EFFECT OF ENERGY REBOUND MAGNITUDE ON ELECTRICITY CONSERVATION IN SELECTED AFRICAN COUNTRIES

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ABSTRACT

Energy efficiency has especially been touted as potentially viable for scaling down the energy consumption of countries. Nonetheless, economists have questioned the potency of efficiency policies in reducing energy consumption due to the so-called rebound effect. The size of this effect has however been debated and contested, particularly in energy underserved regions of developing countries. This study employs a stochastic frontier model and a Generalize Method of Moment to investigates the magnitude of the rebound effect and examine its effect on electricity conservation in 29 African countries between the period 2010 to 2019. Based on the country grouping adapted in the study, the result suggested an average rebound size of 0.74% and -0.28% for low-income economies and 0.029% and -3.86% for high-income economies within the short and long term respectively. In addition, the result revealed that all the countries with partial and super-conservation rebound effects had an encouraging electricity conservation potential both within the short- and long-term. However, the contrary was true for countries with backfire rebound effects. The study, therefore, recommends the need to reinforce energy efficiency initiatives through efficiency standards and labeling in appliances and construction as well as subsidies on efficient electrical appliances and for energy audits.

Keywords: Rebound effect, energy efficiency, stochastic frontier analysis, Africa

INTRODUCTION

Ever since the 1970s, energy efficiency has widely been considered a potentially cost-effective and environmentally sustainable means of reducing consumption of unclean energy and cutting back on associated carbon emissions. However, economists remain skeptical about the potency of efficiency improvement in reducing energy demand since efficiency improvement is associated with a fall in effective energy prices which in turn incentivizes the consumption of more, rather than less energy services (Greening, Greene & Diglio, 2000). This so-called rebound effect was first idealized by Jevon (1865) and popularized by Brookes (1978), Khazoom (1980) and Saunders (1992). The effect has now become an important part of climate policy and plays a crucial role in understanding the potency of efficiency policies in achieving sustainable development. But questions about its magnitude and effect are still unclear; and remain much more debated in developing countries where energy needs are largely unmet, but also significantly generated from unclean sources (IEA, 2017; Thomas, 2012).

What is known about the rebound effect is based upon a large and growing body of empirical literature. Although, over the last four decades, much more information have been available on the rebound effect, however, the absence of a common definition as well as a clear mechanism through which the effect manifest remains a major theoretical issue (Sorrell, 2007; Gillingham et al. 2015). In addition, issues relating to a commonly accepted method of determining the effect and comparing results across studies have equally generated huge controversies (Zhang & Lawell, 2017; Zhou, *et al*., 2018). Greening et al. (2000) however conclude that the type of efficiency improvement introduced to estimate the rebound effect is of crucial importance and significantly minimizes potential computational bias. Nonetheless, a more accurate estimate of the rebound size would require a correct measure of efficiency, a comprehensive data set, and a robust methodology.

Previous studies have tried to estimate the rebound effect from three types of efficiency sources. One set of studies infer the rebound size from estimates of own-price elasticity of specific energy types (e.g. Stapleton, Sorrell & Schwanen, 2016; Zhang & Lawell, 2017). However, works in this category erroneously assume that energy consumers respond to price and efficiency changes alike. Another strand of literature examines the effect of arbitrarily assumed level of efficiency improvement in triggering the rebound effect (e.g. Wei & Liu, 2017; Zhou, *et al*., 2018). However, these studies are unfortunately based on questionable market and institutional. The last group of studies elicits the rebound size from estimated economy-wide technical efficiency levels (e.g. Orea, Llorca & Filippini, 2015; Adetutu *et al*., 2015; Kipouros, 2017). These latter studies interestingly utilize estimated technical efficiencies to determine countries' rebound sizes. Nonetheless, how this is modeled possibly creates significant bias and therefore potentially miscompute actual rebound sizes.

Most studies in the rebound literature focus on rebound sizes emanating from efficiency improvement in energy sources such as coal, gasoline, and crude oil or primary and secondary sources. Furthermore, available studies are mostly based on developed countries, with scanty evidence from developing countries, especially Africa. Faced with disturbing electricity access profiles, African countries are beginning to look into energy efficiency to manage their electricity crises. The traditional supply-oriented approach to managing this crisis has lately been considered inadequate and unsustainable (Warren, 2015, IEA, 2012, 2019). Enhancing the efficiency of electricity usage is therefore increasingly becoming a possible alternative to closing the wide gap between electricity demand and supply in most countries. However, the efficacy of efficiency policies in effectively scaling down electricity demand especially in African countries remains largely unclear. This study, therefore, attempts to fill this important gap. The remaining part of the study is structured as follows: section two reviews the existing literature. Section three specifies the model and highlights data issues. Section four discuss and analyze the empirical findings. Section five conclude and put forward recommendations.

LITERATURE REVIEW

The existing literature on the rebound effect can be grouped into three based on the sources of efficiency improvement employed to elicit the rebound size. The first set of studies infer the rebound effect from own-price elasticity. For instance, Soft (2010) examined the sensitivity of world oil prices to changes in supply to investigate the effect of replacing a gallon of fossil fuel with renewable fuels. Sorrell and Stapleton (2018) however estimate the long-run direct rebound effect for UK road freight for the period 1970-2014 with respect to fuel cost of goods moved and the price of fuel. Similarly, Stapleton, Sorrell and Schwanen (2016) used vehicle fuel efficiency (km/MJ), the fuel cost of driving (£/km), and road fuel prices (£/MJ), to examine the direct rebound effect from personal automotive travel in Great Britain. Small Vender (2007) concluded that the rebound effect increases with an increase in fuel cost of driving in the US. Moshiri and Aliyev (2017) found efficiency improvement in passenger car gasoline consumption in Canada to be associated with high rebound size. Frondel and Vance’s (2011) study of asymmetric price response in Germany concluded that consumer responses to price changes were symmetric and a rebound size of 58% was present for single-vehicle households. From the foregoing studies, aside from the misleading assumption that consumers always symmetrically respond to changes in energy prices, these latter studies erroneously assume consumers respond to changes in prices and efficiency alike. These assumptions are not only unsupported but also empirically unsubstantiated.

The second set of literature uncovers the rebound size from imposed exogenous efficiency shocks. Notably, these studies mostly use Computable General Equilibrium models. For example, Wei and Liu (2017) assumed a 10% above business-as-usual efficiency improvement to estimate the global rebound size and found a 70% and 90% rebound and associated emission by 2040 respectively. Likewise, Koesler et al. (2016) interrogated the energy leakage hypothesis by examining the effect of a 10% efficiency improvement in Germany’s production and manufacturing sector and found significant rebound spillovers. Also, Barker et al. (2009) examined the effect of a 10% direct rebound on the indirect rebound size coming from the transport, residential, service, building, and industrial sectors for the period 2013-2030.

Similarly, Thomas (2012) studied the effect of an assumed 10% direct rebound on the indirect rebound effect coming from household re-spending and found that for every 10% direct rebound, an indirect rebound of 5-15% of primary energy and CO2 emission occurs. But Thomas and Azevedo (2013) investigated the effect of an assumed 10% direct rebound effect and cross-price elasticity on the re-spending effect from household residential energy efficiency investment. However, Allan *et al*. (2007) instead used a 5% technical efficiency improvement across all sectors in the UK and found a rebound size of the order 30-50%. Likewise, Lu *et al*. (2016) found super-conservation in electricity but a partial rebound in petroleum, crude, oil, and gas for a 5% efficiency improvement in China. Zhou, *et al*. (2018) also found rebound sizes of the range 22.0% (coal) to 51.5% (gas supply) in China for a 5% efficiency improvement. These latter studies are generally weakened by the inherently unrealistic market and institutional assumptions of their macro models, but also because they imposed efficiency shocks that are arbitrary and unspecific to particular energy types.

The last group of literature makes use of actual technical efficiency levels of countries. They generally employ stochastic frontier models to estimate efficiency scores of countries, and therefrom, determine the rebound effect. Llorca and Jamasb (2016) for instance used a stochastic frontier model to estimate the fuel efficiency of freight transport and derived an average rebound size of the range of 0.55% to 61.6% across 15 European countries between 1992 and 2012. Orea, Llorca and Filippini (2015) extended the stochastic frontier model of Filippini and Hunt (2011, 2012) to allow for a non-zero rebound, and applied it to determine the rebound size of US residential energy demand between 1995 and 2011. However, the two versions of the extended model were too restrictive; producing either super-conservation or partial rebound effect.

Following Orea, Llorca and Filippini (2015), Zhang and Lin (2018) employed a stochastic frontier model to study the rebound effect from fuel efficiency improvement of China's road transport system and concluded that a rebound size of the range 7.2% to 82.2% was present. Unlike Orea, Llorca and Filippini (2015), Kipuros (2017) used a two-stage approach to estimate the economy-wide rebound size for 39 developing countries from 1989 to 2008 and found the rebound magnitude of the range 57.4% and 85.6% in the short and the long run respectively. Similarly, Adetutu *et al*. (2015) also analyzed the impact of energy efficiency improvement on economy-wide rebound size for 55 OECD and non-OECD countries and found an average rebound of 56% in the latter countries, but 49% in the former.

This last group of studies is challenged by their use of restrictive models, particularly those proposed by Orea, Llorca and Filippini (2015), although the two-stage approach employed by Kipuros (2017) and Adetutu *et al*. (2015) addressed this pitfall. However, neither of the latter two studies appropriately benchmarked their studied countries as all the countries were erroneously assumed to be directly comparable. This assumption, in turn, is fundamentally flawed and inaccurate because contending countries remain significantly heterogeneous in their factor inputs and output sizes.

This study is nonetheless situated within the last group of literature but addresses their identified weakness. Also, the study contributes to the existing literature in three ways. Firstly, it sheds light and deepens understanding of the understudied electricity rebound size. Secondly, it extends analysis beyond the estimation of rebound size to its effect on electricity conservation. Lastly, with a purposeful focus on African countries, it brings to bear new evidence of the rebound size in energy underserved regions.

METHODS

A three-stage approach is used to determine the effect of the rebound size on electricity conservation. The efficiency levels of countries are estimated in the first stage. The rebound sizes are computed from an augmented electricity consumption function in the second stage. And the sizes of the rebound effect are evaluated for electricity conservation in the third stage.

First stage model specification

The widely applied energy demand equation of Filippini and Hunt (2016) has been argued to be inadequate. However, the Shepard distance function of Zhou *et al*. (2012) remains conveniently flexible to work with. Therefore, following Lin and Du (2013), the energy distance function is specified as:

$$D_E(K, L, E, Y) = \sup\{\delta : (K, L, E|\delta, Y) \in T\} \quad (1.0)$$

where it is assumed that $E/D_E(K, L, E, Y)$, is the hypothetical energy-use efficiency level if a country is efficient, and its reciprocal, $EEI = 1/D_E(K, L, E, Y)$ is the economy-wide efficiency index. The right-hand side of this equation is presented in a translog form as:

$$\ln\left(\frac{1}{E_{it}}\right) = \beta_i + \beta_K lnK_{it} + \beta_L lnL_{it} + \beta_Y lnY_{it} + \beta_{KL} lnK_{it} lnL_{it} + \beta_{KY} lnK_{it} lnY_{it} + \beta_{LY} lnL_{it} lnY_{it} + \beta_{KK}(lnK_{it})^2 + \beta_{LL}(lnL_{it})^2 + \beta_{YY}(lnY_{it})^2 + \beta_t t + v_{it} - u_{it} \quad (1.1)$$

β_i captures unobserved, time-invariant, country-specific heterogeneity. v_{it} is a normal random variable with zero mean and $u_{it} = lnD_E(K_{it}, L_{it}, E_{it}, Y_{it})$ is a non-negative, truncated-normal term that captures time-varying inefficiencies. K, L, E, Y represent capital, labor, electricity consumption, and income respectively. t is the underlying time trend representing exogenous technological improvements. Eq. (1.1) is a True Fixed Effect Specification. The mean of the truncated-normal term and the variance of the idiosyncratic term are parameterized to account for heterogeneities in production technologies and homoscedasticity in the variance equation (Belotti *et al., 20*13):

$$u_{it} \sim \mathrm{N}^+(\mu, \sigma^2_{uit}).$$

$$\mu_{uit} = \exp(\boldsymbol{h}'_{it}\phi) \quad (1.2)$$

$$\sigma^2_{vit} = \exp(\boldsymbol{\psi}'_{it}\eta). \quad (1.3)$$

where $\boldsymbol{h}'_{it}$ and $\boldsymbol{\psi}'_{it}$ are vectors of exogenous variables in the conditional mean of the inefficiency term and the conditional variance of the idiosyncratic term respectively. ϕ and η are vectors of unknown parameters to be estimated. In addition, the Jondrow et al. (1982) predictor offers the marginal benefits of being able to account for units' heterogeneities in the mean equation of the inefficiency term and simultaneously estimate the parameters of the latter and the frontier (Belotti *et al., 20*12). Thus, following Jondrow et al. (1982), this study computes the efficiency scores as:

$$Eff = \exp(-\hat{u}) = e^{-\hat{u}} \quad (1.4)$$

where Eff is the efficiency term derived from the specified exponential function.

Second stage model specification

The system GMM of Blundell and Bond (1998) addresses the likely endogeneity and autocorrelation problem in addition to the partial adjustment feature of the energy consumption function. It has also been found to be relatively stable, efficient, and safe when compared to standard panel models (Alberini & Filippini, 2011). Accordingly, the augmented electricity consumption equation is shown as:

$$lnE_{it} = \xi_i + \gamma lnE_{it-1} + \xi_1 lnP_{it} + \xi_2 lnY_{it} + \xi_3 lnEff_{it} + \xi_4 P_{it}Eff_{it} + \xi_5 Y_{it}Eff_{it} + \xi_6 P_{it}Y_{it} + (\phi_i + \varepsilon_{it}) \quad (1.5)$$

where E_{it} is the long-run equilibrium level of electricity consumption by the ith country at time t, and E_{it-1} is its lagged term. Eff_{it} is countries' computed efficiency levels, P_{it} and Y_{it} are the real prices of electricity and real income respectively. The interactive terms $P_{it}Eff_{it}, Y_{it}Eff_{it}$, and $P_{it}Y_{it}$ offer two benefits: firstly, the non-linear effect of price, income, and efficiency on electricity consumption can be explorable. Secondly, the interaction also allows for computing countries' rebound sizes. ϕ_i is the unobserved country-specific error term, and ε_{it} is the idiosyncratic error term.

Following Saunders (2000), the rebound size is obtained as one plus the elasticity of electricity consumption with respect to efficiency improvement. Accordingly, the short-run and long-run elasticities are derived from equation (1.5) as:

Short run: $\eta_{SR}^{E} = \frac{dlnE}{dEff} = \xi_3 + \xi_4 P_{it} + \xi_5 Y_{it}$ (1.6)

Long-run: $\eta_{lR}^{E} = \frac{(\xi_3 + \xi_4 P_{it} + \xi_5 Y_{it})}{1-\gamma}$ (1.7)

And the rebound size for each country is computed as $R_{SR} = 1 + \eta_{SR}^{E}\ and\ R_{LR} = 1 + \eta_{lR}^{E}$, for the short-run and long-run respectively.

Third stage model specification

Following Evans, Filippini and Hunt (2013), a baseline scenario where countries are assumed to adopt best practices is formulated as:

$$\overline{E}_i^* = \overline{E}_i \times \overline{EF}_i.$$

where $\overline{E}_i^*$ is the best practice level of electricity consumption of the ith country, $\overline{EF}_i$ is the average efficiency level obtained from the first stage, and $\overline{E}_i$ is the average level of current electricity consumption. Therefore, the average electricity conservation of each country assuming zero rebounds is computed as:

$$Ec_i = \overline{E}_i - \overline{E}_i^*$$
(1.8)

However, with a non-zero rebound size, average electricity conservation would be:

$$Ec_i^R = Ed_i(1 - R_i)$$
(1.9)

where R_i is the average rebound of the *ith* country over the sample period. Ec_i and Ec_i^R are the average electricity conservation levels with and without zero rebound size respectively.

Data sources and description

This study uses an unbalanced annual panel dataset spanning 2010 to 2019 for 29 African countries. The choice of time period, as well as sample countries, is informed by data availability. Data such as total labor force, gross fixed capital formation, GDP, electricity consumption, population, the share of manufacturing value-added, the share of agricultural sector value-added and land area were all sourced from the World Bank World Development Indicator data catalog. Only real energy price index, a proxy for electricity tariff, was sourced from the International Labor Organization Statistics databank. The World Bank 2020 fiscal year countries' classification considers countries with GNI per capita of $1,025 or less as low-income; between $1,026 and $3,995, as lower-middle-income; and between $3,996 and $12,375 as upper-middle-income countries. However, this study regards countries in the low-income group as low-income economies[1], and those in lower-middle-income economies and upper-middle-income economies as high-income economies[2].

RESULTS AND DISCUSSION

Descriptive Statistics

Table 1 summarizes the descriptive statistics for the two income groups. The countries are grouped based on income levels for two reasons. Firstly, because energy consumption is income-dependent, which in turn, plays a key role in determining a country's efficiency level. Secondly, the grouping offers a second-best approach to appropriately benchmarking efficiency among contending countries. A more compelling approach would be to introduce some form of benchmarking criteria that systematically groups countries into like-terms. Unfortunately, this algorithm is currently unavailable.

[1] These countries include Liberia, Sierra Leone, Malawi, Rwanda, Ethiopia, Uganda, Togo, Guinea, Gambia, Benin, Mozambique

[2] These countries are Tunisia, Egypt, Cote d'Ivoire, Senegal, Cameroon, Kenya, Morocco, Ghana, Nigeria, Gabon, Lesotho, Mauritania, Zimbabwe, Zambia, Cape Verde, Namibia, Mauritius, South Africa

Table 1: Descriptive Statistics

Economies	High-income Economies		Low-income	
Variable	Mean	Std. Dev.	Mean	Std. Dev.
Real Income (PPP, billion $)	168875.9	2749944	23092.23	27020.47
Electricity Cons. (kW per capita)	823.3083	1016.275	100.4045	123.0423
Capital (% of GDP)	23.84453	8.387875	21.69389	4.063389
Total labor force (Million, people)	9517.783	12299.63	7916.741	11074.60
Real Energy Price Index	61.91811	10.85302	72.62109	9.977316
Land Area (In Sq. kilometer)	487733.9	381985.5	245212.7	331258.0
Total population (Million, people)	27394.57	39103.89	18735.63	24548.47
Manufacturing Val. Add. (% of GDP	11.8752	3.885994	7.292897	3.730476
Agricultural Val. Add. (% of GDP	13.11255	8.12642	31.67636	10.40396

Source: Author, using WDI and ILOSTAT dataset

The result in Table 1 suggests that there is a significant difference between the two income economies. In high-income economies, it would be observed that more factor inputs are employed to produce output, although the variation between countries sharing this average value is larger. Conversely, in low-income economies, one finds a relatively lower quantity of production inputs and correspondingly, a lower output. However, the variation around these mean values is less spread, suggesting that most countries in the group have similar input-output sizes. Another noticeable difference lies in the cost of energy prices and the economic structure of the two income groups. While energy prices are lower and agricultural activity contributes a lesser share to overall output in high-income countries, the contrary is obtainable amidst low-income economies. These structural differences can have important implications for both economies' energy intensity and efficiency. It is, therefore, crucial to examine how these factors affect each group's efficiency levels.

Estimate of Electricity-Use Efficiency Level of Countries

Table 2 shows these estimated frontier parameters. All the variables are in their mean-adjusted logarithmic form which offers two important benefits.

Table 2: Estimated Stochastic Frontier Model

Variables	*Low-income Ec.*	*High-income Ec.*
Cons.	4.288	-13.316
	(0.894)	(0.436)
lny.	-2.120***	-0.716***
	(0.002)	(0.000)
lnk.	1.681**	0.813***
	(0.020)	(0.000)
lnl.	2.233***	0.925***
	(0.000)	(0.000)
$lnk * lny$.	2.292**	-0.263**
	(0.010)	(0.018)
$lnk * lnl$.	-2.268**	0.238**
	(0.026)	(0.024)
$lnl * lny$.	3.880***	-0.032
	(0.000)	(0.703)
$lnl * lnl$	-1.868***	0.219***
	(0.000)	(0.000)
$lnk * lnk$	-1.095**	0.288***
	(0.011)	(0.000)
$lny * lny$	-2.022***	-0.110**
	(0.000)	(0.010)

*where***, **, and * imply statistical significance at 1%, 5% and 10% respectively. p-values are in parenthesis. Maximum-Likelihood estimations of the models were obtained using Stata 14.0.*

Source: *Author Using Stata 14.0 Software.*

The first advantage is that it allows the estimated parameters to express elasticity at their respective sample mean. Secondly, it allows the variables of the estimated translog function, which is a second-order approximation of the true function, to express deviation from its mean value.

The result from Table 2 suggests that low- and high-income economies respond differently to changes in their frontier parameters: low-income economies respond much more than high-income economies. A general conclusion from the result however is that both models meet an important condition of the Shepard energy distance function: Input is non-decreasing in output, and output is non-increasing in input.

Table 3: Average Electricity-use Efficiency Level of Selected African Countries

Low-income Economies			High-income Economies		
Country	Efficiency	Rank	Country	Efficiency	Rank
Liberia	0.912	1	Tunisia	0.944	1
Sierra Leone	0.901	2	Egypt	0.934	2
Malawi	0.889	3	Cote D'ivoire	0.913	3
Rwanda	0.849	4	Senegal	0.890	4
Ethiopia	0.847	5	Cameroon	0.888	5
Uganda	0.839	6	Kenya	0.888	5
Togo	0.815	7	Morocco	0.879	6
Guinea	0.773	8	Ghana	0.866	7
Gambia	0.739	9	Nigeria	0.830	8
Benin	0.705	10	Gabon	0.808	9
Mozambique	0.264	11	Lesotho	0.692	10
			Mauritania	0.608	11
			Zimbabwe	0.496	12
			Zambia	0.478	13
			Cape Verde	0.430	14
			Namibia	0.425	15
			Mauritius	0.423	16
			South Africa	0.317	17

Source: Author

Table 3 summarizes the average electricity-use efficiency scores of low- and high-income economies using the Jondrow et al. (1982) predictor. The scores are scaled from zero to one; where one implies perfectly efficient and zero mean perfectly inefficient. Within each income group, the scores have also been ranked in ascending order. One interesting conclusion from the estimated efficiency scores is that there is room for improving the efficiency of electricity use in all the 29 African countries since no country was perfectly efficient.

Table 4 presents the estimated result of the augmented electricity consumption function. The signs and magnitude all turn out to be as expected and are mostly statistically significant. For instance, the estimated coefficient on price (ξ_1) is negative and greater than unity. This suggests that, on average, a unit change in electricity prices reduces electricity demand by 1.857kW per capita. Also, the estimated coefficient on income (ξ_2) is positive but less than unity such that, a unit increase in real income, increases electricity demand by 0.317kW per capita. Efficiency in the use of electricity also turned out to reduce the demand for electricity. This is because as consumers use more energy-efficient technologies and adopt efficient practices, their overall electricity consumption falls. Specifically, the estimated coefficient on electricity-use efficiency (ξ_3) is negative and also less than unity. This intuits that electricity demand falls less than proportionality as the efficiency in electricity use increases. This is such that a unit improvement in energy efficiency reduces electricity demand by 0.757kW per capita.

The coefficient on the interactive term between price and efficiency (ξ_4) turned out to be positively signed and statistically significant. This suggests that in countries with higher electricity prices, higher energy-use efficiency tends to be associated with higher electricity demand. Specifically, a one percent rise in electricity prices, for every one percent improvement in energy-use efficiency, electricity demand increases by as much as 1.678 percent. Also, the coefficient on the interactive term between income and efficiency (ξ_5) appears to be negatively signed and statistically significant.

Table 4: Estimated Electricity Consumption Function

$$lnE_{it} = \xi_i + \gamma lnE_{it-1} + \xi_1 lnP_{it} + \xi_2 lnY_{it} + \xi_3 lnEff_{it} + \xi_4 P_{it}Eff_{it} + \xi_5 Y_{it}Eff_{it} + \xi_6 P_{it}Y_{it} + \xi_7 t + (\phi_i + \varepsilon_{it})$$

Regressors	Estimated Coefficients
C	-91.00 (0.240)
lne_{t-1}	0.895*** (0.000)
lnp	-1.857** (0.010)
lny	0.317*** (0.000)
$lneff$	-0.757*** (0.000)
$lnp * lneff$	1.678* (0.059)
$lny * lneff$	-0.403*** (0.000)
$lny * lnp$	-0.187* (0.050)
t	0.455 (0.237)
Number of instruments	25
AR (1)	0.068
AR (2)	0.126
Hansen test	0.715

*where ***, ** and * denote statistical significance at 1%, 5%, and 10% respectively. p-values are reported in parenthesis. The full result, including year dummies, are reported in the appendix.*

Source: Author Using Stata 14.0

These findings suggest that, in countries with higher income, higher efficiency tends to be associated with lower demand for electricity and vice versa. This further implies that as the income levels of countries rise, and more energy-efficient technologies and practices are adopted, electricity demand tends to decline, thereby increasing energy savings. Particularly, a one percent rise in energy efficiency, for every one percent higher income level, electricity demand falls by 0.4 percent. Also, the interactive term between price and income appears to be negatively signed and statistically significant. This means that in countries with higher income, higher electricity prices tend to be associated with a fall in energy demand and vice versa. This is because both higher income and higher energy prices encourage the adoption of energy-efficient appliances. More so, both equally spur the need for decoupling economic growth from energy consumption through a shift to more efficient path-dependence and lock-ins which, ultimately, reduces aggregate energy demand. Precisely, a one percent rise in income level, for every one percent increase in electricity prices, electricity demand falls by 0.187 percent. Lastly, the overall GMM models appear to be stable in the long run and robust. The long-run equilibrium size of 0.895 is not explosive. The first and second Autoregressive conditions are satisfied. And the instruments are valid as suggested by the Hansen statistics.

From the estimated parameters in Table 4, the short- and long-run rebound effect sizes are computed for both low- and high-income economies. The result is presented in Table 5. Notably, the rebound sign ranges from positive to negative. A positive rebound sign suggests that energy savings achieved through improved efficiency would be taken back or re-consumed. However, the extent to which such take-back occurs depends on the rebound size; such that positive and greater than unity rebound size means that all energy saving would completely be taken back (backfire), while positive but less than unity suggest that energy-saving would only partially be taken back (partial rebound). Conversely, negative rebound sign suggests that for every unit of energy-saving associated with improved efficiency, such saving would not be re-consumed, but freed up. The extent to which such energy conservation is achieved also depends on the size of the rebound effect; such that negative and less than unity imply that energy saving is realized more than the proportionate increase in efficiency improvement.

From Table 5, for low-income economies, it would be observed that most of the countries showed partial rebound effect except Gambia, Rwanda, and Togo which show evidence in support of backfires within the short term.

Table 5: Average Rebound and electricity conservation magnitude of Selected African Countries*

Low-income Economies			High-income Economies		
Country	Short Run	Long Run	Country	Short Run	Long Run
Benin	0.703(6.96)	-0.484(34.81)	Cameroon	0.313(18.43)	-2.436(92.15)
Ethiopia	0.165(6.11)	-3.173(30.55)	Cape Verde	1.438(-130.70)	3.191(-653.49)
Gambia	1.191(-5.42)	1.953(-27.08)	Cote D'ivoire	-0.085(17.22)	-4.426(86.11)
Guinea	0.560(7.67)	-1.201(38.34)	Egypt	-1.346(214.8)	-10.731(1074.00)
Liberia	0.865(0.72)	0.323(3.62)	Gabon	0.042(178.59)	-3.788(892.94)
Malawi	0.877(1.38)	0.387(6.92)	Ghana	0.010(34.56)	-3.949(172.79)
Mozambique	0.744(85.00)	-0.281(425.0)	Kenya	-0.150(17.63)	-4.75(88.15)
Rwanda	1.005(-0.02)	1.026(-0.12)	Lesotho	1.125(-9.75)	1.626(-48.73)
Sierra Leone	0.689(0.62)	-0.553(3.09)	Mauritania	1.088(-5.99)	1.439(-29.93)
Togo	1.137(-2.78)	1.685(-13.87)	Mauritius	0.481(544.92)	-1.595(2724.58)
Uganda	0.246(7.77)	-2.772(38.87)	Morocco	-0.849(159.70)	-8.243(798.52)
			Namibia	0.404(543.46)	-1.980(2717.32)
			Nigeria	-1.269(45.74)	-10.346(228.70)
			Senegal	-0.21(20.86)	-5.051(104.31)
			South Africa	-1.069(6147.42)	-9.344(30737.09)
			Tunisia	-0.550(104.61)	-6.748(523.07)
			Zambia	0.389(200.85)	-2.053(1004.23)
			Zimbabwe	0.754(102.33)	-0.228(511.65)

* where computed average electricity conservation is in parenthesis and measured as kwh/capita.

For countries with a partial rebound, a unit increase in energy-saving associated with improved efficiency would increase their energy consumption, but less than proportionately. For countries with backfire, however, an increase in energy-saving associated with improved efficiency would result in a more than proportionate increase in their energy consumption. However, within the long term, countries like Benin, Ethiopia, Guinea, Mozambique, Sierra Leone, and Uganda show super-conservation. For this group of countries, energy-saving associated with improved efficiency would result in a more than proportionate decrease in energy consumption. Conversely, it would be observed that both Liberia and Malawi had a relatively smaller partial rebound, while Gambia, Rwanda, and Togo, further deepened in their backfire response to improved efficiency within the long term.

The findings are slightly different for high-income economies. For instance, even within the short term, seven countries showed super-conservation. Cote d'Ivoire, Egypt, Kenya, Morocco, Nigeria, Senegal, South Africa, and Tunisia all had negative rebound signs, suggesting their incredible response to energy-saving associated with improved efficiency. In addition, seven other countries, however, show evidence of partial rebound. Cameroon, Gabon, Ghana, Mauritius, Namibia, Zambia, and Zimbabwe all had positive but less than unity rebound magnitude, suggesting that partial energy saving can be achieved in these countries within the short term. On the other hand, only three countries portray backfire. Cape Verde, Mauritania, and Lesotho all had positive and greater than unity rebound sizes. Interestingly, in the long run, however, all the countries, except those with backfires in the short term, showed impressive super-conservation potential.

Summarily, for low-income economies, and within the short term, the average energy rebound is 0.74%, while within the long term, it is -0.28%. This suggests that this group of countries as a whole showed a partial rebound within the short term, but super-conservation within the long term. What this implies is that both within the short and long term, energy savings are possible. On the other hand, high-income economies showed an average short-run rebound of 0.029% and a long run of -3.86%. This latter group of countries equally shows partial rebound within the short run and super-conservation within the long run. However, they appear to be relatively more responsive within the short and long term. In comparison with previous works, this study finds similar results in several respects. For instance, to the extent that these results show considerable super-conservations within the long term for both low and high-income economies, these results are consistent with the findings of Kipuros (2017) and Turner (2009). In addition, similar to the findings in Wen *et al*. (2018) and Adetutu *et al.* (2015), the result also supported the existence of backfires in few countries. Lastly, these results provide support to the existing debate in the literature regarding the expectedly larger rebound size in low-income economies than in high-income economies (see Gillingham *et al.*, 2015).

Consequently, the short and long-run average electricity conservation levels are computed along with their corresponding rebound sizes. These values are presented in parenthesis in Table 5. Positive values represent the presence of an encouraging energy conservation potential, while negative values suggest a discouraging potential. The extent of these potentials in turn depends on the average size of the conservation coefficients. Overall, the result suggests that demand-side management policies aimed at reducing or stabilizing electricity consumption through energy efficiency initiatives like the deployment of energy-efficient technologies would prove very potent in scaling-down demand in all the sample countries except those with backfire.

Conclusion and Recommendations

Electricity consumption is considered a critical vehicle for economic development. However, the consumption and production of electricity, particularly when carried out inefficiently or generated from unclean sources, can pose a significant challenge for sustainable development through its effect on climate change and energy security. This challenge is especially worrisome in Africa where more than 70% of generated electricity is fossil fuel-based and demands are perennially on stratospheric levels. Though improving the efficiency of electricity use is considered a potentially viable means of stabilizing or managing electricity consumption, the potency of efficiency policies, particularly in the regions, is unfortunately unclear due to the so-called rebound effect magnitude.

This study, therefore, investigated the size of the rebound effect as well as its effect on electricity conservation for 29 African countries and found that average short run and long run rebound size was 0.74% and -0.28% in low-income countries and 0.029% and -3.86% in high-income countries respectively. This suggests that, on average, efficiency improvement would be associated with some reduction in electricity consumption in both the short and long term. Furthermore, the study found the potentials for electricity conservation in all countries, except those with backfire rebound effects. It is therefore recommended that there is a need to reinforce energy efficiency initiatives through efficiency standards and labeling as well as provide subsidies on efficient electrical appliances and for energy audits.

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REFERENCES

Adetutu, M. O., Glass, A. J. & T. G. Weyman-Jones (2015). Economy-wide Estimates of Rebound Effects: Evidence from Panel Data. *MPRA Paper* No. 65409. Retrieved from http://mpra.ub.uni-muenchen.de/65409/.

Allan G., Hanley N., McGregor P. G., Swales J. K. & K. Turner (2007) The impact of increased efficiency in the industrial use of energy: A computable general equilibrium analysis for the United Kingdom. *Energy Economics*, 29 *(4)*, 779-798.

Barker, T., Dagoumas, A. & J. Rubin (2009). The macroeconomic rebound effect and the world economy. *Energy Efficiency* (2009) 2:411–427. DOI 10.1007/s12053-009-9053-y

Belotti, F., Daidone, S., Ilardi, G. & V. Atella (2012). Stochastic Frontier Analysis Using Stata. *The Stata Journal*. DOI: 10.2139/ssrn.2145803.

Blundell, R. & S. Bond (1998). Initial conditions and moment restrictions in dynamic panel data models. *Journal of Econometrics 87*, 115-143.

Brookes, L. (1978). Energy Policy, the Energy Price Fallacy and the Role of Nuclear Energy in the UK. *Energy Policy* 6: 94-106.

Evans, J., Filippini, M. & L. C. Hunt (2013). The contribution of energy efficiency towards meeting CO2 targets. *Handbook on energy and climate change*.

Filippini, M. & L. C. Hunt (2011). Energy Demand and Energy Efficiency in the OECD Countries: A Stochastic Demand Frontier Approach. *The Energy Journal* 32(2): 59-80.

Filippini, M. & L. C. Hunt (2012). US Residential Energy Demand and Energy Efficiency: A Stochastic Demand Frontier Approach. *Energy Economics* 34(5):1484-1491.

Filippini, M. & LC. Hunt, (2015). Measurement of Energy Efficiency Based on Economic Foundations. *Energy Economics* (2015), doi: 10.1016/j.eneco.2015.08.023

Filippini, M. & L. C. Hunt (2016). Measuring persistent and transient energy efficiency in the US. *Energy Efficiency* (2016) 9:663–675. DOI 10.1007/s12053-015-9388-5.

Frondel, M. & Vance, C. (2011). Re-identifying the rebound –what about asymmetry? *Ruhr economic papers* #276

Gillingham, K. (2011). The consumer response to gasoline price changes: empirical evidence and policy implications. *a dissertation submitted to Stanford university in partial fulfillment of the requirements for the degree of doctor of philosophy*.

Gillingham, K. (2013). *Identifying the Elasticity of Driving: Evidence from a Gasoline Price Shock in California.*

Gillingham, K. (2013). Identifying the Elasticity of Driving: Evidence from a Gasoline Price Shock in California. *Journal of Regional Science & Urban Economics*.

Gillingham, K., Matthew, K., David, R. & G. Wagner (2013). The Rebound Effect is Over-played. *Nature* 493, 475-476.

Gillingham, K., Matthew K., David R. & G., Wagner. (2014). The Rebound Effect and efficiency policy. RFF DP 14-39.

Gillingham, K., Matthew K., David R. & G., Wagner. (2015). The Rebound Effect and efficiency policy. *Review of Environmental Economics and Policy*.

Greening, L. A., Greene, D. L. & C. Diglio (2000). Energy efficiency and consumption-the rebound effect-a survey. *Energy Policy* 28 (2000) 389-401

IEA (2012). Spreading the net: the multiple benefits of energy efficiency improvements.

IEA (2017). Energy access outlook 2017 from poverty to prosperity.

IEA (2019). Africa energy outlook 2019. Retrieved from www.iea.org/africa2019

Jondrow, J., Lovell, C. A. K., Materov, I. S., & P. Schmidt (1982). On the Estimation of Technical Inefficiency in The Stochastic Frontier Production Function Model. *Journal of Econometrics* 19 (1982) 233-238. North-Holland Publishing Company.

Kipouros, P. I. (2017). *Energy Efficiency and the Rebound Effect in Developing Countries.* Surrey Energy Economics Centre, School of Economics University of Surrey.

Koesler, S., Swales, K., & K. Turner (2016). International Spillover and Rebound Effects from Increased Energy Efficiency in Germany. *Energy Economics 54 (2016) 444–452*. http://dx.doi.org/10.1016/j.eneco.2015.12.011

Lin, B. & K. Du (2013). Technology gap and China's regional energy efficiency: A parametric metafrontier approach. Energy Economics 40 (2013) 529–536. http://dx.doi.org/10.1016/j.eneco.2013.08.013.

Lin, B. & P. Tian (2015). The energy rebound effect in China's light industry: a translog cost function approach. *Journal of Cleaner Production* xxx (2015) 1-9. http://dx.doi.org/10.1016/j.jclepro.2015.06.061.

Llorca, M. & T. Jamasb (2016). Energy Efficiency and Rebound Effect in European Road Freight Transport. *Cambridge Working Paper Economics*: 1654.

Lu, Y., Liu, Y. & M. Zhou (2016). *Rebound Effect of Improved Energy Efficiency for Different Energy Types: A General Equilibrium Analysis for China*. *CAMA Working Paper* 38/2016 June 2016

Moshiri, S. & K. Aliyev (2015). Rebound Effect of Efficiency Improvement in Passenger Cars on Gasoline Consumption in Canada. *Ecological Economics* 131 (2017) 330–341. http://dx.doi.org/10.1016/j.ecolecon.2016.09.018

Orea, L., Llorca, M. & M. Filippini (2015). A new approach to measuring the rebound effect associated to energy efficiency improvements: An application to the US residential energy demand. *Energy Economics* 49 (2015) 599–609. http://dx.doi.org/10.1016/j.eneco.2015.03.016.

Saunders, H. D. (2000). Does predicted rebound depend on distinguishing between energy and energy services? *Energy Policy* 28 (2000) 497-500.

Small, K. A. & K. Vender (2007). Fuel Efficiency and Motor Vehicle Travel: The Declining Rebound Effect. *UC Irvine Economics Working Paper* #05-06-03.

Sorrell, S. (2009). Jevons' Paradox revisited: The evidence for backfire from improved energy efficiency. *Energy Policy* 37 (2009) 1456–1469. doi: 10.1016/j.enpol.2008.12.003

Sorrell, S. & L. Stapleton (2018). Rebound effects in UK road freight transport. Transportation Research Part D 63 (2018) 156–174. https://doi.org/10.1016/j.trd.2018.05.006.

Stapleton, L., Sorrell, S., & T. Schwanen (2016). Estimating direct rebound effects for personal automotive travel in Great Britain. *Energy Economics* 54 (2016) 313–325. http://dx.doi.org/10.1016/j.eneco.2015.12.012.

Thomas, B. A. (2012). Energy Efficiency and Rebound Effects in the United States: Implications for Renewables Investment and Emissions Abatement. Carnegie Mellon University Pittsburgh, PA.

Thomas, B. A. & I. L. Azevedo (2013). Estimating direct and indirect rebound effects for U.S. households with input–output analysis. Part 2: Simulation. *Ecological Economics* 86 (2013) 188–198. http://dx.doi.org/10.1016/j.ecolecon.2012.12.002.

Turner, K. (2013). "Rebound" Effects from Increased Energy Efficiency: A Time to Pause and Reflect. *The Energy Journal*, Vol. 34, No. 4 (2013), pp. 25-42.

Turner, K. (2009). Negative rebound and disinvestment effects in response to an improvement in energy efficiency in the UK economy. *Energy Economics* 31 (2009) 648–666. doi: 10.1016/j.eneco.2009.01.008.

Warren, P. (2015). Demand-Side Management Policy: Mechanisms for Success and Failure. UCL Energy Institute University College London (UCL).

Wei, T. & Y. Liu (2017). Estimation of Global Rebound Effect Caused by Energy Efficiency Improvement, *Energy Economics* (2017), doi: 10.1016/j.eneco.2017.05.030.

Wen, F., Ye, Z., Yang, H., & K. Li, (2018). Exploring the rebound effect from the perspective of household: An analysis of China's provincial level. ENEECO (2018), doi: 10.1016/j.eneco.2018.08.018.

World Bank (2020): World Development Indictors (2020edtion). Mimas, University Manchester. DOI: http://dx.doi.org/10.5257/wb/wdi/2020-01-30

Zhang S. & B. Lin (2018). Investigating the rebound effect in road transport system: Empirical evidence from China. *Energy Policy* 112 (2018) 129–140. http://dx.doi.org/10.1016/j.enpol.2017.10.010

Zhang, J. & C. L. Lawell (2017). The Macroeconomic Rebound Effect in China. *Ecological economics* 67 (2017) 202-212.

Zhou M., Liu, Y., Feng, S., Liu, Y. & Y. Lu (2018). Decomposition of rebound effect: An energy-specific, general equilibrium analysis in the context of China. *Applied Energy* 221 (2018) 280–298. https://doi.org/10.1016/j.apenergy.2018.03.074.

Zhou, P., Ang, B. W. & D. Q. Zhou (2012). Measuring economy-wide energy efficiency performance: A parametric frontier approach. *Applied Energy* 90 (2012) 196–200 doi: 10.1016/j.apenergy.2011.02.025.