Bring Back our Light: Power Outages and Industrial Performance in Sub-Saharan Africa

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April 1, 2016

Abstract

Power cuts have become a characteristic feature of many Sub-Saharan African economies. This paper attempts to estimate the firm level impact of power outages using panel data on firms from 15 Sub-Saharan African countries. Further, I evaluate the impact of electricity self-generation in ameliorating the effects of power outages on firm performance using a quasi-experimental approach. Results from the analysis reveal significant negative effects of electricity shortages on firm revenue and productivity. Finally, contrary to the notion that self-generation may be helpful for firms during outage periods, evidence from this paper suggest that reliance on self-generation is associated with productivity losses albeit short run revenue gains.

JEL Codes: D04, D24, L11,L94,O12,O13,Q41

Keywords: Power outages, Sub-Saharan Africa, Electricity, Productivity, Firms

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1 Introduction

Provision of quality infrastructure is regarded as one of the major conduits of economic growth and development. Access to quality infrastructural services such as transport, telecoms and electricity(energy) offers significant benefits to economic activities via lowering the marginal cost of information diffusion, trade, production, distribution and consumption of goods and services.

Evidence from the literature attest to the micro and macroeconomic gains from electricity provision. Dinkelman (2011) for instance documents the positive employment and growth effects of electrification on rural communities in South Africa and thus underscores the potential 'growth drag' of reducing access to electricity.

Unfortunately however, the quality of electricity supply in low and lower-middle income economies is woefully unsatisfactory. In many developing countries, access to stable, uninterrupted supply of electricity is regarded as a luxury. Firms and households struggle to gain access to power and even when they do, they must be prepared to endure several hours in the day (night) without power (Eifert et al., 2008; Alby et al., 2012). In Sub-Saharan Africa (SSA) for instance, the performance of the electricity sector has been abysmal. Despite marginal gains in enhancing access to electricity, the quality of supply remains poor. Power outages have become endemic in many countries. The average number of power outages in a given year in the region is estimated[1] to be 102 (World-Bank, 2015). A worrying feature of this phenomena aside its frequency, is the erratic nature of outages. Even in instances where outage periods are planned, the schedules are rarely followed, thereby making it difficult for firms and households to plan their activities.

The uncertainty and access constraints to electricity extant in the developing world and the implications on businesses and household welfare has spurred interest in the literature on outage effects and firm responses (Bloom et al., 2013; Alam, 2013; Allcott et al., 2014; Fisher-Vanden et al., 2015). Allcott et al. (2014) provides a comprehensive analysis on the effects of electricity shortages on firm productivity in India. Results from their study reveal that a percentage increase in shortages reduces firm revenue by 0.68%. The effects on productivity was however, insignificant. Fisher-Vanden et al. (2015) also estimate the effect of electricity shortages on productivity of Chinese firms and show that firms re-optimize their production inputs by substituting materials for energy during outage periods. The results further show that firms respond to power shortages by engaging in outsourcing to avoid productivity losses, despite the cost associated with outsourcing.

Empirical evidence on the productivity losses from power cuts in SSA is however

[1] http://www.enterprisesurveys.org/data/exploretopics/infrastructure

not forthcoming, even though electricity shortage is regarded as a major constraint to enterprises in the subregion. Existing studies on SSA have mainly concentrated on firm responses during outage periods (see. Steinbuks and Foster, 2010; Alby et al., 2012)

This paper therefore, seeks to extend the discussions on the economic impact of unreliable power supply in SSA by providing firm level evidence. The aim of this study is two folds: First, to estimate the effects of power outages on firm revenue and productivity. Secondly, I seek to answer the question of whether electricity self-generation during power holidays help to ameliorate the underlying effects of outages on firm revenue and productivity.

The empirical strategy of the paper is summarized as follows: The first part estimates the impact of outages on firm performance using a panel data of firms in 15 SSA countries and then predict the impacts across the countries included in the data. The second part of the analysis however evaluates the impact of self-generation. The endogenous nature of outage intensity in its relationship with firm performance and responses posses a challenge to identification. Thus to sufficiently estimate causal impacts, I utilize variations in hydro-electric generation and real price of diesel as instruments. The productivity effects are therefore assessed using the Instrumental Variable (IV) estimator while the role of self-generation is analyzed using quasi-experimental approaches (i.e. the Difference-in-Difference(DID) and endogenous treatment effect estimators).

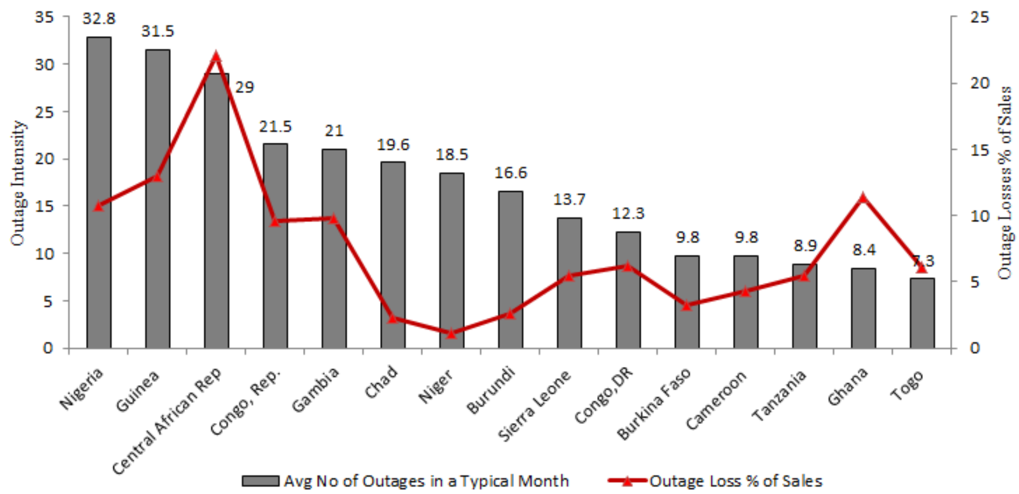
Findings from the study reveal significant impacts of electricity shortages on firm revenue and productivity. For every percentage increase in outage intensity, firm revenue declines by 0.7% with the associated productivity losses ranging between 0.6% and 1.5%. Further, I show that even though self-generation may generate short run revenue gains, the overall effects on productivity is negative. This is largely due to adjustment costs which tend to add up to the operating cost of the firms, and thereby reducing investment and their competitiveness.

The remainder of this paper is structured as follows. In the next section, I provide a brief overview of outage trends in SSA. Section 3 presents the conceptual model of the paper. The empirical strategy is outlined in section 4. A description of the data is presented in Section 5, while the results are analyzed in Section 6. Section 7 concludes the paper.

2 Overview of Outage Trends in SSA

Official data on outage frequency and durations in SSA are typically unavailable, due to the poor data management systems in countries in the region. Nonetheless, the Enterprise Survey data offers some information on firms reported number and duration of outages in a typical month. The dataset reveal that the monthly average number (duration) of outages in SSA is 8.5(4.8 hours) compared to 3.5(2.5 hours) in East Asia and Pacific, 17.6(6.5 hours) in the Middle-East and North Africa, 25.4 (3.1 hours) in South Asia, and 2.8 (1.5 hours) in South America and Caribbean.

Fig 1. Power Outage Trends in SSA

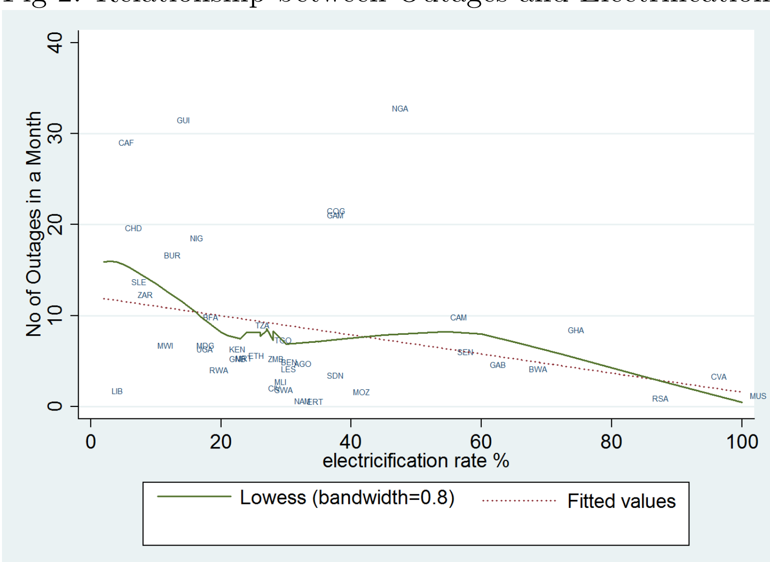


Source: Enterprise Survey Database (2015)

Within SSA, Nigeria, Guinea and Central African Republic records the highest number of outages as shown in Fig 1. The associated firm revenue losses are also considerably high, particularly in Central African Republic, Guinea and Ghana(see. Fig 1). The uncertainties in electricity supply and the resultant costs to firms have led many enterprises to adopt self-generation as an adaptation measure to mitigate the effects. In countries such as Angola, Nigeria, Congo DR and Chad, more than 70% of firms captured in the survey utilize generators to produce own-power during outage periods. Interestingly, the petroleum sector in these countries is not bereft of crises. Shortages of petroleum products such as gasoline and diesel is common among SSA countries, further compounding the problem of inadequate supply of electricity to firms, as access to diesel by firms to power in-house generators sometimes becomes a challenge (Steinbuks and Foster, 2010).

A popular school of thought in the discussion of electricity shortages has been the argument that the increasing incidence of power outages is mainly as a result of the fact that many African countries have expanded electricity access significantly without a commensurate increase in installed capacity. To test this claim, I conduct a correlation analysis between electrification rate and frequency of outages (see: Fig 2). The evidence however suggest otherwise as a negative correlation is observed. It shows that power outages are less common in countries with greater percentage of population having access to electricity and vice versa. This therefore suggest that electricity shortages in many of the countries can be attributed to inefficiencies in the power sector than mere expansion in access.

Fig 2. Relationship between Outages and Electrification Rates



Source: World-Bank (2015) and IEA (2015)

3 Model

In this section, I provide a simple model to demonstrate the effects of electric power outages on firm productivity following the approach of Allcott et al. (2014). I begin by assuming a representative firm i at time t producing output Y_{it} using a Cobb-Douglas production technology which satisfy the usual assumptions of being twice differentiable and concave

$$Y_{it} = A_{it} K_{it}^{\alpha_K} L_{it}^{\alpha_L} M_{it}^{\alpha_M} E_{it}^{\alpha_E} \tag{1}$$

where $\alpha_K, \alpha_L, \alpha_M, \alpha_E$ represent factor shares of capital stock K, labour L, materials M, and energy E respectively. A captures factor productivity.
In producing output Y, the firm incurs cost given by the function

$$C_{it} = P^K K_{it} + P^L L_{it} + P^M M_{it} + P^E E_{it} \tag{2}$$

where P^K, P^L, P^M, P^E represent respectively the input cost per unit of capital stock, labour, materials, and energy[2]. Assuming reliable supply of all production inputs, the optimal decision facing the representative firm is to maximize profit:

$$Max \quad \Pi_{it} = P^Y Y_{it} - P^K K_{it} - P^L L_{it} - P^M M_{it} - P^E E_{it} \tag{3}$$

For simplicity, the output price (P^Y)is normalized as a numéraire under the assumption of perfect competition in the output market. Also let's denote factor input as $F_j, \forall j = K, L, M, E$. Therefore the optimality condition for factor j from equation (3) while dropping firm and time subscripts can be expressed as

$$\alpha_E \frac{Y_j}{F_j} = P^j \tag{4}$$

This marginal condition states that the firm will utilize the input j up to the point where the marginal revenue product is equal to its price.

So far I have analyzed the simple production decision that firms face in a market with no imperfections in input supply. However, as argued in this paper, access to inputs such as electricity is highly constrained, at least, within the study region. Therefore I show in the following sections how constraints in supply of electricity affect firms' total factor productivity (TFP).

First, let θ be the probability of having access electric power for production, such that $\theta \in (0, 1]$. Thus, $\theta < 1$ during outage days where grid supply of electricity is unreliable; while $\theta = 1$ represent the case of no power cuts and the firm receives constant access to grid electricity (which corresponds to the analysis presented above). The case where $\theta = 0$ is ignored in this model as it implicitly refers to case where firms do not have access electricity at all times.

During periods of power outages, two options arise: either the firm shuts down production or rely on self-generation, i.e. via use of generators. Therefore the total electricity input requirement for the firm can be expressed as the weighted sum of electricity from national grid ($E_{G,it}$) and electricity from own generation ($E_{O,it}$),

[2]Note that at this stage no distinction is made between the sources of energy input so a uniform price is assumed.

$E_{it} = [\theta E_{G,it} + (1-\theta)E_{O,it}]$. For firms with no in-house generation, $E_{O,it} = 0$. This suggest that for firms under electricity constraints, their corresponding production technology equivalent to equation(1) can be expressed as:

$$\begin{aligned} Y_{it} &= A_{it}K_{it}^{\alpha_K}L_{it}^{\alpha_L}M_{it}^{\alpha_M}\left(\theta E_{G,it} + (1-\theta)E_{O,it}\right)^{\alpha_E} \\ &= A_{it}K_{it}^{\alpha_K}L_{it}^{\alpha_L}M_{it}^{\alpha_M}E_{it}^{\alpha_E}\left(\frac{\theta E_{G,it} + (1-\theta)E_{O,it}}{E_{it}}\right)^{\alpha_E} \end{aligned} \tag{5}$$

By setting $W_{it} = \left(\frac{\theta E_{G,it}+(1-\theta)E_{O,it}}{E_{it}}\right)^{\alpha_E}$, $0 \leq W \leq 1$ measures the weighted sum of grid and self generation share of total electricity input requirement. Taking logarithm of equation (5) represented in lower cases yields:

$$y_{it} = a_{it} + \alpha_K k_{it} + \alpha_L l_{it} + \alpha_M m_{it} + \alpha_E e_{it} + w_{it} \tag{6}$$

Hence, the total factor productivity (TFP) is equal to $a_{it} + w_{it}$, where $a_{it} > 0$ and $w_{it} \in (-\infty, 0]$. To analyze the effect of power outages on TFP, the following propositions are explored.

Proposition 1: Unconstrained Electricity Supply Assume a case where there are no power outages and firms experience constant and reliable supply of electricity, such that $\theta = 1$, $E_{G,it} = E_{it}$ and $W_{it} = 1$, then $w_{it} = 0$ and $TFP_{it} = a_{it}$. This forms the baseline scenario whereby firm level productivity is determined by factors other than electricity shortages. In propositions 2-4, I analyze the case of supply imperfections and the effects of firm coping strategies (self-generation) on total factor productivity.

Proposition 2: Electricity supply imperfections without self-generation In the case where firms face irregular supply of electricity, and do not produce own-power, then $\theta < 1$, $E_{O,it} = 0$, and $W_{it} < 1$. This results in $w_{it} < 0$ and $TFP_{it} < a_{it}$. In other words firm level productivity is always reduced whenever firms with no backup generators experience outages.

Proposition 3: Electricity supply imperfections with partial self-generation Assume a case whereby firms produce own-power during outage days, however, the amount of in-house electricity generated is not commensurate to the supply shortfalls created by the power cut. That is, $\theta < 1$, $E_{O,it} > 0$, but $\theta E_{G,it} + (1-\theta)E_{O,it} < E_{it}$ and hence $W_{it} < 1$. This implies that w_{it} will still be less than zero and $TFP_{it} < a_{it}$ even though the productivity losses will be less than in proposition 2.

Proposition 4: Electricity supply imperfections with full self-generation Finally, I assume a case whereby firms are able to fully compensate the electricity supply shortfalls with in-house generated power during outage periods such that $\theta < 1$, $E_{O,it} > 0$ and $W_{it} = 1$. The resultant effect is that firm productivity unaffected by power outages, i.e., $TFP_{it} = a_{it}$. However, there are reasons to believe that this condition is rarely met in the long run. One major reason is the differences in the cost of electricity supply from grid and self-generation. In many developing economies, the per kilowatt cost of electric power from self generation is higher than grid supply ($P^E_{O,it} > P^E_{G,it}$). For instance, cost of own-generation in Africa ranges between US$ 0.3-0.7 per KWH, compared with price of grid electricity estimated to be around US$ 0.14 (Steinbuks and Foster, 2010; AfDB, 2013). Thus in the spirit of "cost minimization", firms are unable to compensate fully for electricity losses with self generation during outage periods and still produce profit maximizing output levels given the prevailing market price. Even when firms are able to produce the own-power to cover the supply shortfall, they are either only able to do so in the short run or forced to make trade-offs such as laying off workers and/or reducing investment into other areas of the production, which in the long run affect productivity negatively.

4 Empirical Strategy

The empirical strategy for this paper is categorized into two main parts: first, I examine the impact of power outages using both firm level. In the second part, I evaluate the effectiveness of firms' adaptation strategies to mitigate the effects of power cuts on revenue/productivity, via engaging in electricity self-generation as a back-up source, when grid supply is curtailed.

4.1 Impact Estimation

To estimate the causal impact of power outages, let's consider the parsimonious model expressed in equation (7)

$$y_{ijdt} = \beta + \delta Outages_{ijdt} + \gamma X_{ijdt} + \psi_j + \eta_d + \lambda_t + \epsilon_{ijdt} \tag{7}$$

where y_{ijdt} is the outcome variable [3] for firm i in country j, in industry d, at time

[3] including firm revenue and productivity.

t; $Outages_{ijdt}$ represents the power outage intensity, X_{ijdt} is a vector of control variables: while ψ_j, η_d and λ_t represent country, industry and time fixed effects respectively; with ϵ_{ijdt} as the error term. Also, β, γ and δ are parameters to be estimated. The main parameter of interest,δ, measures the total effect of outage intensity on the outcome variable.

4.1.1 *Identification Strategy*

The true causal effect of outages $\hat{\delta}$ in equation (7) can be recovered only if outage is exogenous in the model. However there are reasons to believe that outage intensity is endogenous in the model. For instance, the intensity of outages could be correlated with other factors directly influencing firm level output/productivity, such as the location of the firm, industry composition, prevailing economic conditions in the country, institutional quality, etc. At the same time, given the relative difficulty in obtaining precise measures for outage intensity, the possibility of measurement errors in the outage index cannot be ignored, thereby resulting in 'attenuation biases' (Allcott et al., 2014).

This calls for an exogenous instrument(s) for outages in order to properly identify the model. Such instrument(s) must satisfy the exclusion restriction assumption such that, it should be highly correlated with outages but should affect firm production only via outages. Therefore, I exploit the variations in hydro-electric generation as an instrument. Electricity from hydro dams is an important source of power for many countries considered in this study. For instance, the average share of electricity from hydro sources in total electricity generation over the period 2000-2011 is about 96%, 99% , 70.7% and 74% in Ethiopia, Congo D.R, Angola and Ghana respectively [4]. Now, since hydro generation is highly dependent on rainfall patterns, variations in hydro generation are exogenously determined. Evidence have also shown that years of major electricity crises in these countries coincide directly to periods of low recorded rainfall. Therefore variations in hydro generation is exogenous and affect firm output only through outage.

4.2 Electricity Self-Generation and Productivity

In this section, I examine the effect of self-generation on firms' revenue/productivity using a quasi-experimental approach. Identification of the true causal impact of

[4] Zimbabwe (60%), Tanzania(70%), Nigeria(30%) and Kenya(48%), based on data from the US Energy Information Agency's International Energy Statistics. http://www.eia.gov/cfapps/ipdbproject/iedindex3.cfm?tid=5&pid=53&aid=1

self-generation option as an adaptation measure requires a valid counterfactual. In doing so I focus on a subset of firms in the dataset which did not self-generate during the first wave ($t = 0$) of the panel dataset. In the second wave, I consider firms that invested into self-generation as treated whiles firms that still remained totally dependent on grid supply as the control group. Thus, I implicitly drop firms that either self-generate during both rounds of the survey or switched from self-generation to full dependence on grid supply.

In order to specify the reduced form model, lets define y_{ijdt} and X_{ijdt} as before; $T_{ijdt}[0, 1]$ as a treatment indicator, where $T_{ijdt} = 1$ if firm is treated and $T_{ijdt} = 0$ if otherwise. Given these, I specify the reduced form model as follows

$$y_{ijdt} = \alpha + \theta T_{ijd} + \gamma X_{ijdt} + \psi_j + \eta_d + \lambda_t + \epsilon_{ijdt} \tag{8}$$

where α is the intercept, Ψ_i, ψ_j, η_d and λ_t represent firm, country, industry and time fixed effects respectively; whiles ϵ_{ijdt} is the residual term. Rewriting equation (8) in first differences I obtain:

$$\Delta y_{ijdt} = \beta + \theta_1 \Delta T_{ijdt} + \phi \Delta X_{ijdt} + \Delta \epsilon_{ijdt} \tag{9}$$

If we believe that selection into treatment (i.e generator use) is random and exogenous, $\hat{\theta}$ from an OLS estimation of (9) can be inferred as the average treatment effect. However, the decision to self-generate, in practice, is unlikely to be exogenous. Firms decision to generate own-power to supplement grid supply could be correlated with observable factors that influence productivity,such as outage intensity, location of the firm, type of products produced by the firm; and unobservable factors as well. Hence $Cov(\Delta\epsilon_{ijdt}, \Delta T_{ijdt}) \neq 0$. This implies that treatment is endogenous and thus $\hat{\theta}_{OLS}$ will be biased and inconsistent. To overcome this identification problem, I estimate a treatment effect model with an endogenous treatment. This involves estimating a two step reduced form model whereby I estimate the first stage by regressing the treatment indicator on a set of instruments and exogenous variables via a probit model and a second stage regression of the outcome variable on predicted values from the first stage and the exogenous variables as shown in equation (10)

$$y_{ijdt} = \alpha + \theta T_{ijdt} + \gamma X_{ijdt} + \psi_j + \eta_d + \lambda_t + \epsilon_{ijdt} \tag{10}$$

$$T^*_{ijdt} = \pi Z + \gamma X_{ijdt} + \mu_{ijdt} \tag{11}$$

where $T_{ijdt}=\{^{1 \text{ if } T^*>0}_{0 \text{ if otherwise}}$

The error terms $(\epsilon_{ijdt}, \mu_{ijdt})$ are assumed to be bivariate normally correlated, with $Var(\epsilon_{ijdt}) = \sigma^2$, $Var(\mu_{ijdt}) = 1$, $Cov(\epsilon_{ijdt}, \mu_{ijdt}) = \rho\sigma^2$ (see: Cameron and Trivedi, 2010).

Again, the empirical challenge herein is finding an appropriate instrument for self-generation. Two candidate instruments are explored: variations in hydro-electric generation and real price of diesel (gasoil). Petroleum prices are key determinants of firms' decision to self-generate power, as most generation plants and mini-grid rely on diesel as fuel. Given that prices of oil products are largely determined by world market forces, variations in prices can be deemed as exogenous. Even in instances where these products are subsidized [5], the subsidies are rolled out nationally. Hence, firms can be assumed to have no influence on the final price. Also, variations in hydro-generation is strongly linked to power outage intensity which in turn affect firm's decision to invest in self-generation or otherwise.

The identification strategy is that conditional on firm characteristics, variations in diesel prices and hydro-generation do not affect firm performance independently of firms' decision to self-generate. Therefore, conditional on the instrument validity, $\hat{\theta}_{IV}$ measures the average treatment effect of self-generation on firm performance.

Furthermore, it is also interesting to examine whether the share of electricity from self generation matters in the impact of self-generation firm revenue and productivity. In other words, is the impact of self-generation homogeneous for each share of electricity generated from own sources or there is heterogeneity in the impacts contingent on the share of electricity supplied from own-generators? This is particularly important due to the differences in cost between the two sources of electricity. To answer these questions, I substitute the treatment indicator in equation (10) with share of total electricity input generated by the firm, defined as SG_{ijdt}. The reduced form equation then becomes

$$y_{ijdt} = \alpha_0 + \alpha_1 SG_{ijdt} + \gamma X_{ijdt} + \psi_j + \eta_d + \lambda_t + \epsilon_{ijdt} \tag{12}$$

Equation(12) is estimated via an instrumental variable estimator whereby variations in hydroelectric generation and real price of gasoil (diesel) are again exploited as instruments for SG_{ijdt}.

[5] Energy subsidies were common in many African countries until recent times when they are gradually being phased out.

5 Data

The firm level analysis relies heavily on panel data from the Enterprise Survey dataset provided by the World Bank. This survey contains data on firm attributes and the major constraints to doing business.To obtain the final dataset the following strategy was used. For each country, I focus on firms surveyed in the latest two (2) rounds of the panel dataset. Due to the problem of attrition commonly observed in panel data, the total number of firms constituting the panel are relatively low across the surveyed countries. Also, the timing of the surveys differ across countries. All monetary data were converted into 2011 USD prices using the GDP deflator and real PPP exchange rates. Therefore the final dataset is a panel of 2,144 firms in 15 countries surveyed at different time periods ranging between 2003 and 2014. Table A2 in the appendix gives a brief summary of firms in each country as well as the time period. To account for these time variations in the dataset, time fixed effects are applied.

With the exception of hydroelectric generation and price of diesel, all data used in the firm level analysis were obtained from the Enterprise Survey database. Hydroelectric generation and price of diesel, were obtained respectively from the US Energy Information database on International Energy Statistics [6], and the International Fuel Price database of GIZ [7] complemented with data from local government agencies.

A notable drawback of the Enterprise Survey dataset is that it does not contain information on final output of firms. Therefore, total annual sales (revenue) are used as proxy for output[8]. Thus, the measure of productivity used in this study can be thought of as "revenue productivity".

In computing total factor productivity (TFP), two approaches were explored: the ordinary least square (OLS) method and the Levinson-Petrin (LP) productivity estimator.The main limitation of estimating productivity using OLS approach is the correlation between input levels and the unobserved productivity shocks, thereby leading to biased estimates (Griliches and Mairesse, 1998). The LP estimator is however considered to be a more robust estimator of productivity as it overcomes the simultaniety between productivity shocks and inputs by using intermediate inputs as proxies (Petrin et al., 2004). As a result, the main TFP measure of interest is the TFP estimated using the Levinson-Petrin approach denoted as TFP_LP. The OLS version (TFP_OL) is included as a robustness check.

The measure of power outage intensity used here refers to the average number of

[6]http://www.eia.gov/cfapps/ipdbproject/iedindex3.cfm?tid=5&pid=53&aid=1

[7]http://www.giz.de/expertise/html/4282.html

[8]The implicit assumption then is that firms stock of inventory is zero, i.e., firms sell whatever they produce in a given year. The plausibility of this assumption is however debatable

times a firm experience power outages in a typical month. Admittedly, this measure is imperfect since it gives no further information on the duration and timing of the interruptions, which ultimately determines the effect on the firm's production process and the response thereof (Fisher-Vanden et al., 2015). Nevertheless, in the presence of data constraints, this measure can still be relied on to understand the effect and response of firms to power outages. Also, the irregular nature of power cuts in the study area means that firms always operate under the electricity uncertainty.

5.1 Variability in hydro-electric generation

As indicated earlier, I exploit variabilities in hydro-electric supply as an instrument of power outages in our econometric model. Variability in hydro generation is measured as the deviation from the mean annual generation (AH_i) over the period 2003-2014 (see equation 13).

$$Hydro\ Var_{jt} = log\,(H_{jt}/AH_j) \tag{13}$$

where H_{jt} is the hydro-electric generation in country j at time t. The choice of the time period is mainly informed by the data period, as the firm data set ranges between 2003 and 2014. Descriptive statistics of the data used are presented in table A1 in the appendix.

6 Results

The analysis herein consist of two parts: first, I analyze the effects of outages on firm revenue and productivity and then proceed to evaluate the impact of electricity self-generation on firm revenue and productivity.

6.1 Outages and Firm Performance

I begin the analysis with an exploratory correlation analysis between the number of power outages and firm revenue/productivity. This is achieved via an OLS estimation of equation(7).

The results shown in Table 1, reveal a strong and significant negative correlation between intensity of power outages and firm revenue/productivity. However, this cannot be inferred to be a causal impact due to endogenous nature of the relationship between outages and the outcome variables in the model. Therefore, in overcoming this identification issue, I re-estimate the model using the IV approach by using variations in hydro-electric generation as instrument for power outages.

Table 1. OLS Regression: Effects of Power Outages on Firm Revenue/Productivity

	(1) Revenue	(2) Revenue	(3) TPF_LP	(4) TFP_LP	(5) TFP_OL	(6) TFP_OL
log of outage	-0.374***	-0.226***	-0.143**	-0.0945*	-0.153***	-0.0791
	(0.0679)	(0.0727)	(0.0577)	(0.0558)	(0.0556)	(0.0533)
Constant	14.38***	12.65***	-0.479***	0.436**	0.248***	0.394**
	(0.187)	(0.369)	(0.101)	(0.183)	(0.0941)	(0.166)
Firm controls	No	Yes	No	Yes	No	Yes
Industry FE	Yes	Yes	No	Yes	No	Yes
Year FE	Yes	Yes	No	Yes	No	Yes
Country FE	No	Yes	No	No	No	No
Observations	2831	2731	973	967	973	967
Adjusted R^2	0.193	0.374	0.010	0.224	0.013	0.204

Robust standard errors, clustered at firm level. * $p < 0.1$, $^{**}p < 0.05$, *** $p < 0.01$.
TFP_OL & TFP_LP represent TFP estimated from OLS and Levinson-Petrin estimators respectively

However, for this instrument to be regarded as sufficient to generate exogenous impact of outages on the outcome variables, it must pass a series of instrument validity tests. Accordingly, the first stage regression model is estimated and shown in columns (2-9) of Table (2). Column 1 however, is an OLS estimation of the correlation between the hydro and outages. Results from the first stage regression shows that variations in hydro-electric generation is a strong predictor of the number of power outages. Given the measure of the variations, increases in hydro generation (over and above the mean annual level) is associated with a reduction in outage intensity. The instrument further passes all the important instrument validity tests of under-identification and weak instruments. For instance, the cluster and heteroscedastic robust Angrist-Pischke F-statistic ranges between 42 and 237 which when compared to the Stock and Yogo (2005) critical values indicate a rejection of the null hypothesis that the instrument is weak. Also, the Kleibergen-Paap LM test also reject the null hypothesis that the models estimated are under-identified.

In the second stage (Table 3), we find significant and robustly negative effects of power outages, confirming the results of the OLS estimation in table 1. Columns (1-2) shows the results of the effect of power shortages on firm revenue. It shows that a percentage increase in the number of power outages reduces firm revenue by about 0.7%. The effects on productivity (columns 3-8) is also negative and significant, ranging between -0.6 and 1.5. Thus a percentage increase in outage intensity is associated with a decline in firm level productivity by between 0.6% and 1.5%.

Table 2. First Stage Regression: Power Outages and Firm Revenue/Productivity

	(1) Outages	(2) Outages	(3) Outages	(4) Outages	(5) Outages	(6) Outages	(7) Outages	(8) Outages	(9) Outages
Hydro Var	-0.343*	-0.381***	-0.355***	-0.197***	-0.232***	-0.271***	-0.197***	-0.232***	-0.271***
	(0.170)	(0.0248)	(0.0235)	(0.0303)	(0.033)	(0.0337)	(0.0303)	(0.033)	(0.0337)
Constant	0.0226	0.00437	2.021***	1.907***	2.488***	0.127	1.907***	2.488***	0.127
	(0.123)	(0.0386)	(0.0691)	(0.0310)	(0.120)	(0.110)	(0.0310)	(0.201)	(0.110)
Firm controls	No	No	Yes	No	Yes	Yes	No	Yes	Yes
Industry FE	No	No	Yes	No	No	Yes	No	No	Yes
Year FE	Yes	Yes	Yes	No	Yes	Yes	No	Yes	Yes
AP F-Stat	-	236.7	227.8	42.42	47.98	64.37	42.42	47.98	64.37
Obs	3175	2831	2731	973	967	969	973	967	969

Dependent variable is log of no. of outages in a typical month

Robust standard errors, clustered at firm level. Column 1 clustered at country level

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

These results unequivocally suggest that power shortages serves as negative shock to the performance of firms in the dataset, in terms of constraining production process and consequently, productivity of factor inputs. This confirms the model predictions in proposition 2. An important issue in the relationship between electricity shortages and productivity is the extent of heterogeneity in the impacts. That is, there are differences in the ability of firms to cope with a negative shock such as power cuts and this ultimately imply that the impacts are unlikely to be uniform across a wider spectrum of firms. For instance, manufacturing firms who rely heavily on electric power to operate their machinery are more likely to be affected by electricity shortages than firms where probably electricity is a secondary input rather than a primary input. Therefore to control for these factors, firm attributes and industry fixed effects are included in the models.

Table 3. IV Regression: Effects of Power Outages on Firm Revenue/Productivity

	(1) Revenue	(2) Revenue	(3) TFP_LP	(4) TFP_LP	(5) TFP_LP	(6) TFP_OL	(7) TFP_OL	(8) TFP_OL
log of outage	0.243	-0.702***	-1.490***	-1.543***	-1.011***	-0.943***	-0.736***	-0.600***
	(0.223)	(0.219)	(0.360)	(0.292)	(0.199)	(0.273)	(0.196)	(0.143)
Constant	14.18***	14.74***	2.099***	0.106	0.737***	1.759***	0.474**	0.637***
	(0.200)	(0.504)	(0.706)	(0.846)	(0.240)	(0.538)	(0.220)	(0.195)
Firm controls	No	Yes	No	Yes	Yes	No	Yes	Yes
Industry FE	No	Yes	No	No	Yes	No	No	Yes
Year FE	Yes	Yes	No	Yes	Yes	No	Yes	Yes
KPLM	260.2	204.6	40.00	50.11	67.49	40.00	50.11	67.49
CDF	270.3	232.2	27.70	39.98	55.11	27.70	39.40	55.11
AP	236.7	227.8	42.42	47.98	64.37	42.42	47.98	64.37
Obs	2831	2731	973	840	969	973	967	969

Robust standard errors, clustered at firm level. Dependent variables are in logs.* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.
TFP_OL & TFP_LP represent TFP estimated from OLS and Levinson-Petrin respectively.
AP and CDF are the Angrist-Pischke and Cragg-Donald Wald F-stat tests of weak instruments respectively.
KPLM is the Kleibergen-Paap LM test for under-indentification.

Moving forward, I use the estimates in table 3 (columns 2 & 5) to calculate the predicted impacts of electricity shortages on firm revenue and productivity in the sampled countries. Results from the prediction (see fig. 3) reveal significant heterogeneity in the impacts on firm performance across the countries. It shows thats power outages have highest predicted (mean) impact on Nigerian firms while South African firms experience the least impact. The interpretation of these impacts is that, for instance, a percentage increase in the intensity of power outages in Nigeria results in a decline in firm revenue and productivity by approximately 2.3% and 3.3% respectively. An interesting observation is that countries with the highest predicted impacts such as Nigeria, Cameroon and Ghana have higher outage intensities as highlighted in fig 1.

Fig 3. Predicted Impacts of Electricity Shortages

6.2 Electricity Self-Generation and Firm Performance

Given the above negative impacts of power outages, firms in the region operating under such electricity supply constraints have over the years improvised strategies to mitigate the effect of the shock on their activities. One of such strategies has been to self-generate power through generators and mini power plants.

Despite the popularity of this strategy as an adaptation option to grid power supply uncertainty, the exact impact of self-generation in ameliorating the overall effects of power cuts remains to be fully assessed. In this section, I attempt to identify this impact using quasi-experimental approaches, specifically, a Difference-in-Difference (DID) and endogenous treatment effect estimators. To conduct this quasi-experiment, I focus the analysis on firms that did not self-generate in wave 1 of the panel dataset, despite the electricity supply uncertainty. Within this group, some firms resorted to self-generation after the first wave, while others remained fully dependent on grid supply. This forms the assignment rule utilized in the experiment.

Therefore I categorized firms into two categories: a treatment group which consist of firms that transitioned to self-generation to complement grid supply after wave 1; and a control group composed of firms that remained totally reliant on grid supply in both periods. Implicitly I do not include firms that generated power from own sources during both rounds of the panel due to the challenge of finding a good counterfactual for this group.

Thus to identify the effect of treatment, I conduct a difference-in-difference estimation of the firm revenue and productivity between the treatment and control groups while controlling for other covariates such as firm age, size, industry fixed effects, and country fixed effects. Results shown in table 4 represents differences in mean revenue and productivity between firms that adopted self-generation and those that did not generate own-power during outage periods. In each period and for each variable, I estimate the differences between the treated and control firms as represented by Δ. Comparing mean revenues among the two groups, I find positive difference between treated firms and control firm in the baseline. This difference also increases after the treatment period and is reflected in the positive and significant estimate of the DID which basically measures the difference between the change in the mean revenue between treated and control firms during the follow-up period and the comparable change in revenue at the baseline. The positive and significant DID estimate measures the effect of the adoption of self-generation strategy on firms' revenue. In other words, the results in column 7 suggest that conditioned on other firm attributes, firms that resorted to own-electricity generation during power outage periods recorded higher production levels thereby boosting revenues relative to firms that did not rely on own-supply when electricity supply from the grid was cut.

Table 4. DID Estimations: Self-Generation and Firm Revenue/Productivity

	Baseline			Follow-Up			
	1	2	3	4	5	6	7
	Control	Treated	Δ(2-1)	Control	Treated	Δ(5-4)	DID(6-3)
Revenue	12.046	12.407	0.361***	9.980	10.932	0.952***	0.591***
	(1.614)	(1.635)	(0.132)	(2.101)	(2.103)	(0.153)	(0.211)
TFP_LP	3.469	3.492	0.023	5.830	5.811	-0.019	-0.042
	(3.486)	(3.486)	(0.075)	(5.015)	(5.022)	(0.137)	(0.170)
TFP_OL	4.043	4.134	0.091	6.417	6.484	0.066	-0.025
	(3.198)	(3.203)	(0.62)	(4.688)	(4.687)	(0.149)	(0.170)

Robust standard errors, clustered at firm level in parenthesis

Variables are in logs.Covariates are included. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

However, the impact on productivity is negative but insignificant. The conclusion ensuing from this analysis is that, whereas firms that rely on self-generated power during periods of power holidays may boost production and hence revenues, the effect of this action on productivity is not discernible. Several reasons may account for this result: first, even though firms may turn on their generators they may not be able to generate the full electricity requirement that meet optimal production mainly due to the cost of self-generation. That is, firms may only be able to partially offset the drop in power supply rather than maintain the same level of supply as they would have obtained in the absence of outages, due to the high associated cost. Secondly, the cost of generation may either exactly offset the benefits from generation or in most cases outweigh the benefits.

Further, a crucial assumption in the difference-in-difference analysis advanced above is the random assignment of firms in the treatment group. However, the nature of the dataset implies that this assumption is far from reality. Given, that the decision to invest in self-generation is endogenous– in the sense that firms' take the decision conditioned on a number of factors (both observable and unobservable)– the difference-in-difference estimation is likely to suffer from "selection bias".

To solve this bias, I proceed to estimate an "endogenous treatment effect" model whereby the assignment into treatment is no longer assumed to be exogenous but endogenous. Results are shown in table 5. The log likelihood (LR) test of independent equations is significant (except columns 2-3), indicating that the treatment variable is endogenous in the model and hence the need to utilize an instrumental variable approach in order to estimate the causal impact of treatment. From the first stage results, the instruments(diesel price and variations in hydro generation) are shown to be significant and strong predictors of firms decision to rely on generators for electricity supply during power holidays. Increases in hydro-electricity generation as well as real price of diesel reduces the probability for firms to self-generate.

The second stage results shows the average treatment effect(ATE) of self-generation on revenue and TFP. Juxtaposing the results herein with the difference-in-difference estimate shows interesting conclusions. Similar to the results in table 4, columns (1-2) of table 5 shows a positive treatment effect on firm revenues. This confirms the assertion that firms' use of generators to produce electricity during outage periods may help in boosting production and revenue. The most surprising result, however, is the effect of treatment on productivity. Columns (4-6) shows a significant and negative effect of treatment on total factor productivity. The implication of this result is that, firms that self-generate are less productive than a comparable group which did not produce own power during power holidays. A plausible explanation for this result is that reliance on self-generation while (may be) helpful to at least sustain production in the short run, the associated marginal costs are higher, thereby stifling firms ability to devote resources towards improving the efficiency of other factor inputs to enhance productivity.

Table 5. Endogenous Treatment Effect Model:Self-Generation and Firm Revenue/Productivity

	(1)	(2)	(3)	(4)	(5)	(6)
	Δ Revenue	Revenue	Δ TFP_LP	TFP_LP	Δ TFP_OL	TFP_OL
Second Stage Treatment Effect Model						
Treat	3.232***	2.911***	0.528	-1.255***	-2.528***	-1.116***
	(0.529)	(0.523)	(0.430)	(0.323)	(0.367)	(0.302)
Constant	0.0540	13.41***	3.943**	0.0397	5.582***	1.112
	(1.784)	(1.806)	(1.796)	(1.229)	(1.559)	(1.076)
First Stage Probit: Dep. Var is Treat						
Hydro Var.	-0.247***	-0.161***	-0.469***	-0.266***	-0.407***	-0.249***
	(0.0688)	(0.0547)	(0.133)	(0.0626)	(0.123)	(0.0604)
Price of Diesel	-1.300***	-0.949***	-1.417**	-1.166***	-1.552*	-1.158***
	(0.247)	(0.181)	(0.650)	(0.277)	(0.799)	(0.277)
Constant	-0.103	-0.199***	0.220	-0.141*	0.304**	-0.139*
	(0.0740)	(0.0633)	(0.145)	(0.0824)	(0.127)	(0.0834)
LR	23.81***	0.253	0.373	4.398 **	50.66 ***	5.061**
Firm controls	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	551	1005	138	573	138	573

Dependent variables and price of diesel are in logs. Treat is treatment indicator measuring firm adoption of generator.Robust standard errors, clustered at firm level. LR test of independent equations ($\rho = 0$) follows a chi-square distribution. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Finally, in this section, a counter argument to the treatment effect and DID analysis above is that the treatment indicator does not really capture the extent to which firms rely on self-generation during power holidays. Instead, it only measures whether firms switch to self-generation sources when there are shortages in grid supply. As argued by Allcott et al. (2014), although some firms may acquire generators, they may not utilize it because of improvements in grid supply and hence economically beneficial to rely on grid electricity than generators. To test this claim, I estimate the relationship between the share of firms' total electricity input obtained from generators and firm revenue/productivity using the reduced form model in equation(12) (see table 6).

Table 6. IV Estimation: Effects of Self Generation Share on Firm Revenue/Productivity

	(1) Revenue	(2) Revenue	(3) TPF_LP	(4) TPF_LP	(5) TPF_LP	(6) TFP_OL	(7) TFP_OL	(8) TFP_OL
lnself_share	-1.345***	-2.535***	-1.411***	-0.316***	-0.249***	-0.660***	-0.251***	-0.235***
	(0.360)	(0.530)	(0.359)	(0.0787)	(0.0738)	(0.250)	(0.0732)	(0.0675)
Constant	16.83***	18.04***	2.270***	-0.113	0.366	1.435**	0.333	0.449**
	(1.161)	(1.888)	(0.816)	(0.269)	(0.225)	(0.570)	(0.256)	(0.212)
Firm controls	No	Yes	No	Yes	Yes	No	Yes	Yes
Industry FE	No	Yes	No	No	Yes	No	No	Yes
Year FE	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Country FE	Yes	Yes	No	No	No	No	No	No
KPLM	48.91	37.25	35.36	143.5	146.7	35.36	143.5	146.7
CDF	32.53	23.08	16.98	99.61	94.16	16.98	99.61	94.16
AP	28.29	20.48	21.56	97.50	97.34	21.56	97.50	97.34
Obs	1617	1550	680	674	675	680	674	675

Dependent variables are in logs. Robust standard errors, clustered at firm level. TFP_OL & TFP_LP represent TFP estimated from OLS and Levinson-Petrin respectively. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

According to the results, increasing the share of electricity input produced by generators is associated with declining revenues and total factor productivity. The general conclusion from the results in tables 5 and 6 is that greater self-generation has a negative long run impact on firm productivity, albeit, a positive short run gains in output/revenue. This can be largely attributed to the high cost associated with operating generators for the purposes of producing power. Thus the greater dependence on own-power generators for electricity reduces the profitability of firms, resulting in lower investments into other critical areas of production, thereby affecting productivity negatively. Therefore, the real impact of self-generation on firm productivity may not be positive as otherwise expected.

7 Conclusion

This paper presents evidence of the micro effects of power outages in Sub-Saharan Africa, by investigating the impact of electricity shortages on the performance of firms. Further, the paper presents evidence of the impact of electricity self-generation – as an adaptation strategy to power outages – on firm performance.

Using a panel data on 2,144 firms in 15 SSA countries, results from the paper shows a significant and negative impact of power outages on firm revenue and productivity. Also, the impacts are heterogeneous across countries, with the highest impact among Nigerian firms while South African firms are the least affected. Further, contrary to expectations that self-generation during outage periods may ameliorate the negative impacts of power outages on firm performance, evidence from this paper suggest otherwise. I find that reliance on self-generation may have long run negative impact on firm productivity. This is mainly due to the high marginal cost associated with self-generation thereby constraining firms' ability to invest into other factor inputs to boost productivity.

The results derived in this paper have far reaching policy implications. First, finding lasting solutions to the recurrent energy crises extant in almost all countries in the region should be a paramount developmental goal. This is because, improved provision of electricity has positive growth potentials via boosting output, productivity, employment, foreign direct investment and income. Secondly, even in the presence of power crises, reducing the uncertainties regarding outage periods can be extremely beneficial. This can be achieved via planned and full information disclosure of outage schedules, thereby helping firms to plan and organize their production activities efficiently.

Finally, firms' decision to rely on power self-generation during power holidays must be carefully evaluated to identify the associated costs and benefits before such actions can be undertaken. In the event of a high marginal cost of self generation, re-organization of productive activities to fully utilize grid power when available and less reliance on self-generated power during outage periods may be beneficial rather than depending heavily on own-generated power.

8 Appendix

Table A1. Summary Statistics-Firm Data

Variable	Mean	Std. Dev.	Min.	Max.	N
Revenue (log)	14.133	3.106	0	25.934	3741
log of outage	2.045	1.006	0	6.899	3175
Real price of diesel (log)	-0.001	0.42	-0.912	0.560	4288
log of TFP_OL	0	1.244	-14.512	9.957	1201
log of TPF_LP	-0.687	1.317	-15.306	9.811	1201
log of firm age	2.617	0.75	0	5.118	4105
self gen share of total	0.255	0.274	0	1	1792
size of the firm	1.596	0.751	0	3	4239

Table A2. List of countries in the firm data

	Panel Wave	
Country	1	2
Angola	2006	2010
Burkina Faso	2006	2009
Cameroon	2006	2009
Congo D.R.	2010	2013
Ghana	2007	2013
Kenya	2007	2013
Malawi	2009	2014
Mali	2007	2010
Nigeria	2009	2014
Rwanda	2006	2011
Senegal	2007	2014
South Africa	2003	2007
Tanzania	2006	2013
Uganada	2006	2013
Zambia	2007	2013

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