \tag{16}$$

$$\sigma_{LE} = \left[1 + \frac{-a_{LE}(\eta_L/\eta_E)a_{EE}}{-\eta_L + \eta_E}\right]^{-1} \tag{17}$$

$$\sigma_{PE} = \left[1 + \frac{-a_{PE} + (\eta_P/\eta_E)a_{EE}}{-\eta_P + \eta_E}\right]^{-1} \tag{18}$$

In the above $\sigma_{KL}, \sigma_{KP}, \sigma_{KE}, \sigma_{LP}, \sigma_{LE}, \sigma_{PE}$ indicate inter-factor/inter-fuel elasticities between capital-labor, capital-petroleum, capital-electricity, labor-petroleum, labor-electricity, and petroleum-electricity respectively. Positivity implies that the inputs are substitute while negativity implies complements.

4.2. Process of estimation

Looking at the economic behavior of our data (see Fig. 2) and because of the interaction and squared terms of our input variable in Eq. (4), there is the likelihood of the model to suffer from multicollinearity (a statistical term or phenomenon that describes a two or more predictor variables in a multiple regression model that are highly correlated). In this situation the coefficient estimates may change drastically in responds to slight changes in the model or data. With n inputs, the number of parameters that need to be estimated totalizes $n(n+3)/2$ if all inputs have translog components in the model. In this situation the number of parameters 'swells' with the number of inputs included in the model which leads to over parameterization. In the model framework proposed by Smyth et al. [27] the translog component for capital and labor and the substitution elasticities between these factors and energy inputs were not computed. This has decreased the number of parameters to be estimated and draws attention to only inter-fuel elasticities of substitution. In order to take care of any problem of multicollinearity, this paper employs the ridge regression technique proposed by Hoerl and Kennard [44] for our estimation. The ridge estimator is obtained by solving $(X'X+kI)\hat{\beta}_i = h$ to give $\hat{\beta}_i = (X'X+kI)^{-1}h$; where $h = X'Y$, k is the ridge parameters or the biasing parameter which satisfies $k \geq 0$ and I is an identity matrix. In general, there is an optimum value of k for any problem. But it is desirable to examine the ridge solution for a range of admissible values of k. Small positive values of k improves the conditioning of the problem and reduces the variance of the estimates. While biased, the reduced variance of ridge estimate often results in a smaller mean square error when compared to least-squares estimates. Hoerl gave the name ridge regression to his procedure because of similarity of its mathematics to methods he used earlier, i.e. 'Ridge analysis', for graphically depicting the characteristics of second order responds surface equation in many predictor variables. In the econometric literature, several methods of obtaining the optimal value of the ridge parameter have been proposed. This paper uses the ridge trace plot method which is the most used in the literature. Coefficients are estimated with various levels of k from zero to one. The $\hat{\beta}_i$ coefficients are then plotted with respect to the values of k and the optimal value is chosen at the point where the $\hat{\beta}_i$ coefficients seem to stabilize.

5. Estimated results and discussion

Given the high number of estimated parameters in our translog formulation, we begin with an investigation of multicollinearity in the data using the approach of Kmenta [45]. According to Kmenta, a simple measure of the degree of multicollinearity is obtained by regressing each of the independent variables on the remaining independent variables. The calculated coefficient of determination (R^2) from the regression can then be used as a measure of the degree of multicollinearity in the sample. In this study, the values obtained for (R^2) corresponded to 0.98, 0.96, 0.9, and 0.9 for capital, labor, petroleum and electricity respectively (see Table 2). The results suggest a very severe multicollinearity and consequently a problem in the study.

The results from the GLS estimator compared to those of GMM estimator looked quite similar. The results are not presented in this paper to conserve space but are certainly available upon request from the authors.

These results have compelled us to adopt the ridge regression procedure in the study and we deem it to be the most appropriate econometric technique since coefficient estimates for multiple linear regression models rely heavily on the independence of the model terms. From the ridge trace plot presented in Fig. 3, we adopted 0.65 as the ridge parameters since it is approximately at this value that the coefficients of the variables seems to stabilize (see Fig. 3). Results of the ridge regression run are shown in Table 3. From the result we can see that petroleum and labor have the expected sign while capital and electricity fail to conform to the expected sign. This is the fact after following all required econometric procedures and looking at the F statistics value, nothing seems to be wrong with our model specification. One must not twist facts to suit theory but rather twist theories to suit facts in research analysis therefore the result is explainable in the context of the Ghanaian energy economy. The result indicates that, petroleum and labor are

positively and significantly linked to the output of the Ghanaian economy this is not surprising since our data plot for labor has shown an increasing trend in employment and with Ghana's oil find in commercial quantity shows why petroleum is having more impact on the economy. Although economic activities in Ghana rely on electricity and capital as a driving force, little or negative gains have be realized in terms of output (GDP) due to heavy debt incurred by the electricity production and distribution agencies where capital invested into these sectors are mismanaged and at the end, national resources which could have been used to increase output or GDP growth are rather used to pay debts of

Table 2
Degree of multicollinearity (rounded up to 2 decimals).

Variables	R^2
Capital	0.98
Labor	0.96
Petroleum	0.90
Electricity	0.90

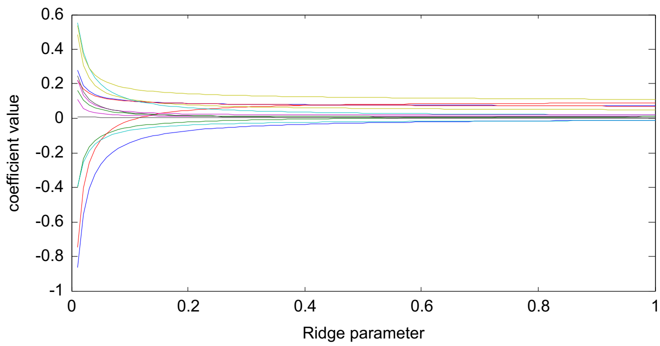

Fig. 3. Ridge trace plot of the coefficient estimate of the ridge regression.

Table 3
Ridge regression estimates.

Variable	Coefficient
LNK	−0.0215
LNL	0.0031
LNP	0.0835
LNE	−0.0177
LNK × LNL	0.0106
LNK × LNP	0.0552
LNK × LNE	0.0031
LNL × LNP	0.0759
LNL × LNE	0.0099
LNP × LNE	0.0745
$(LNK)^2$	0.0268
$(LNL)^2$	0.0200
$(LNP)^2$	0.1176
$(LNE)^2$	0.0012
Ridge *K*	0.65
F-statistics	71.681

Table 4
Output elasticity of alternative inputs in the Ghanaian economy.

Year	Capita	Electricity	Labor	Petroleum
1980	2.140371	1.485574	2.142899	6.529989
1981	2.117959	1.47535	2.131238	6.485946
1982	2.105965	1.484137	2.138349	6.498094
1983	2.099813	1.474696	2.129244	6.465726
1984	2.143745	1.486643	2.147104	6.533087
1985	2.155489	1.476001	2.140373	6.52146
1986	2.166412	1.488736	2.154803	6.567358
1987	2.182867	1.500047	2.168445	6.611947
1988	2.198592	1.511698	2.18226	6.656446
1989	2.2171	1.522189	2.195473	6.700989
1990	2.21439	1.509915	2.184897	6.670121
1991	2.22264	1.510728	2.187902	6.681354
1992	2.219642	1.518912	2.195993	6.701032
1993	2.251192	1.514782	2.198035	6.720142
1994	2.263136	1.532095	2.216747	6.775489
1995	2.263199	1.533786	2.219498	6.781509
1996	2.265872	1.536871	2.223917	6.793787
1997	2.274114	1.533854	2.223509	6.795296
1998	2.274538	1.535518	2.226131	6.800157
1999	2.280902	1.547071	2.238786	6.837009
2000	2.298512	1.559771	2.254093	6.886305
2001	2.308556	1.559455	2.255456	6.895122
2002	2.294805	1.563324	2.25699	6.892185
2003	2.312226	1.569506	2.264999	6.921211
2004	2.330917	1.576223	2.273811	6.954545
2005	2.335801	1.577309	2.275618	6.962829
2006	2.324674	1.578242	2.275045	6.95673
2007	2.324947	1.579247	2.276764	6.95957
2008	2.331978	1.578483	2.278141	6.966044
2009	2.337532	1.588978	2.289377	6.998585
2010	2.364262	1.604071	2.308046	7.061929
2011	2.374554	1.605515	2.311818	7.076909
2012	2.389016	1.605541	2.314848	7.091183
Average	**2.254113**	**1.537099**	**2.144057**	**6.780306**

electricity production and distribution agencies. For example Volta river authority (VRA) and Electricity Company of Ghana (ECG) which are the main energy production and distribution agency in Ghana runs on debt therefore all gains made towards output are being consumed by the debt incurred from these agencies as a result of poor management, high rate of distribution loses and corruption. According to Volta river authority website (vraghana.com) [46] outstanding debt to be paid by the company which is the main electricity producer in Ghana in 2013 alone stands at 1.750 billion usd. Our results clearly indicate that electricity and capital are not positively linked to output of the Ghanaian economy; however these results must be interpreted with care and not to mean that capital and electricity are not important or do not contribute to economic activities in Ghana but rather the positive contribution of these two parameters are being “eroded” through corruption and mismanagement.

Even though the estimated result from Table 3 shows that the Ghanaian output seems to be driven by labor and petroleum, output elasticities have been computed and reported for all the inputs. This is necessary because these results are needed for the computation of substitution elasticities among the inputs. As we can see from the results of the substitution elasticities among the inputs in Table 4, all inputs namely capital, labor, electricity and petroleum shows positive output elasticities which indicate an increasing consumption trend of these inputs over time as the Ghanaian economy grows. The computed output elasticities of all the inputs were found to be elastic with the elasticity of petroleum highlighting the highest degree of responsiveness in output of the Ghanaian economy for a unit change in petroleum consumption. This might be in the positive direction towards increasing the gross domestic product of the country since the recent oil find will make petroleum products readily available for consumption however the environmental hazards posed by this increasing consumption of petroleum must be looked at hence the need for pragmatic policies to find cleaner energy sources and introduce fuel mix where a percentage of cleaner fuel is mixed with petroleum to reduce the impact of CO_2 emissions from future surge in the use of petroleum use as the economy grows.

With results from the output elasticities of the various inputs in Table 4, we computed the elasticities of substitution for the various inputs and results reported in Table 5. The results from Table 5 show elasticities of substitution between capital and labor, capital and petroleum and labor and petroleum having positive and unitary elasticities while capital and electricity, labor and electricity and petroleum and electricity having positive but close to unity elasticity. These results indicate that all input pairs considered in the study are substitutes. The result of substitutability between petroleum and electricity is of great interest to the Ghanaian energy economy due to environmental problems that petroleum consumption might cause in the near future. Although our results from Table 3 show negative contribution of electricity to the economic growth of Ghana, results from Table 5 suggest that there is potential substitutability between petroleum and electricity in the Ghanaian economy which is consistent with findings in the literature including Smyth et al. [27] on Chinese iron and steel sector. Though the results from Tables 3 and 4 are conflicting, the later results imply that Ghana has the potential of switching from GMG emitting petroleum to electricity which is a cleaner energy source if the management of electricity production is improved to minimize distribution losses and reduction of corruption in the power production and distributing sector thereby reducing the adverse effect of environmental hazards from petroleum use, providing energy security by reducing its vulnerability to international oil shocks and reducing its balance of payment

Table 5
Substitution elasticity of alternative inputs in the Ghanaian economy.

Year	σ_{KL}	σ_{KP}	σ_{KE}	σ_{LP}	σ_{LE}	σ_{PE}
1980	0.212380408	1.003808308	0.997910478	1.008576996	0.987724852	0.98646262
1981	0.588759718	1.003860601	0.997861251	1.008629498	0.987702025	0.98637264
1982	0.780694563	1.003905576	0.997758079	1.008606271	0.987664182	0.98637749
1983	0.763356461	1.003910905	0.997779241	1.008646241	0.987675887	0.9863172
1984	0.263922623	1.003798801	0.99792004	1.008565869	0.987785615	0.98646774
1985	2.711618073	1.003754462	0.998020711	1.008587705	0.987866963	0.98647065
1986	5.525364834	1.003741924	0.998006334	1.008528558	0.987892687	0.9865562
1987	2.949819877	1.003711001	0.998021323	1.008472679	0.987931226	0.98664174
1988	2.408016581	1.003682833	0.998031614	1.008417214	0.987966178	0.98672487
1989	1.797758388	1.003646405	0.998057954	1.008363698	0.988012052	0.98681076
1990	1.487819476	1.003639628	0.998101314	1.008403704	0.988050044	0.98676734
1991	1.388389445	1.003619207	0.998128956	1.008390872	0.98809036	0.9867948
1992	1.685165875	1.003638475	0.998082267	1.008362587	0.98808446	0.98682125
1993	1.228401855	1.00354917	0.9982153	1.008347366	0.988199901	0.98688485
1994	1.268486953	1.003540467	0.998187499	1.008277372	0.98821657	0.98697562
1995	1.288839385	1.00354331	0.998180861	1.008268373	0.988234907	0.98698601
1996	1.303848543	1.003541252	0.998177827	1.008252494	0.988257414	0.98700828
1997	1.241843666	1.003516713	0.998218856	1.008252476	0.98830571	0.98702146
1998	1.25497075	1.003517881	0.998213721	1.008244439	0.988321976	0.98702887
1999	1.302302364	1.003516927	0.998189788	1.008198451	0.988335879	0.98708806
2000	1.282865093	1.003488187	0.998200643	1.008140934	0.988375846	0.98717468
2001	1.228335828	1.003462532	0.998236242	1.008133439	0.98840552	0.98719778
2002	1.346695332	1.003502077	0.998173468	1.008132014	0.988362568	0.98717883
2003	1.262418076	1.003464434	0.99820962	1.008100559	0.988391804	0.9872331
2004	1.209781011	1.003425606	0.998246814	1.008065477	0.988425312	0.987296
2005	1.197572542	1.003415332	0.998258856	1.008057544	0.988437369	0.98731324
2006	1.247186147	1.00344498	0.998218079	1.008061919	0.988410634	0.98729546
2007	1.256079699	1.003445549	0.998215108	1.008057077	0.988422647	0.98729952
2008	1.224558469	1.003428107	0.998241737	1.008050957	0.988460287	0.98731772
2009	1.256184793	1.003427572	0.99822015	1.008012088	0.988468249	0.98736687
2010	1.213412066	1.003380876	0.998251787	1.007943499	0.988522957	0.98747674
2011	1.18833215	1.00335872	0.998279772	1.007928649	0.988562099	0.98750848
2012	1.156577557	1.003324514	0.998325127	1.007915595	0.988613079	0.98754241
Average	**1.440053291**	**1.003576131**	**0.998125479**	**1.008272503**	**0.98818719**	**0.98696301**

deficits from importation of petroleum products. In practice, substituting electricity to petroleum will be a "mirage" without implementing pragmatic policies to curb corrupt practices by officials in the power production and distribution sector and also reducing the high rate of transmission losses in the power sector of Ghana. Turning our focus on the substitutability between capital and energy, there has been mix result as to whether these two inputs are substitutes or complements. While Berndt and Wood [13]; Magnus [47]; Fuss [15] and others found capital and energy to be complements, others have found capital and energy to be substitutes (e.g., Griffin and Gregory [48]; Pindyck [4]). In our study, we found substitution elasticity between capital and energy to be positive and close to unity over the sample period and the result being consistent with findings in the literature (e.g. Smyth et al. [27] on Chinese iron and steel sector; Wesseh et al. [11]; on Liberian economy, Vega-Cervera and Medina on Portugal [49]. This result suggests that, removal of energy subsidy and price ceiling to reflect the real cost of energy in Ghana will reduce energy use and increase capital intensiveness. In this study, the substitution type which could be possible will involve the use of manual operation, semi-mechanical and some production process (Smyth et al. [27]; Ma et al. [25]). Looking at substitutability between energy and labor, one can clearly see that there is slight increase over time. Substitutability between energy and labor is a little higher than that between capital and energy which demonstrates the fact that there are more incentives for labor investment than capital inputs which can even be observed from Fig. 2. This should not be a surprise since this is the actual situation in the Ghanaian economy where there has been rising labor investment and relatively low capital incentives.

In this paper, we also made an attempt to assess the relative difference in technical progress of all input pairs considered over time. In this attempt, we employed the aggregate translog production function of the Ghanaian economy and combined them with the output elasticities and estimated coefficients from Eq. (4). The function we used in this calculation can be given as

$$RD_{ij} = (a_i/\eta_i) - (a_j/\eta_j) \tag{19}$$

In the above equation, RD_{ij} represents the difference between technical progress of inputs i and j a_i and a_j are estimated coefficients from Eq. (4) while η_i and η_j shows the output state of technical knowledge. If RD_{ij} is positive it shows a direct indication that the state of technical progress for input i is faster than input j. Negative RD_{ij} however means that the state of technical progress for input j is faster than input i while when RD_{ij} become zero it implies there is equality in technical progress for both inputs. The result of this analysis is presented in Fig. 4. As can be seen, there exists some differences in the relative technological progress of the four inputs however the differences are very small and there is much evidence of convergence in technological progress over time which is an evidence of efficiency in technological progress for the various inputs over time. Apart from capital and petroleum which shows a negative difference in relative technological progress with a slight increase over time, all other resources paired with capital shows positive difference in technological progress over time. On the other hand, the difference in relative technological progress between labor and electricity and petroleum and electricity is positive with slight decline over time while labor and petroleum shows negative difference in relative technological progress.

These results seem to indicate that even though the state of relative technical progress of capital is faster than electricity and labor faster than capital, petroleum is playing a major role in the energy consumption mix of the Ghanaian economy while labor investment is doing better than capital inputs however with

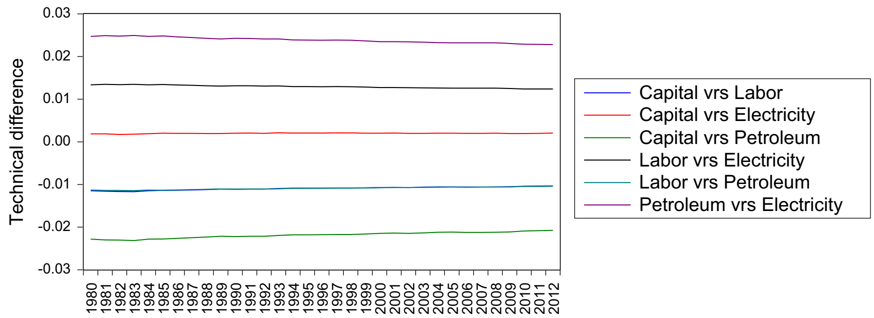

Fig. 4. Difference in technical progress among different inputs.

evidence of convergence suggest there is the potential of substituting electricity which is a cleaner energy source to petroleum over time.

6. Conclusion and suggested policies

In this study, we employed the log linear translog production and cost function to attempt investigating technical change, inter-factor and inter-fuel elasticity of substitution between capital, labor, electricity and petroleum for a yearly classical factor and energy inputs over the period 1980–2012. The ridge regression estimation technique was introduced in our estimation after our data shown evidence of multi-collinearity. Over this period, several findings were documented by the use of empirical applications. First, our finding shows a clear evidence of positive and significant link between petroleum and labor to the Ghanaian economy; however all inputs namely capital, labor, electricity and petroleum were found to be substitutes. Second, our finding shows evidence of convergence in technical progress among the different inputs which is a strong indication that electricity is a substitute for petroleum over time in the Ghanaian industrial economy. This potential switch from GHG emitting petroleum to a cleaner energy source (electricity) will bring the ability to fuel the Ghanaian industrial economy in a cleaner environment and reduce the adverse environmental effects from petroleum use. This switch will also reduce the balance of payment deficit through reduction in petroleum import; provide energy security and limiting Ghana's vulnerability to international oil shocks. This potential switch would be virtually impossible if electricity distribution systems are not improved to reduce the high rate of distribution losses and gearing policies towards reduction of corruption and mismanagement of funds in the power sector. Third, the study unravels a potential substitution between capital and energy which implies that, when energy consumers are made to bear the full cost of energy by removing all forms of energy subsidy and price ceiling will tend to reduce energy use and boost capital formation however labor tends to show a higher substitutability to energy than capital which is a clear indication that labor has a higher investment incentives than capital in the Ghanaian economy. Finally our results indicated a strong convergence in differences in technical progress among all inputs therefore improving on the technological advancement of any of the inputs could make it a potential dominant over each pair over time.

6.1. Policy suggestion

Results from this paper will give a major boost to the Ghanaian energy economy especially in the aspect of international outcry for reduction in CO_2 emission and to contribute its quota to the global climate change mitigation effort more so to fulfill its own shared growth and development agenda in a cleaner environment. Ghana's agenda of achieving universal access to energy by the year 2020 through Ghana energy development and access project (GEDAP) must be carried out vis-à-vis cost and a cleaner environment therefore its future energy policies will target the reduction of CO_2 emissions and minimization of energy production cost. In fact Ghana has set a target of increasing the share of renewable energy (not including large scale hydroelectricity production) in its energy mix from the current pantry of 0.13% to 10% by 2020 and reducing CO_2 emissions by 10% in the same year however this target could be altered significantly following the discovery of oil in commercial quantity in 2010. Overcoming the challenge of balancing Ghana's energy mix will highly depend on pragmatic policies and how industries will respond to the changes these policies will bring.

First, our findings suggests all inputs are substitutes with their differences in technical progress having a convergence outlook which implies all inputs are efficient over time hence government's energy policies aiming at finding alternative energy source could be done by putting more incentive and technological improvement in the promotion of the favored input by the policy. Example, since electricity and petroleum are substitutes, Ghanaian government can put more resources in the development of electricity and also encouraging industries to use electricity by offering various incentives through taxes, subsidies and electricity infrastructural development to promote the switch from GHG emission petroleum to electricity use. According to Wang et al. [50] there exist some level of rebound effect in the Chinese urban residential electricity consumption as a result of government's CO_2 emissions reduction policies through electricity consumption efficiency. This should guide policies by Ghanaian government to take into consideration the effect of electricity rebound. Second, the switch from one factor to another comes with a cost since there is the need for new equipment and machines, technology and new production cost and this will bring a higher capital expenditure which can wholly not be passed on in the form of price increase to consumers. Therefore this might call for government's intervention to implement strategies by building infrastructure, providing tax rebates and if possible providing some form of cost subsidy to various industries to be able to adjust to the high production cost due to change in factor.

Third, Government must formulate policies to curb all factors that will alter the promotion of any input that is highly favored for substitute to the other to enhance the realization of the purpose of the substitutability. Example, substituting electricity for petroleum must be done by putting mechanisms in place to reduce high rate of distribution losses, eliminating corruption and mismanagement in the power sector in the case of Ghana.

Fourth, our findings pointed out petroleum to be the driving force of Ghana's economy and switching from petroleum to other renewables to help reduce CO_2 emission will take a long time therefore government policies must aim at providing incentives for fuel mix programs where consumers will enjoy some form of incentives when they mix a percentage of biodiesel to their petroleum product.

Finally, some researchers (e.g. Smyth et al. [27], Zhang and Wang [51]) have pointed out the significant efficiency advantage of larger enterprises over their smaller counterparts with an insight to larger enterprises' ability to substitute one factor to the other and the resulting productivity effect depending on their sizes thus bringing about merger hence the need for Ghana merger control agency to formulate consistent merger control policies.

Despite the contribution of this study, it is not without limitations after following all econometric procedures however these limitations are deemed to be a new door to further research and model improvement. The ridge regression which has been adopted to solve the problem of multicollinearity also added a degree of biased to the model while trying to correct for multicollinearity hence, the specification in the study should not be considered as a perfect tool.

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