The Impact of Cross-country Heterogeneity on Consumer Energy Efficiency: Evidence from a Panel of African Countries

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The Impact of Cross-country Heterogeneity on Consumer Energy Efficiency: Evidence from a Panel of African Countries

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Abstract

Considering the widespread depletion of global energy resources, the efficient use of energy is required to guarantee energy access and reduce energy poverty. To this end, this study investigates the level of residential energy efficiency for 17 African countries during the period 1980-2011. Using the parametric stochastic frontier analysis (SFA), we estimated residential energy demand and energy efficiency. Further, we modelled the impact of cross-country heterogeneity on the level of energy use efficiency. Results indicate an average efficiency level of 70%, implying modest levels of residential energy efficiency across our sampled countries. Moreover, we observed that cross-country variation in energy efficiency levels is influenced by national characteristics. Based on our results, we argue that energy policies should be conditional on country-specific factors and considerations.

Keywords: Residential Energy Demand, Energy Efficiency, Panel Data, Stochastic Frontier Analysis, Cross-country Heterogeneity

JEL codes: D12, Q4, Q5, C23, C51

1. Introduction

Energy plays an important role in every economy through the provision of services to both consumers and producers. More specifically, energy contributes to consumer welfare through end-use services such as cooling, heating, cooking, and driving. Energy also serves as an input in the production process, alongside capital, labour, and raw materials. Some of the most crucial global development issues such as poverty and climate change are related to energy use. While poverty is linked to limited energy access (energy poverty), climate change is partly attributed to the greenhouse emissions resulting from energy use. Consequently, never has it been more important for governments and policy makers around the world to devise methods and policy actions to manage economic prosperity through adequate and affordable access to energy, while also curbing greenhouse emissions. This encapsulates the regulatory dilemma that governments and energy policymakers face when addressing the issue of energy consumption[1].

In the past two decades, a consensus emerged concerning the potential role of energy efficiency improvement towards improving the productivity of energy services, to the extent that a given level of energy delivers a higher value of satisfaction (or equivalently, a given level of satisfaction is attained using less energy). Therefore, energy efficiency improvement has become a vital component of energy policy formulations, as it can provide the basis for managing and aligning future energy demand with the potential ideal. This is important because energy policymakers are presently encouraging cleaner and more parsimonious use of natural resources in order to improve energy security and access, as well as mitigate the adverse effects of climate change.

The evaluation of energy efficiency in this study is crucial for a number of reasons. First, in practical policy settings, a clear understanding of underlying behavioural and technological aspects of energy markets (backed by reliable quantitative analysis) is required by government and policy makers. More specifically, they require information (estimates) about energy efficiency and the potential of country characteristics (heterogeneity) on energy efficiency. From a regulatory point of view, efficiency benchmark performance can inform and impact energy policy through the provision of information on how to target sources of improvement within their energy systems. Furthermore, it is also possible for policymakers to design energy reforms using the experiences of more efficient countries. This will help in the allocation of scarce public resources towards evidence-based strategies/projects/technologies that have been tested.

Second, this study is made all the more important by the limited number of panel energy efficiency studies across African countries. Of course, the widespread availability of studies on developed countries/regions has contributed to the understanding of energy efficiency trends in these developed countries/regions. This is reflected in the depth and progress of energy (efficiency) policy designs in these regions. Further, due to the growth potential of many developing and fast emerging countries, it is likely that future global energy consumption will be driven largely by developing countries; hence an understanding of efficiency possibilities in developing countries is important.

Third, many African countries have relatively lower end-use energy prices due to energy subsidies, and this has also stimulated higher energy consumption. Therefore, considering the huge future growth potential of many African countries, significantly higher levels of energy consumption will be required to fuel this future growth. More specifically, Wolfram et al (2012) showed that most of the medium-term growth in global energy use will come from developing countries as they lift people out of poverty due to rising incomes. They argued that as households come out of poverty and join the middle income groups, they acquire appliances such as refrigerators, and vehicles which require energy to use and to manufacture.

Fourth, because this study controls for the impact of observable inter-country heterogeneity, it is possible to evaluate the extent to which the prevailing/unique circumstances of sampled countries might have contributed to the efficient use of energy, or otherwise. This is appealing from a policy point of view since Kumbhakar and Lovell (2003) showed that such cross-country effects shape the “operating environment” and affect the level of efficiency in each country, thus they constitute the effect of “natural,” legal or policy-induced barriers across countries (see Milner and Weyman-Jones, 2003). In short, these cross-country effects will pinpoint to policy makers, the country-specific sources (constraints) of variation in energy use behaviour[2]. They can then design policies to influence these constraints accordingly. For instance, a country where switching towards alternative renewable energy will improve energy efficiency may have to provide tax relief or subsidies or less-than-market interests on loans to finance the acquisition of these technologies.

Finally, the efficiency performance frontier yields information on the degree of parsimony required by each country to close the gap between actual and potential energy performance. This information would help policymakers communicate the precise adjustments required to the different stakeholders. Furthermore, the policymakers are then able to incentivize the desired behavioural and technical changes by designing policy actions to support energy infrastructure and eliminate rent-seeking in natural resource extraction. This information will equally equip utilities to better understand how to design and incorporate demand-side management in their business plans. Such programme designs will help to gain higher energy users participation, thereby inducing demand response measures that are customized for each household appliance, such as turning off lighting, air conditioning, non-essential appliances etc.

The residential sectors across most African countries account for a significant proportion of total energy use. Given this data insight, it can be argued that meaningful energy policy designs for African countries require a sound understanding of residential energy demand behaviour. Moreover, as stated above to achieve parsimonious energy use and to restrict the accompanying greenhouse effects, energy efficiency improvements are required in residential energy use.

The remainder of this paper proceeds as follows. Section 2 presents a review of the relevant literature. In section 3, we set out the methodology and data set used in this study. Section 4 contains the preliminary estimation results and offers a detailed discussion on these results. In section 5, we provide concluding remarks and policy insights from the study.

2. Literature review

Africa presently accounts for a relatively small share of global energy consumption. However, continuous/progressive economic growth and development will lift millions out of poverty into the middle-income group and stimulate rapid urbanization; resulting in higher levels of energy consumption and greenhouse emissions (see Goel and Korhonen, 2012). The energy challenges faced by many African countries are well documented by Iwayemi (1998). It can be argued that for the region to ensure sustainable growth and development and eradicate extreme poverty, it is necessary to have affordable, reliable and efficient energy supply (Turkson and Wohlgemuth, 2001). However, given the increasing depletion of global energy resources and the concerns about global climate change, the attainment of these objectives is a huge challenge.

One of the most widely acceptable approaches to addressing this issue is through energy efficiency improvements. Thus, the estimation of energy efficiency has become more prevalent in recent energy economics literature. The two broad approaches to estimating energy efficiency are the parametric stochastic frontier analysis (SFA) and the non-parametric data envelopment analysis (DEA). Both methods construct a frontier against which units (firms or countries) in a sample are benchmarked, with the distance between each observation and the frontier representing a measure of 'slack' or inefficiency. The DEA and SFA employ different methodologies in constructing this frontier estimation. While the DEA has the advantage of flexibility, in that it makes no underlying assumption about the estimated function, it has the disadvantage of assuming no random white noise, that is the DEA attributes all the errors in the model to firm or unit inefficiency. The SFA, on the other hand, allows for a composed error term containing a traditional symmetric error term to capture sampling and specification errors; and a one-sided error term to capture inefficiency. Although the SFA's weakness is that it makes assumption about the estimated function, it can be argued that its allowance for a composed error term is plausible and closer to reality. Given these considerations, this study employs the SFA approach, so that subsequent literature review focuses on the SFA.

One of the early empirical SFA studies is Buck and Young (2007) who estimated an aggregate energy demand frontier for a sample of Canadian commercial buildings while also controlling for building characteristics. Boyd (2008) estimated an energy use frontier function for a sample of US wet corn milling plants. Filippini and Hunt (2011) estimated aggregate energy efficiency for 29 OECD countries using an energy demand

SFA. Similarly Zhou et al (2012) estimated a stochastic energy demand function for a sample of 21 OECD countries. More recently, Filippini and Hunt (2012) also estimated energy efficiency in residential energy demand for a panel data of 48 American states.

From the brief review of literature above, it can be seen that most of the available energy efficiency studies have focused on OECD and other developed economies of the world. Considering the importance of residential energy demand across Africa, and the need for efficient energy use across these countries, it is surprising that, as far as is known, a study on the level of efficiency and the potential impacts of country-specific heterogeneity on efficiency across several African countries has not been conducted previously. This is an important gap in literature, which this study will attempt to fill. The premise for an energy efficiency study for a sample of African countries is different from that of OECD countries. While studies on OECD countries are focused on the contributions of efficiency savings towards greenhouse emissions reduction (and towards meeting emissions targets), this study is focused on investigating the factors that can potentially explain energy efficiency. More specifically, in the OECD countries, one could argue that the focus is on correcting market failure arising from environmental pollution, while this paper is focused on the potential to reduce the problem of policy failure by understanding the major drivers of energy efficiency. Although the contexts are different, in both cases, an optimization problem arises, which the frontier approach to analysing efficiency addresses.

3. Methodology and data

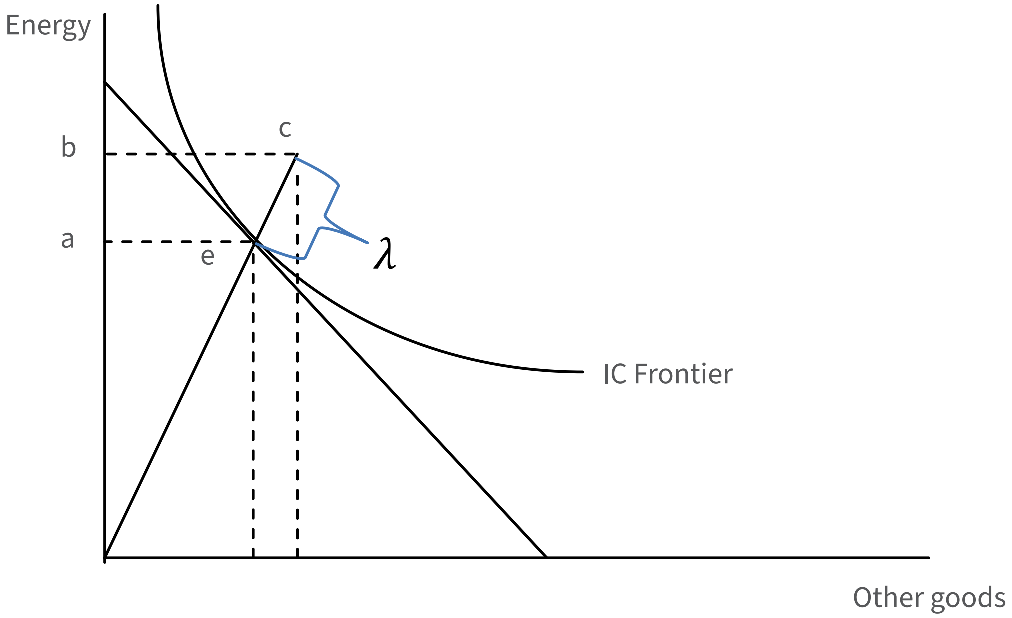
In this study, we estimated an energy demand frontier for our sample of African countries using the stochastic frontier analysis (SFA) (Aigner et al, 1977; Meeusen and van den Broeck, 1977). The SFA allows for a composed error term comprising a traditional two-sided error term which captures random noise and a one-sided error term to measure inefficiency. The objective is to estimate energy efficiency by constructing a "best-practice" energy demand frontier against which we can unravel the degree to which a country could potentially reduce residential energy use, relative to this efficient frontier.

We proceed by specifying the model used in this study. Following a number of studies (Liu, 2004; Filippini and Hunt, 2011), it is assumed that the residential energy demand function of each country in our sample can be written in panel context as:

$$E_{it} = f(P_{it}, Y_{it}, \boldsymbol{z}_{it}, \delta t) \tag{1}$$

where E_{it} represents residential energy consumption of country i in time t, P_{it} denotes energy price, Y_{it} is income (given by GDP), while $\boldsymbol{z}_{it}$ is a vector[3] containing several cross-country factors such as climate, tastes, technology, geography, economic structure, size and trade; δt captures technological progress through a time trend. Our modelling objective is to construct a residential energy demand frontier for the countries in our sample. This frontier represents the efficient or "best-practice" level of residential energy demand, which is demonstrated in Figure 1.

Figure 1: Frontier of consumer preference



Assuming a consumer purchases two goods (energy and "other goods") with his income, so that his preferences can be formulated into an indifference curve. The IC frontier represents the efficient consumption bundle, since it is the highest possible energy consumption level, given his/her income. However, if the consumer is located at point c, it is easy to see that this yields a greater level of energy use, but is above the frontier[4]. The distance between point c and point e is a measure of energy inefficiency, which this study measures[5]. To measure this energy efficiency we estimate λ, which is the distance between point c and the estimated frontier. In other words, we would estimate the maximum magnitude of λ by which a country's energy demand can be radially contracted, while the initial level of satisfaction remains feasible. To this end we may re-specify Equation 1 as a frontier function:

$$E_{it} = \alpha_i + \beta_1 P_{it} + \beta_2 Y_{it} + \boldsymbol{\pi} \boldsymbol{z}_{it} + \delta t + v_{it} + u_{it} \quad (2)$$

where all variables remain as previously defined, a_i is a country-specific intercept term while π' contains the estimated coefficients on the cross-country variables. As stated previously, the SFA allows for a composed error term with two components: v_{it} is the traditional error term representing white-noise, which captures sampling, specification and measurement errors, while the non-negative one-sided error term

v_{it} is a measure of the distance or slack in energy use, relative to the frontier. It is a measure of the feasible contraction of energy required to project an inefficient country onto the efficient frontier. u_{it} is treated as a random variable distributed across sampled countries with a known asymmetrical probability density function and it is estimated as the conditional expectation of the one-sided error term, exp(u), given the composed error, $v + u$:

$$E[u_{it} | v_{it} + u_{it}] \tag{3}$$[6]

$$\text{where } \varepsilon_{it} = v_{it} + u_{it} \tag{4}$$

In other words, the source or measurement of efficiency is obtained by deriving the probability density function for u, conditional on every numerical realization of the composed error term ε_{it}. As shown by Filippini and Hunt (2012), the energy efficiency of each country i in period t is given by:

$$Eff_{it} = \frac{E_{it}^{Min}}{E_{it}} = exp(-u_{it}) \tag{5}$$

E_{it} is the observed level of energy demand while E_{it}^{Min} is the minimum possible energy demand which is on the frontier. In terms of our interpretation of model results, an efficiency value of one indicates a country is on the frontier (100% efficient), while a value lower than one (100%) indicates energy inefficiency.

Cross-country characteristics and energy efficiency

The typical frontier analysis assumes homogeneity of consumers by constructing a common frontier, against which sample countries are benchmarked, so that the estimated efficiency is attributed solely to consumer choices. But in reality, consumers across different countries differ in terms of their circumstances (e.g. climate, tastes, geography, area size, economic structure, energy policies/regulations etc.), to the extent that these cross-country effects (heterogeneity) are likely to influence consumer behaviour (and by extension their level of energy efficiency). Hence, it is possible to relax the assumption of homogeneity of consumers by allowing cross-country heterogeneous variables to affect the level of consumer efficiency. This approach is useful in econometric modelling of frontier functions because it allows us to capture the exogenous circumstances facing consumers across different countries which affect the level of their energy efficiency (see Kumbhakar and Lovell, 2003)[7].

There are two broad approaches to introducing exogenous variables into the efficiency term. Under the first approach, efficiency term u_i is assumed to follow the truncated normal distribution, but the constant mean assumption is relaxed so that the mean of the pre-truncated inefficiency distribution is parameterized (i.e. the inefficiency is a function of the exogenous variables)[8]:

$$u_{it} \sim N^{+}(\mu_{it}, \sigma_{it}^{2}) \tag{6}$$

Here the mean of the inefficiency term is given by $\mu_{it} = \boldsymbol{\varphi}' \boldsymbol{z}_{it}$. Where $\boldsymbol{z}_{it}$ contains variables such as temperature, population density, trade openness, urbanization, industrialization, and quality of governance. These variables are all defined in the data section below. Under the second approach, the exogenous effects are introduced into the inefficiency term by scaling its distribution so that the assumption about constant variance of the truncated normal distribution is relaxed. In this case the variance is a function of the exogenous variables[9]. A number of notable papers jointly referred to as RSCFGH[10] parameterize the variance of the pre-truncated efficiency distribution as follows:

$$u_{it} \sim \mathcal{N}^{+}(0, \sigma_{u_{it}}^{2} \tag{7}$$

$$\sigma_{u_{it}}^{2} = \exp(\boldsymbol{\gamma}' \boldsymbol{z}_{it}) \tag{8}$$

Alvarez et al (2006) provide a technical explanation of the practical advantages and the desirability of the scaling property. They show that scaling offers an intuitive economic interpretation in that u_{it} is taken as a country's base efficiency level, which captures natural abilities within the country, which is assumed to be random, so that the extent to which these natural abilities or skills are exploited depends on the operating environment which is captured by exogenous influences, z_{it}. The scaling property also allows for a straightforward interpretation of the parameter $\boldsymbol{\gamma}$ because scaling functions such as the exponential function, yield coefficients that are derivatives of the log of efficiency with respect to the exogenous variables: $\gamma = \partial \ln{(u_{it})} / \partial z_{it}$ for $u_{it} = \exp(\boldsymbol{z}_{it}, \boldsymbol{\gamma}) \cdot u_{it}{}^{*}$ so that the coefficients can be interpreted as the quantitative effects of exogenous variables on inefficiency.

Hadri (1999) extends the RSCFGH specification to the case where the variance of the two-sided error term is also assumed to be a function of the two-sided error term:

$$v_{it} \sim \mathcal{N}(0, \sigma_{v_{it}}^{2}) \tag{9}$$

$$\sigma_{v_{it}}^2 = \exp(\boldsymbol{\delta}'\boldsymbol{z}_{it}) \quad (10)$$

We estimated the three models specifications[11] and selected the model that provides the best fit for our model using diagnostics such as the Likelihood ratio (LR) and Wald tests.

Data set

This study is based on a panel data set, constructed for 17 African countries[12] over the period 1980-2010, comprising 497 observations in total. The size of our data sample derives largely from the limited availability of data, especially for energy consumption and energy prices. We are therefore constrained to eliminate countries for which we could not find the key or core variables (energy use and energy price).

Table 1: Descriptive statistics

497 Observations	Variable	Mean	SD	Min	Max
Per capita residential energy use (toe)	E	0.219	0.119	0.046	0.542
Energy price (2005=100)	P	65.030	43.368	0.082	222.426
Per capita household income (2005 ppp)	Y	1610.353	1721.650	81.441	11719.70
Industrial share of value added (%)	IND	31.574	14.367	6.419	78.664
Trade openness (%)	OPEN	65.421	25.354	6.320	156.862
Temperature (Degree Celsius)	TEMP	23.396	3.088	16.920	29.380
Pop. Density (ppl per sq. km of land area)	DENSITY	46.763	32.574	2.421	175.355
Urbanization rate (%)	URBAN	42.303	16.076	10.410	77.563
Institutions (political rights)	INST	4.970	1.607	1	7
Subsidy (1=Presence of subsidy, 0 otherwise)	SUB	0.728	0.445	0	1
Alternative energy tech (% of total energy use)	ALT	2.210	2.915	0	13.881

Our data set relies heavily on information taken from different sources as follows: our dependent variable E, is the per capita[13] residential end-use energy demand and it is derived by dividing total final residential energy consumption (in ktoe) by total population. It is important to clarify that this total residential energy demand contains the different energy sources (e.g. electricity, gas, coal, petrol etc). Y is the per capita income which is derived using the labour share of national income by multiplying this labour share and real GDP to obtain total household income. Both variables are taken from the Penn World Table (PWT Version 8.0) (Feenstra et al, 2013). Total household income is then normalized into per capita terms by dividing by population. P, the end-use energy price, is defined as consumer energy price index available on the ILOSTAT database and Thompson DataStream.

As explained previously, cross-country heterogeneity is captured using a number of observable exogenous variables, which were all obtained as follows. Population density measures the impact of size of a country or the dispersion of people. It is defined as people per sq. km of land area. Trade openness allows us to evaluate the channels through which international flow of goods and services may impact energy efficiency. It is defined as the sum of exports and imports of goods and services as a share of GDP. Urbanization is the rate or ratio of people living in urban areas. This variable allows us to capture the shifts in population across a country. Industrialization allows us to assess the impact of changing economic structure on energy efficiency. It is defined as industrial sector share of value added. To capture the effect of diffusion of energy technology on energy use, we included a variable "alternative energy technology," which is the share of renewable and other energy technologies in total energy use. These five variables — population density, trade openness, urbanization, industrialization and alternative energy technology — are all downloaded from the World Bank development indicators database.

We have also controlled for the effect of energy subsidies using a dummy variable which indicates whether energy subsidies are present in a country (presence of subsidy=1 and 0 otherwise). To identify these countries in order to derive this dummy variable, we followed cross-country information on energy subsidies found in IMF (2013a, b). Finally, temperature captures the impact of climatic variation and it is represented by the average annual temperature in degree Celsius. This is obtained from the Tyndall and UNDP climate databases. We also account for the role of institutions, since strong institutions are required to pursue the required energy sector reforms towards improving energy efficiency. The institutions variable is represented by the Index of the level of political rights, which we obtained from the Freedom House Database. The descriptive/summary statistics of the data set are presented in Table 1.

4. Empirical results

Estimates from SFA model

The main results of this study are presented in this section. Before proceeding to any estimation, we attempt to verify the nature of the error structure of our data set. The typical stochastic frontier function assumes homogeneity of producers and homoscedasticity of the errors. However, as shown in some empirical works, in the presence of heteroscedastic errors, it is possible to relax these assumptions by introducing exogenous variables into the error terms. Kumbhakar and Lovell (2000) argue that failure to control for observable heterogeneity in the components of the composed error term can create considerable bias in the inefficiency estimates and this may affect inferences derived from the SFA model. Hence, it is in this light that our model estimation is predicated on the assumption that the errors are heteroscedastic in nature.

However, to avoid arbitrary assumption of heteroscedastic error structure across our panel data, we conducted robustness checks using the LR test procedure recommended by Wiggins and Poi (2001). The LR test approximately follows a chi-square distribution by nesting the homoscedastic model in the heteroscedastic model under the null hypothesis of homoscedasticity. The LR chi2 (16) = 427.91 clearly rejects the null, indicating the presence of heteroscedasticity in the data structure. We then proceeded to estimate the heteroscedastic SFA model where we allowed the cross country variables to influence the inefficiency component of the error. We also estimated the alternative Hadri99 double-heteroskedastic model where the cross-country variables are allowed to influence both the inefficiency component of the error, as well as the traditional one-sided idiosyncratic error term.

To select a preferred model, we then tested the Hadri99 double-heteroscedastic as an unrestricted version of single-heteroscedastic model under the null that the parameters in the variance of the two-sided error are jointly zero. The LR test statistic is given by $LR = 2(\ln L_U - \ln L_R)$ where L_U is the maximized value of the log likelihood of the unrestricted model and L_R is the maximized log likelihood of the restricted model. The LR test statistic is asymptotically distributed as a chi-square distribution χ_p^2 , where p represents the number of restrictions (six in our case). This test returns an LR-stat value of 306.22, which again clearly exceeds the chi-square distribution value of 16.81 for 6 d.f. This is strongly supported by the Wald test statistic of 722.20 which also exceeds the chi-square distribution at 1%.

Table 2: Estimated SFA panel model

Double-HET Model	Coefficient
Constant	0.396***
	(0.014)
Energy Price	-0.051**
	(0.023)
Per capita income	0.022
	(0.030)
Temperature	-0.103***
	(0.006)
Time	0.012***
	(0.001)
Inefficiency Regression (u_it)	
Alternative technology	-0.089**
	(0.042)
Industrialization	0.041***
	(0.014)
Institutions	-0.208***
	(0.067)
Population density	1.370***
	(0.137)
Subsidy	1.594***
	(0.260)
Trade openness	-0.013**
	(0.006)
Urbanization	0.105***
	(0.012)
Log likelihood	-142.01

Standard errors in parentheses. *, **, *** denote statistical significance at 10, 5 and 1%, respectively

Therefore, based on the range of diagnostic checks conducted above, we conclude that our data set favours the double-heteroscedastic SFA model where exogenous variables influence both the inefficiency term and the two-sided error term. Thus, all our subsequent analysis is based on our preferred model, the Hadri99[15] which is presented in Table 2. The preferred model shows that the estimated coefficients have the expected signs and are statistically significant, with the exception of per capita income.

Since the energy price and per capita income variables are in logarithmic form, the estimated coefficients can be directly interpreted as price and income elasticities, respectively. The estimated own price elasticity and income elasticity are about -0.051 and 0.022 respectively, and they are somewhat lower (in absolute terms) than most other previous studies on developed economies. The elasticities indicate that, ceteris paribus, a 1% increase in income will on average result in a 0.022% increase in residential energy use, while a 1% increase in energy prices will likely reduce residential energy use by 0.051%. The coefficient on temperature is negative, implying that energy consumption decreases as temperature rises. This result is consistent with the findings of Petrick et al (2010) who found a negative relationship between residential energy demand and annual temperature for an unbalanced panel of 157 countries over three decades. Similarly, Bigano et al (2006) established that residential energy responded negatively to temperature increases for some OECD and non-OECD countries.

The inefficiency effects[15] (i.e. the impact of cross-country factors on residential energy efficiency) are all significant and largely have the expected signs too. We go into greater detail on the inefficiency effects results in the next section.

Cross-country efficiency effects

Turning to the cross-country heterogeneity, we incorporated several exogenous variables into the analysis by allowing the variables to affect the level of energy efficiency performance. Overall, estimation results suggest that indeed, cross-country differences partly explain the level of energy efficiency across sampled countries. This implies that meaningful attempts to increase residential energy efficiency must embody country-specific considerations. Our results indicate that larger countries in terms of population density appear to be more energy inefficient. Similarly, we find that countries with higher levels of industrialization and urbanization are found to have higher levels of inefficiency results. The population density variable captures the number of people per sq. km of land area and the coefficient on this variable indicates that as more people cluster in an area, they tend to use energy inefficiently. The results on population density, urbanization and industrialization are not surprising, considering the inter-linkages and in-relatedness between these three factors which usually mean that they move in the same direction. In other words, as shown in studies such as Deng et al (2008), these variables (urbanization, industrialization and population density) are likely to have similar impact on energy use (in terms of direction of change or nature of relationship with energy demand).

Turning now to the impact of industrialization on residential energy efficiency, the result supports Schafer (2005) who argued that during initial stages of development, most of the energy is consumed in the residential sector, essentially for heating and cooking and relying heavily on biomass (including fuel wood, switch grass, cowdung, etc.) with its comparatively inefficient combustion. He showed that the onset of industrialization and build-up of energy-intensive infrastructures, industrial energy use and carbon emissions arise more strongly.

The result on trade openness shows that trade plays a role as a channel of technology transfer and diffusion. In the trade literature, it is well established since the work of Coe and Helpman (1995) that technology spills over across countries through the channel of trade flows. More specifically, Gallagher et al (2012) showed the vast majority most of the technology transfer that occurs in the economy is conducted by private companies through licensing arrangements, foreign direct investment, and trade.

The coefficient and the sign on energy subsidies are not surprising at all, indicating that countries with energy subsidies have greater levels of energy inefficiency. A more striking observation is the size of the subsidy effect, which is shown to be the largest amongst the inefficiency effects in terms of magnitude. This confirms the a priori expectation that energy subsidies represent a key source/determinant of energy inefficiency. Moving now to the coefficient on alternative energy, this is shown to increase efficiency, such that countries with more diverse energy sources/mix (i.e. countries with greater share of renewable and alternative sources of energy) are more energy efficient. This finding is consistent with IAE (2015) that through diversification, alternative renewable energy sources offer the benefit of reduced fossil fuel dependency, reduced local air pollution and increased access to modern energy services that are less intensive. This should alert policymakers to the long-term potential of renewable energy to improve energy efficiency.

Finally, it is shown that countries with better institutions are likely to be more energy efficient. This is consistent with DeCanio (1998) who found that bureaucratic and organizational barriers could limit energy-saving investments. As shown by Painuly (2001), some barriers (e.g. regulatory and institutional) to energy efficient technologies may be specific to a country or a region.

Having discussed the results on the efficiency effects, it is important to elaborate on how/why these country-specific factors matter, especially in terms of the energy efficiency benchmark, and particularly for the purpose of energy policy reforms. The cross-country efficiency effects provide a conditional basis/guidance on policy reforms arising from the energy benchmark. For example, since results from this study indicate that trade openness tends to improve energy efficiency; "less-open" countries can draw policy experiences from countries with greater levels of trade openness that are more energy efficient. In the same vein, the results on energy subsidies imply that countries with large energy subsidies per GDP (or per capita) can derive policy insight from countries that have reformed/eliminated energy subsidies. In addition, such countries can also undertake a "treatment-type" approach, whereby the energy pricing strategy of non-subsidy countries are also considered ex-post policy reforms.

Having interpreted and discussed our preferred model, we now shift our attention to the estimated energy efficiency from the model. In the next sections, we set out and discuss the efficiency scores from our preliminary modeling work.

Estimates of energy efficiency

The descriptive statistics of estimated efficiency scores are given in Table 3. An efficiency score of 100% for a country would indicate that such a country possesses the relative 'best practice' level of residential energy which yields the highest possible amount of satisfaction for a given level of energy consumption.

Table 3: Summary of estimated energy efficiency scores

	Summary measure
Min	0.137
Mean	0.703
Max	0.991
Std. dev.	0.221

Based on the results, it is shown that the overall average level of energy efficiency across our sample countries during the 1980-2010 period is 0.70. We identify reasonable variation in estimated efficiency levels across countries and overtime, as shown by the standard deviation of 0.22. The country closest to the estimated frontier has an efficiency level of 0.99 while the lowest efficiency score recorded across the sample is 0.14.

Table 4 presents the average efficiency scores and rank for each of the countries in our sample over the entire study period[16]. The efficiency estimates show that Zambia is the closest to the estimated demand frontier, while Kenya and Ethiopia appear to be close to the frontier as well. Conversely, the estimates show that Morocco had the least relative level of energy.

In terms of the estimated distance function, one could summarize by saying that, relative to Zambia, the average efficiency level of 0.70 shows that for the typical country in our sample, there is scope for improved energy use performance by countries in our sample by reducing inefficient energy use by 30%. In particular, we find that, based on the efficiency scores, MENA countries such as Morocco, Tunisia and Egypt appear to be the farthest from the frontier[18]. In fact, one intriguing discovery that can be inferred from our analysis is that energy efficiency is region-specific as the countries that are close to the frontier (i.e. the most efficient) are from the Southern and Eastern Africa regions[19] while at least three efficient countries are from the MENA region. A closer look at the IEA energy subsidy data, for instance indicates that Egypt's subsidy per capita in 2014 stood at $276 with the total subsidy representing 8% of GDP.

Table 4: Energy efficiency scores and rank by country

Country[17]	Average	Rank
Algeria	0.633	12
Botswana	0.919	4
Congo	0.689	10
Côte d'Ivoire	0.851	7
Egypt	0.468	15
Ethiopia	0.929	3
Ghana	0.793	8
Kenya	0.954	2
Libya	0.690	9
Morocco	0.207	17
Nigeria	0.610	14
Senegal	0.611	13
South Africa	0.650	11
Tanzania	0.892	5
Togo	0.856	6
Tunisia	0.386	16
Zambia	0.956	1

5. Conclusion and policy recommendations

This study attempts to estimate residential energy efficiency across 17 African countries. To achieve this, we estimated a stochastic frontier energy demand function to model energy efficiency across sampled countries. In addition, we attempt to model the effects of cross-country heterogeneity on the estimated energy efficiency.

The estimated levels of energy efficiency in this study indicate an efficiency of 70%. Further, in line with Milner and Weyman-Jones (2003), we found significant cross-country variation in energy efficiency levels. This is consistent with our observation about the influence of cross-country characteristics on relative energy efficiency levels. Estimation results suggest efficiency-reducing effects from population density, urbanization and industrialization. Conversely, it seems that trade openness and strong institutions improved energy efficiency over the sample period. Based on the results in this study, it appears that policies aimed at improving energy use need to carefully consider these cross-country characteristics. We offer the following policy considerations.

Given the results on population density and urbanization, a policy strategy across sampled countries would be to explore the concentration arising from population and urban clustering. Kassakian et al (2011) elucidated that electricity system losses tend to decline somewhat with increasing population density, since clustered dwellings can be served by nano-grid power systems. This could result in less power loss and increase overall system efficiency and mitigate the issue of energy access (see Welsch et al, 2013). This is supported by Lariviere and Lafrance (1999) that high-density cities use less electricity per capita than low-density ones.

On industrialization, the policy strategy would be to reduce system inefficient industrial processes, equipment and plants (Geller et al, 2004). This could be achieved through tax breaks and alternative energy subsidies with the aim of encouraging energy-efficient best practices from the outset in new industrial facilities. Further, Mckane and Price (2007) argued for a portfolio of industrial policies that is designed to assist companies in developing this supporting context for energy efficiency, while also providing consistency, transparency, engagement of firms in programme design and implementation, and, most importantly, allowance for flexibility of industry response.

The coefficient on trade suggests that sample countries can use foreign trade as a channel for foreign technological spillover (see Liao et al, 2009). One policy approach is to attempt to exploit technological progress through cross-border learning and research and development (R&D) (see Fischer and Newell, 2008). One channel could be the encouragement of FDIs that have the potential for transmission and diffusion of energy technology.

The impact of institutions suggests that vibrant regulatory bodies can contribute towards more efficient use of energy. This speaks to the potential role of economic and political reforms in improving energy efficiency across African countries. Energy regulators and policy makers need to develop a package of economic, financial, technological and behavioural incentives to support energy-efficient practices. One way to start is to facilitate educational and awareness-raising campaigns, provision of information, promotional and training programmes and demonstration projects across sampled countries.

Finally, as is the case with econometric studies of this nature, our analysis and results are limited by data availability, but we have demonstrated, to a reasonable degree of confidence, the dimensions of energy demand using well-established modelling procedures and available data.

Notes

1. This study is focused on residential energy consumption. The residential sectors across most African countries account for a significant proportion of total energy use (See IEA, 2014). It can therefore be argued that meaningful energy policy designs for African countries require a sound understanding of residential energy demand behaviour.

2. Furthermore, because countries differ in many ways (e.g. in terms of size, economic structure, geography, climate etc.), these differences may affect energy consumption behaviours. These differences shape the underlying circumstances in each country, and this is likely to result in varying energy configurations and practices. Hence, policymakers/governments need these expositions to enhance policy effectiveness and reliability of energy planning and projections.

3. Later on, we show how the stochastic frontier model allows these z-variables to enter into the different parts of the model.

4. Of course at the first time of asking, it would appear that point c yields a greater level of satisfaction since it appears to be higher than point e. However, microeconomic intuition suggests that point c is unaffordable to the consumer since it exceeds his budget line. In reality, point c is possible in the presence of energy subsidies and weak environmental regulations, which allow consumers to extract and use energy resources at a social cost. This consumption arrangement is in fact a basis for inefficient energy demand across many countries today.

5. The idea here is that we want to model the minimum possible energy use for a given level of income and at a given energy price.

6. E in Equation 3 is the conditional mean of the efficiency distribution, which is different from E_{it}, the energy consumption variable. Using this conditional term E is the standard econometric representation of the conditional expectation of the inefficiency term, so we retain the same notation as in the wider literature.

7. Failure to account for these exogenous effects may potentially result in omitted variable bias.

8. Models under this first approach include Kumbhakar et al (1991); Huang and Liu (1994); and Battese and Coelli (1995). The three models are jointly classed as KGMHLBC.

9. The impact of exogenous variables on the variance of inefficiency is particularly crucial since the variance parameters of the model are the key devices in the estimation of inefficiencies.

10. Including Reifschneider and Stevenson (1991), Caudill and Ford (1993), Caudill et al (1995) and Hadri (1999).

11. We also estimated the true-SFA models suggested by Greene (2005) to control for the persistent effect of energy subsidies across African countries. We are grateful for the comments of resource persons of Group 5 during the Bi-annual conference where we were alerted to the possibility that these subsidies potentially represent a major source of inefficiency.

12. Algeria, Botswana, Congo, Côte d'Ivoire, Egypt, Ethiopia, Ghana, Kenya, Libya, Morocco, Nigeria, Senegal, South Africa, Tanzania, Togo, Tunisia and Zambia

13. We are grateful to the resource persons who suggested that we convert our key variables such as energy consumption and income to per capita basis in order to address the challenges arising from size and outlier bias in the data set.

14. We are grateful for the comments from a number of resource persons regarding the need to capture and/or separate subsidy effects from inefficiency since energy is subsidized by a good number of African countries. To this end, we have introduced a dummy variable to capture the subsidy effects.

15. It should be noted that the efficiency effects shown in Table 2 indicate the impact of the exogenous variables on energy inefficiency, such that our interpretation is that if a variable increases inefficiency, then it invariably decreases efficiency.

16. It is important to note that the estimated resource efficiency of each country cannot be interpreted as the position of each country (in itself or on its own), but a relative measure of a country's natural resource efficiency compared to the most resource efficient country on the frontier (as well as the other countries in the sample).

17. Best practice and least efficient countries in bold italics.

18. Our suspicion on the MENA results is that the efficiency scores might be picking up some subsidy effects. This underscores the need for further evaluation of the effect of subsidies on energy use behaviour across our sample. Our tentative approach of using the True-fixed effects model to pick up some of this subsidy effect clearly shows that when we introduced the country-fixed effects, the energy price co-efficient becomes statistically insignificant, meaning that the fixed effects estimator may be purging the subsidy effect from the price variable. This estimation result is presented in the appendix.

19. We are particularly grateful to Ann Veiderpass for bringing it to our notice that Ethiopia, for instance has a lot of Hydro and wind energy potential (similar to Norway) which permits more efficient energy delivery, especially when/where grid operations are difficult. It is also the case that, in instances when/where grid operations are difficult to deploy, solar lanterns can be useful.

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Appendix

	Variable	Derivation	Data Sources
Per capita residential energy use (toe)	E	Total residential energy/ population	IEA and WDI
Energy price (index 2005=100)	P	Consumer prices, electricity and other fuels	ILOSTAT and Datastream
Per capita household income (2005 ppp)	Y	(Labour share*Real GDP)/ population	Penn Word Tables and WDI
Industrial share of value added (%)	IND	Industrial sector share of total economy value added	WDI
Trade openness (%)	OPEN	Sum of exports and imports of goods and services/GDP	WDI
Temperature (Degree Celsius)	TEMP	Annual average temperature	Tyndall database
Pop. Density (ppl per sq. km of land area)	DENSITY	Number of people living per unit of total area size	WDI
Urbanization rate (%)	URBAN	Population living in urban areas/Total population	WDI
Institutions (political rights)	INST	Index of the level of political rights	Freedom House Database
Subsidy (1=Presence of subsidy, 0 otherwise)	SUB	Dummy: 1 if energy is subsidized, 0 otherwise	IMF (2013 a, b)
Alternative energy tech (% of total energy use)	ALT	Renewable and other energy sources/ total energy use	WDI

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