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Power Outages and Firm Performance in Sub-Saharan Africa

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Abstract

In this paper we assess the extent to which power outages affect the sales of firms across different African economies. We address the potential endogeneity concerns endemic in much of the existing literature by constructing an instrument for power outages based on the varying share of electricity produced by hydro-power as a result of variation in the local climate conditions. Using firm-level data for 14 countries from the World Bank Enterprise Surveys, we find evidence of a negative relationship between an unreliable electricity supply and firms' sales, with a stronger effect for firms that do not own a generator. We find that reducing average outage levels to those of South Africa would increase overall sales of firms in Sub-Saharan Africa by 85.1%, rising to 117.4% for firms without a generator.

JEL classification: O12, O18, O55

Keywords: Firms, hydropower, Africa, river-flow modelling, power outages.

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1. Introduction

The prospects for the continued development of many African economies are significantly better today than they were at the beginning of the century. The gross domestic product (GDP) of the region has doubled since 2000 with an average growth rate for the period 2008-2015 of around 5%. However, a number of hurdles will need to be overcome if Africa is to continue to develop at this rate. One particular concern is the relatively poor state of the electricity network which causes considerable disruption to the power supply of many of Africa's largest cities as a results of generation, transmission and distribution losses. The overall cost of such disruption across sub-Saharan Africa (SSA) is estimated to be as much as 2.1% of GDP with total sales of African firms estimated to be 4.9% lower than they would be if electricity supplies were dependable (Eberhard *et al.* 2011 and IEA 2014). Not surprisingly, firms have identified the unreliability of the electricity supply as one of their main obstacles to expansion. As a result the last two decades have seen an increase in the demand for relatively expensive back-up electricity generation to the extent that firm-owned electricity generators now represent a significant share of the installed capacity in all SSA regions. Since such generators are expensive to operate and, for many SSA firms, are prohibitively expensive to purchase, power outages have the potential to impose significant costs on firms whether or not they own generators. It is therefore important for academics and policymakers to gain a greater understanding of the relationship between the reliability of power supplies and firm performance.

A major concern with previous studies of the impact of electricity outages on firm performance is how to deal with potential endogeneity problems that arise when power outages are used as a determinant of firm performance. Endogeneity may occur if governments deliberately target investment in energy infrastructure close to large, high performing firms in order to support their operations. Similarly, government policies may simultaneously affect firm performance and outage levels. For example, government investment in infrastructure more generally (roads and rail) may improve the reliability of the electricity supply (power lines can then be more easily fixed) but should also help firms to get products to market more quickly.[1]

The contribution of this paper is to quantity the impact of power outages on the total sales of manufacturing firms in SSA taking endogeneity concerns into account by constructing an instrument that is correlated with the incidence of power outages but not with firms'

[1] Other potential sources of endogeneity, and our ability to address them, are discussed later on in the paper.

performance. The construction of our instrument relies of the availability of water for electricity generation which varies across hydropower plants and across countries. Put simply, everything else equal, a decrease in the streamflow to a river that serves a hydro-power plant will lead to a reduction in the amount of electricity produced by that plant which in turn will increase the incidence of power outages in areas served by that plant.[2] However, this reduction in stream flow should not have any effect on the demand for electricity from any given country. Our choice of instrument is motivated by the observation that hydropower plays a prominent role in the portfolio of generation capacity throughout SSA. For example, hydropower accounts for more than 75% of installed capacity in Burundi, Malawi, Mozambique, Uganda, Lesotho, DRC and Zambia (and for more than 90% in the last three). By combining our instrument, derived from the Geospatial Streamflow Model (GeoSFM) for the whole of Africa, with the World Bank firm level survey (WBES) we are able to investigate the impact of power outages on 14 African countries covering the period 2005 to 2013.

Our paper contributes to a strand of the literature that focuses on the effect of energy infrastructure on firm performance. In a study closely related to our own, Allcott *et al.* (2016) also use changes in the supply of electricity from hydropower production as an instrument to estimate the effect of power outages on the Indian manufacturing sector. Their study shows how the overall impact depends on firm characteristics whereby firms with access to back-up generation face increased production costs while those without need to stop production and potentially waste all non-storable inputs. Abeberese (2013) also constructs an instrument for power outages but this time based on the interaction between the share of thermal generation in an Indian state and the retail price of charcoal to assess how varying electricity costs affect firm performance. Other studies that examine the effect of power outages are limited but include Moyo (2012a) who looks at the effect of power cuts on Nigerian manufacturing and Alam (2014) who investigates how Indian sectors with different electricity-intensities respond to power-cuts. A similar approach is

[2] The link between river flow and hydropower is most direct for 'run of the river' hydropower plants which channel a river through a turbine without any storage capacity and are commonly used in Africa. However, over the course of a year we would also expect there to be a relationship between river flow and hydropower from storage (dam based) hydropower plants.

taken by Fisher-Vanden *et al.* (2015) who examine the effects of electricity shortages in China on firm performance.[3]

In a related literature, a series of studies examine the determinants of a firm's decision to invest in back-up generation (Steinbucks and Foster 2010, Alby *et al.* 2013 and Oseni and Pollitt 2015). Studies that consider the broader effect of electrification include Peters *et al.* (2010) and Dinkelman (2011) who investigate the effects of rural electrification schemes on the profitability of micro-enterprises and rural employment respectively, finding in both cases a partial but positive and significant effect. Finally, Lipscomb *et al.* (2013) provide simulations of different development possibilities for the Brazilian electricity grid and conclude that existing models may underestimate the real returns from electrification.[4]

To briefly summarise our results, we find that frequent and unexpected power outages represent a significant burden on African firms. While these effects are perceivable in the overall sample, the damages incurred by the sizeable subset of firms without access to back-up electricity generation (52%) is altogether of a different magnitude. Policies to reduce the average hours of power outages to the levels recorded in South Africa (118 hours a year), the lowest of all African countries, could lead to an increase in sales of 85.1% for all firms, rising to a 117.4% increase for firms that do not possess back-up generation.

The remainder of the paper is organized as follows. In Section 2 we describe our data and present some descriptive evidence. Section 3 describes the GSFM model that we use to construct our instrument. Section 4 presents our econometric methodology and Section 5 presents our empirical results. Section 6 concludes.

[3] The existing literature on the economic effects of infrastructure investment dates to the end of the 1980s, with early studies tending to focus on inter-state differences in infrastructure stock and growth across the US (Aschauer 1989, Holtz-Eakin 1994, Gramlich 1994, Garcia-Mila *et al.* 1996). Other studies looked at the effect of deficient infrastructure on firms' cost structure (Lee *et al.* 1996) or the contribution of diversity in the type of infrastructure to GDP-per-capita growth in countries at different stages of development (Canning and Pedroni 1999). Common problems with the previous literature relate to using common time trends in expenditure in infrastructure across countries and the difficulty of data collection in developing countries. More importantly, for this paper is the issue of possible reverse causality between growth in infrastructure and growth in GDP. These concerns have been partially been addressed by Esfahani and Ramírez (2003) and Luo (2004).

[4] Other studies that consider different micro-level effects of infrastructure investment include those looking at the economic benefit of improving water infrastructure for microenterprises in Uganda (Davis *et al.* 2001); the welfare gain for households for similar improvements in Mexico (Baisa *et al.* 2010); the impact of information and communication technology on agricultural productivity and the fishery sector in Lio and Liu (2006) and Jensen (2007) respectively. Other studies have examined the productivity and distributional effects of irrigation dams in India (Duflo and Pande 2007); the effect of different infrastructure provision on TFP growth of SSA firms (Escribano *et al.* 2009), on firms' cost in Eastern Europe and Central Asia (Iimi 2011) and the export performance of SSA firms (Moyo 2012b).

2. Firm data

Our main source of firm level data is the World Bank Enterprise Survey (WBES) that includes classical balance sheet information as well as a series of continent and country specific variables. Our data are constructed using the most recently available year for all non-island SSA states which have at least 50% of their installed generation capacity in the form of hydropower. Our final sample consists of 14 countries for the period 2006 to 2014. [5] All monetary variables are deflated to 2005 levels using a GDP deflator from the World Bank and then transformed into US dollar values using the Purchasing Power Parity (PPP) Index from the International Monetary Fund.[6]

The World Bank uses stratified random sampling to select firms for the Enterprise Surveys. The strata used by the World Bank are firm size (small firms have 5-19 employees, medium have 20-99 and large have 100+), sector and geographic region and hence, within each of these strata, firms are selected at random. Since the majority of firms tend to be small and medium sized, the Enterprise Surveys oversample large firms because of their importance within most national economies. In principle therefore there are more large firms within our sample than would be the case if our sample were truly representative.[7]

Using information from the questionnaire we derive a number of relevant variables. To construct our power outage variables we calculate the average number of outages per year by multiplying the average number of outages per month by 12. Likewise, our measure of the number of hours of power outage per year is calculated by multiplying the annual number of outages by the average length of an outage (with an upper limit given by the number of hours in a year).

We also generate a set of control variables using the WBES data. To capture the internationalisation of firms we create an exporter dummy that is equal to 1 if a firm exports at least 1% of their annual production. We also create size dummies for small

[5] Our sample of 14 countries appears to be broadly representative of the full sample of African Enterprise Surveys as both samples display good variation in terms of, for example, country size and population levels (the standard deviation of country size is 574.4 (thousand km2) for the full sample and 621.2 for our reduced sample; for population levels the standard deviations are 27.1 (millions) for the full sample and 37.6 for the reduced sample).

[6] As part of our sensitivity analysis our deflated prices using the consumer price index and used the United Nations PPP index. There was no noticeable difference in our results.

[7] Our later results indicate that there is no statistical difference between the impact of outages on sales for small firms and large firms which may suggest that the effect of this oversampling on our results is minimal.

(below 20 employees), medium (between 20 and 100 employees), large (between 100 and 300 employees) and very large firms (above 300 employees). Other dummies are included to control for firms that have access to credit and those firms that are publically traded companies.[8]

Our final sample consists of 2,775 firms, of which 1,328 are in the manufacturing sector (the remaining firms are in the service sector). Firms are not equally divided amongst the 14 different countries. For example, Kenya has the largest number of firms with 518 firms followed by Ethiopia with 376 and the Democratic Republic of Congo with 351. Of the remaining countries, 3 contribute fewer than 100 firms each while the others have between 100 and 350 firms.

Figure 1 presents the average yearly number of hours of outages (the year in question varies by country).[9] The countries with the highest number of hours of outages are the Republic of Congo, Guinea and Uganda. In terms of the number of outages (not shown), the country that experienced the lowest number of outages is Malawi (15.38 in 2008) whereas, in contrast, Burundi experienced 241 outages in 2013. If we consider the average length of an outage, they range from less than 3 hours in Zambia to almost a day in the Republic of Congo. The combination of frequent and long outages means that 8 countries in our sample have firms that face on average more than 500 hours of outages each year.[10, 11]

[Figure 1 about here]

Our primary interest is to estimate the economic damage that electricity outages cause to the firms in our sample. In each questionnaire the business owner is asked to estimate the losses that firms incur as a result of outages measured as a percentage of their output and how the provision of electricity is seen as a constraint on future firm expansion. The correlation between losses in sales and our different measures of outage are not as strong as one might expect which suggests that the industrial sector to which a firm belongs is

[8] A publically traded company is defined as a "shareholding company with shares in the stock market".

[9] The sample of countries, the year of study and the number of cities included in each country is as follows: Angola, 2009, 3 cities, Burundi, 2013, 3 cities, Cameroon, 2008, 3 cities, Congo (Republic of), 2008, 2 cities, Democratic Republic of Congo, 2012, 4 cities, Ethiopia, 2010, 5 cities, Guinea, 2005, 2 cities, Kenya, 2012, 5 cities, Lesotho, 2008, 1 city, Malawi, 2008, 4 cities, Mozambique, 2006, 4 cities, Namibia, 2013, 3 cities, Uganda, 2012, 4 cities, Zambia, 2012, 4 cities.

[10] There is also considerable within country variation in outages. For example in Angola the number of hours of outages range from 508 in Benguela to 2,173 in Huambo while in the Republic of Congo it ranges from 2,991 in the capital Brazzaville to 4,617 in the second city Pointe Noire.

[11] While power outages may result from generation losses or from transmission/distribution losses, a lack of data means we are unable to quantify the relative magnitudes of these different losses.

important in determining how damaging it is to have an unstable energy provision.[12] Figure 2 presents the percentage loss in output as a result of power outages and total number of outages over a year, averaged across industries. A positive relationship is discernible. Similarly, Figure 3 displays losses due to outages and the extent to which firms consider outages to be an obstacle to firm expansion, also averaged across industries. Again, a positive relationship can be observed, as may be expected.[13]

[Figures 2 and 3 about here]

The correlation between our power outage measures and the percentage of firms that find electricity the main obstacle for expansion ranges from 0.05 with respect to the length of outage and 0.11 with respect to the number of hours of outages. The countries in which firms claim to be constrained mainly by the provision of electricity are Uganda, the Republic of Congo, Burundi and the Democratic Republic of Congo. The countries for which energy-related issues are the least relevant include Guinea, Namibia and Angola.[14]

One factor that potentially mitigates against the damage caused by outages is the use of firm level electricity generation through the use of a generator.[15] Foster and Steinbucks (2009) point out that although the generation of electricity through the use of generators is not particularly high at the African continental level there is considerable variation across countries. In their paper, Foster and Steinbucks (2009) track the relevance of in-house generation at the firm-level as a proportion of the installed capacity using information contained in an older version of the WBES. However, such tracking is no longer possible with the current questionnaire. Nevertheless, our data reveal that the continental level of generator ownership is around 52%. However, this hides significant differences across countries. For example, Mozambique has generator ownership rates of around 10% while Angola and Burundi have rates above 70%. The picture is similar when we look at the percentage of electricity that comes from self-generation. The continental average is 26% which is driven by a small number of countries characterized by high generator ownership

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[12] The correlations range from 0.13 between losses and number of outages and 0.22 between losses and hours of outages.

[13] Figures 2 and 3 are averaged across industries to more clearly show the relationships between our variables of interest. A firm-level scatter plot of is difficult to interpret given our large number of firms. In addition, the variable capturing the extent to which firms consider outages an obstacle to expansion takes a value of 1 to 4 and hence a firm-level plot shows obvious clustering around those four values.

[14] In the survey, the question asks, *"Which of the elements of the business environment … currently represents the biggest obstacle for the establishment?"* Hence, a low percentage does not necessarily imply that electricity is not a major obstacle, just that it is not considered *the* major obstacle.

[15] Firms that own generators continue to report outages and so are presumably aware when external supplies are disrupted and their own generator takes over.

and very unreliable electricity supply (e.g. Republic of Congo). As expected, both the percentage of electricity generated in-house and the percentage of generator ownership increases with the total hours of outage.[16]

3. River-flow modelling and the construction of our instrumental variable

Our instrument is based on linking exogenous river flow variation to hydropower plants and then to firms within our data set. The first step is to define the population of hydro-power plants in SSA. For this we use the Platt's World Electric Power Plants (WEPP) database. The WEPP database is the most extensive available source of information on power plants and includes all those plants managed by public utilities or private companies independent of size or generation capacity. In addition to information on installed and operative capacity, power source, turbine type and age of the plant, the database also contains information on the latitude and longitude of the majority of plants. Two other sources of plant location information are the Africa Infrastructure Country Diagnostic (AICD) and the African Dam database.[17]

Table 1 presents the share of hydropower by country according to the WEPP database. As can be seen, hydropower contributes a significant share of electricity in most of the countries in our sample with a high of 97.69% for Lesotho and an average share across all countries of 75.16%.

[Table 1 about here]

The next task is to estimate the stream flow into each hydropower plant. The potential electricity production of a hydropower plant depends on the installed capacity and on the available streamflow. The ideal data would be those from gauge stations located in proximity to the plants. Unfortunately, such data are not readily available on a consistent continental basis for Africa so instead we simulate river flow from relevant observable data. More specifically, we employ the Geospatial Streamflow Model (GeoSFM) developed by the US Geological Survey (USGS) National Centre for Earth Observation and Science

[16] African power pools could, in principle, mitigate the effect of water shortages by allowing countries to import electricity from neighboring countries. In practice, however, this does not appear to be happening to any significant degree. IEA data indicates that in 2013, the latest year of our sample, electricity imports were zero in Angola and Ethiopia and a tiny proportion of electricity production in other countries (e.g. 0.56% in Zambia and 0.98% in Kenya).

[17] These data include those plants working as independent power producers and those who use the power plant to supply electricity for their own production.

(EROS) as part of the Famine Early Warning System (FEWS). GeoSFM is part of a program that begins by defining the spatial extent of the watershed under analysis and combines a Digital Elevation Model (DEM) and information about the river network. The inputs for this aspect come from Hydro1k, a geographic database developed by USGS EROS that contains the whole African river network which is divided into 7,131 unique basins with an average area per basin of 4,200 km^2. The program also requires information on land cover and soil characteristics which play important roles in defining a watershed rate of runoff generation and of overland flow transport. Data on land cover are from the USGS Global Land Cover Characterization and soil characteristic taken from the Digital Soil Map of the World produced by the United Nations Food and Agriculture Organization (FAO) in collaboration with the United Nations Educational Scientific and Cultural Organization (UNESCO). The latter contain a series of information such as soil depth, salinity, texture and water holding capacity. Once combined, these data provide a soil conservation service runoff curve which we use to determine the level of precipitation that becomes runoff

After the set of river basins are created, weather data, namely rainfall and evapotranspiration, are added to the model. Rainfall estimates come from the Climate Prediction Centre (CPC) of the National Oceanic and Atmospheric Administration (NOAA), and are calculated using a methodology developed by Xie and Arkin (1997). Evapotranspiration data are taken from the estimates produced by the FEWS group at USGS EROS.

In generating river flow by basin from the weather data, GeoSFM provides a choice of two routines, namely linear and a nonlinear soil moisture accounting. Given the size of the area under analysis we use the less computational intensive linear routine. The final step is the simulation of the horizontal movement of the runoff generated within each catchment from the catchment outlets to the basin outlets. GeoSFM offers a number of options, namely two linear routines, pure lag and a diffusion analogue, and a non-linear routine which is called the Muskingum Cunge. Again, the less computational intensive pure lag approach is preferred.

To validate the output of our model we provide a brief comparison between flow discharges simulated through GeoSFM and the available historical data. To this end we use the river flow data from the archive collected in the GRDC of the German Federal Institute for Hydrology (BFG, Bundesanstalt für Gewässerkunde). Of the 440 gauge stations in the SSA region, 386 have a long enough data record for the analysis and these are matched to the corresponding basins generated by the GeoSFM model and cross referenced using the ALCOM/WWF classification (Verheust and Johnson 1998). Note that this does not guarantee a perfect geographical association to the exact point in which the gauge station is located.[18]

Following Asante *et al.* (2008) we focus on anomalies to validate our model output.[19] To examine the correlation between the actual and simulated river flow data we employ Copula functions. Copulas are particularly useful in this case since they allow us to express the dependency between non-normally distributed components and to more flexibly model the relationship at the tail of a multivariate distribution. Two main families of Copula are normally used in hydrology: elliptical (Gaussian and Student *t*), which can be extended to arbitrary dimensions but require radial symmetry, and Archimedean which allows us to model upper and lower tail behaviour but can be applied only to bivariate cases.[20]

We calculate the Kendall Tau statistic, which is a non-parametric measure of dependence, for the 10 continent level basins in Africa, which are Lake Chad, Nile (White and Blue), Interbasin 1, Interbasin 3, Interbasin 5, Interbasin 7, Interbasin 9, Zambezi, Congo and Niger. The number of gauge stations for these basins varies significantly, from the Nile with just 2 to a maximum of 64 for Interbasin 5. To summarize our results, which are available upon request, we find that overall, 121 out of the 182 stations show a significant fit using Copula modelling, while only 4 show a negative dependence (3% which is lower than the 12% that we obtain through a simple correlation).[21]

Given our validation of the GeoFSM output, the final stage is to generate our instrument. The process consists of matching the power plants with the productive centres they serve. From our sample of 14 countries we have data for 52 cities. For each city we select the

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18 As previously noted, gauge stations are the most generally used tools to gather hydrological information. Unfortunately, the majority of Sub-Saharan African basins are ungauged. In addition, the gauge stations that have been installed have often been lost due to poor maintenance, war and general unrest or a combination of the two. In comparison with many other areas of the world there is remarkably little historical data available for African river basins.

19 Anomalies are defined as difference between daily observations and long term mean scaled by the standard deviation.

20 For a general statistical treatment see for example Mikosch (2006) or Fredricks and Nelsen (2007), while for a hydrology specific treatment see Genest and Favre (2007) and Schölzel and Friedrichs (2008). Copula functions are receiving increasing attention in hydrology and climate science with applications ranging from field significance to discharge-duration-frequency analysis (see Renard and Lang 2006 for a review of different case studies).

21 The significance of Copulas has been determined via the implementation of the Anderson-Darling test in R through the Copula package developed by Hofert *et al.* (2015). Other applications include Yan (2007), Kojadinovic and Yan (2010) and Hofert and Maechler (2011).

closest power plants. Table 2 presents information on the density of power plants around cities for each country. Density levels vary considerably. For example, 50% of Malawi's power plants are within 50km of a city while no Angolan power plants are within 50km of a city. While electricity is immediately available for consumption at any point on the grid once it has been generated, the relatively poor quality of the transmission and distribution lines across the continent means that the probability of a power outage will almost certainly increase with the distance from the power plant, especially given imports and exports of electricity still make up only a small fraction of total electricity consumed. Following the descriptive evidence in Table 2 we use four different radiuses in our analysis (50, 100, 200 and 300 km) to capture the variation in power plant proximity for the different countries in our sample. As the density of power plants around any production centre (city) is related to the area of the country, we use this criterion to determine which radius to apply for each country. Hence, we use the smallest radius for countries which fall in the smallest quartile for area, the second smallest for those in the second quartile and so on.[22]

[Table 2 about here]

Once we have connected the production centres to the power plants, the final step is to account for the importance of different plants. We do this because a shock to a hydropower plant with a larger generation capacity is likely to have a larger impact on electricity production than a shock to a plant with a smaller capacity. As a result we scale our anomaly variable by the installed capacity of the plant and then aggregate plants to the city level.[23]

4. Econometric Methodology

4.1 Estimation Strategy

Our estimation strategy is to instrument our outage measures (the average number of outages in a year and the average hours of outage in a year) using information about the water available for hydropower generation by estimating the following equation:

[22] Countries in the 50km quartile are Burundi and Lesotho. Countries in the 100km quartile are Uganda, Guinea and Malawi. Countries in the 200km quartile are Congo, Cameroon, Kenya, Zambia and Mozambique. Finally, those countries in the 300km 4th quartile are Namibia, Ethiopia, Angola and DRC.

[23] As a robustness check we re-estimated our results using reported operating capacity from the WEPP database. However, as we cannot link operating capacity to the period of our outage data we prefer to use installed capacity.

$$Y_i = \alpha + \beta_1 X_i + \beta_{ji} Z_i + \varepsilon_i \quad (1)$$

where Y_i is the log of total sales for firm i, X_i is the instrumented version of one of our two outage measures (log of the number of outages or log of the hours of outage) and Z_i is an array of control variables (size dummies, exporter status, age, foreign ownership, public ownership and access to financial credit).[24] Country dummies and 2-digit industry (standard industrial classification (SIC)) dummies are included in all specifications. Standard errors are clustered at the city-level. The main challenge for identification is to explain firm-level variation in power outages using city-level variation only (as the absence of firm data over time prevents us taking a panel estimation approach) and second, to account for the high variability in water availability throughout the year using a single average measure.[25]

4.2 Endogeneity

Having outlined our data and methodology we can now consider with more precision the various ways in which endogeneity may arise and which aspects of endogeneity we are able to address. There are three main endogeneity concerns. First, as mentioned above, governments might improve energy infrastructure close to large and successful firms in order to maintain the high performance of those firms. Similarly, government policies that may affect outage levels may also influence a firm's economic performance. For example, government investment in road networks may enable power lines to be more easily maintained while also improving firms' market access. Second, there may be measurement error in firms' reported incidence of power outages given that the figures tend to be self-reported. Third, the initial decision of a firm of where to locate may be influenced by the quality and reliability of the electricity infrastructure in that location. More specifically, there is the possibility that a firm that has a high level of electricity dependency will chose to locate in a city, region or country with a more reliable electricity supply and, in the

[24] We also tested a conflict dummy capturing incident(s) where armed force was used by an organised actor against another organized actor, or against civilians, resulting in at least 1 direct death at a specific location and a specific date between 1980 and 2016 at the town/village level, as reported by the UCDP GED dataset. We created a dummy equal to one if there was any incident within 100 km from any city included in the sample. In each case the conflict variable was insignificant, perhaps reflecting the relative lack of serious conflict within our sample during the period of our analysis, and had no impact on the estimated coefficients of our variables of interest.

[25] In unreported results we replaced the 2-digit industry dummies with a simple manufacturing dummy. The sign and significance of the coefficients on outages were not affected and the magnitude of the coefficients was very similar. For information on the sector codes see https://www.enterprisesurveys.org/~/media/GIAWB/EnterpriseSurveys/Documents/Methodology/Questionnaire-Manual.pdf.

extreme case, may decide to locate close to a power plant believing that this will mean that power lines will cover shorter distances and hence supplies may be more reliable.

Since we have constructed an instrument that is correlated with power outages but not with firm performance our instrument directly addresses the first form of endogeneity discussed above. In terms of the second, measurement error, this could potentially cause downward attenuation bias of our coefficients. However, as long as the measurement error is not correlated with our instrument then our instrumental variables strategy will be able to alleviate this problem. Since we have no ability to ascertain whether such a correlation exists, some downward bias of our coefficients remains a possibility. Finally, there is the third endogeneity concern relating to firm location which our IV strategy is unable to directly address. That said, our analysis considers realizations of anomalies in a particular year yet it could be argued that firms' location decisions are more likely to respond to *distributions* of anomalies. We attempt to substantiate this point in two ways. First, we examine whether one year anomalies are correlated with firm characteristics, specifically generator ownership and firm sales.[26] We find that yearly mean anomalies are not statistically significant determinants of these latter two variables. Second, we include the mean and the standard deviation of our streamflow variable in our second stage regression to control for the possibility that the distribution of anomalies affects firms' siting decisions. The standard deviation and the mean are insignificant in all 4 tested models. More importantly, the sign and significance of instrumented outages are not affected by the inclusion of the streamflow mean and standard deviation.[27] This provides some reassurance that our results are not unduly influenced by endogeneity relating to firms' siting decisions although we cannot entirely rule out this possibility meaning the coefficients on instrumented outages could be downwardly biased.

5. Results

After cleaning, our sample consists of 2,775 observations. We estimate our baseline OLS regression for all firms (Columns 1 and 2), those without a generator (Columns 3 and 4) and those with a generator (Columns 5 and 6). The results are presented in Table 3.

[Table 3 about here]

[26] We are grateful to the editor for this suggestion.
[27] For reasons of space these results are not reported but are available from the authors upon request.

The immediate observation is that the coefficients on the (log) of hours of power outages (PO) variable is always insignificant. In contrast, the (log) of the number of outages is significant for both the overall sample (Column 1) and for firms without a generator (Column 3). As expected the point estimates are higher for firms without a generator. Firms with a generator do not appear to experience a significant reduction is total sales as a result of the number of power outages. Our results suggest that it is the number of individual outages that matters rather than the accumulated time that the power is disrupted. Although, one might not expect the sales of firms with a generator to be affected, the additional expense of using higher cost electricity from a generator could have an indirect effect on sales through increased input costs. However, as previously discussed the results presented in Table 3 suffer from possible endogeneity concerns.

All other covariates have the expected signs and significance. Relative to medium sized firms, small firms have lower total sales and large and very large firms have larger sales. Both exporters and those firms with access to credit have larger total sales. Likewise, foreign ownership, age and being a publically traded company are positively related to total sales.

The next stage is to present the estimates for the first stage of our 2 stages least square (2SLS) regressions in which our power outage measures are instrumented with the average yearly value of the anomalies, weighted by installed capacity. The results are presented in Table 4. As can be seen, the yearly average value of the anomaly is statistically insignificant for the total sample, suggesting that it is not a valid predictor of power outages, either measured in the number of outages or the accumulated number of hours. However, when we split our sample into those firms with and without a generator it becomes apparent that this lack of predictive power is a result of the firms with generators, suggesting that for firms with generators, power outages are not caused by insufficient river-flow to the nearest hydropower plant. In contrast, for firms without generators our river flow anomaly measure strongly satisfies the relevance condition for an instrument.

[Tables 4 about here]

Having confirmed the validity of our instrument, in Table 5 we present the results from the second stages of our 2SLS regressions. Again, we report results for the all firms, firms without generators and firms with generators and for each we report a model in which no control variables are included alongside our outage variables. For all firms, we find outage variables to be statistically significant for two out of the four models. At the same time, results for endogeneity from under-identification and over-identification tests suggest that the 2SLS estimates are more efficient than the OLS estimates.

[Table 5 about here]

When we divide our sample into those with and those without a generator, for those without a generator we find that both coefficients are now significant and of a greater magnitude than in the OLS results. The results for the firms with a generator confirm the finding of no significance. Moreover, when we look at the test results for firms without a generator they suggest that the 2SLS estimates are to be strongly preferred as we find convincing evidence that there is indeed an endogenous relationship. The coefficients on our control variables are similar to those in the OLS regressions. One may want to note that our findings were confirmed by using a limited information maximum likelihood (LIML) estimation which is more robust to the presence of weak instruments (results available upon request).

Overall, our analysis suggests that once the possible endogeneity between the quality of electricity supply and firm sales is taken into account, the effect on firms which do not have access to back-up generation is much stronger than the OLS estimates suggest. To illustrate the magnitude of our results we use the benchmark of the levels of outages in South Africa since these are the lowest of all countries in the region. Indeed, if the average firm without a generator experienced a reduction in the average hours of outage to the level of the average South African firm (a reduction of 75.7%) our 2SLS results indicate that firm would experience an increase in total sales of 83% (corresponding to around $36m at 2005 PPP). Regarding the number of outages, again if these fell to the level experienced by South African firms (a reduction of approximately 73%), the average firm in our sample without a generator would experience an increase in sales of more than 117%. These increases in sales of 83% and 117% compare with increases of only 3.8% and 12.4% using equivalent models estimated by OLS.[28] The notable difference in the magnitude of these effects clearly illustrates the importance of controlling for endogeneity.

5.1 Extensions and Robustness

[28] These OLS results stem from models 3 and 4 in Table 3 i.e. firms without generators.

In this section we report the results of a number of further robustness exercises and extensions. For reasons of space we report only the results for non-generator firms and do not report coefficients for control variables.

We have ascertained that firms without generators are more affected by outages than firms with generators but we now consider whether large firms are affected differently to small firms and whether capital intensive firms are affected more than labor intensive firms. We define small and large firms as those with fewer, and more than, 20 employees, respectively. A labor intensive firm is defined as one belonging to a sector with average labor costs greater than the country's average labor costs, while a capital intensive firm is defined using the same principle, although we proxy capital intensity with electricity costs due to our lack of capital data. As Table 6 indicates, we find that the effect of outages on firm sales are statistically significant for both small and large firms but the magnitude of the impact is greater for large firms. We find the magnitude of the effect of outages to be slightly larger for capital intensive firms than labor intensive while the latter effects are also only weakly significant. However, in each case a z-test of coefficient equivalence fails to reject the null of equivalence and so the differences between small and large firms and labor and capital intensive firms are not statistically significant. [29]

We also investigate whether firms that serve the local domestic market might be more affected by power outages than firms with export markets due to disruption to local supply chains and infrastructure. By splitting our sample into exporters and non-exporters, Table 6 shows that power outages have a negative, statistically significant effect on sales for non-exporters but the effect for exporters, who are presumably less reliant on the local market, is not statistically significant (although we should perhaps note the significantly reduced sample size for exporters).

While we undertake our main analysis by examining the impact of power outages on firm sales, we now consider the impact on other aspects of firm performance, specifically total factor productivity (TFP) and profits.[30] Table 6 therefore reports the results of estimations in which total sales are replaced as the dependent variable by TFP and profits, respectively. As can be seen, for firms without generators we find that both the number and duration of power outages are statistically significant determinants of both TFP and profits. These

[29] The z-test statistic is calculated as $z = \frac{b1-b2}{\sqrt{(seb1)^2+(seb2)^2)}}$ where b1 and b2 are the two coefficients and seb1 and seb2 are the standard errors associated with each coefficient.

[30] Our dataset does not contain information on firms' capital stocks and so we follow Cui *et al.* (2015) and construct a measure of TFP that does not require data on capital.

results indicate that such outages appear to have a wide ranging impact on firm performance. Standardised coefficients for the effect of the number of outages on total sales, TFP and profits are 2.54, 1.31 and 3.22, respectively. The equivalent standardised coefficients for hours of outage are 1.74, 0.97 and 2.26 for sales, TFP and profits, respectively. It would therefore appear that outages have the largest impact on profits, followed by sales, and the least impact on TFP.[31]

Next, we consider the possibility that rainfall may affect agricultural productivity which then provides spillovers to urban areas. To do this we create a placebo variable in the same way as we create our main instrument but by instead connecting stream flow's anomalies to non-hydroelectric plants rather than hydroelectric plants. We find the placebo variable to be statistically insignificant in the first stage and instrumented outages to be insignificant in the second stage. These results provide some reassurance that our instrument is indeed capturing variation in hydropower.

Finally, it could be claimed that our instrument, which captures the effect of streamflow on hydropower output, might apply better to run-of-the-river hydropower plants, given the immediacy of the streamflow-hydro power output relationship, than to large reservoir-based hydro plants. To test this we now create a new instrument by omitting all reservoir-based hydropower plants from its construction. We find that this has no effect on the sign and significance of the number or hours of outages as a determinant of sales and the estimated coefficients are very similar to those in Table 5. This is perhaps not surprising since, over the course of a year, we would still expect there to be a relationship between streamflow and hydro power from reservoir dams. For instance, Conway *et al.* (2017) point out that Zimbabwe and Tanzania both experienced electricity outages due in large part to reduced rainfall during the El Niño event of 2015–16 despite all of their hydropower being generated by reservoir dams.[32]

[Tables 6 about here]

[31] Standardised coefficients are defined as $\beta_1^* = \beta_1(\frac{\sigma_{xi}}{\sigma_y})$ where σ_{xi} is the standard deviation of independent variable x_i and σ_y is the standard deviation of the dependent variable.

[32] We undertake two further sensitivity and robustness tests but do not report the results for reasons of space. First, given the possibility that firm sales might be correlated with water shortages, if for instance such shortages affect local incomes and hence demand, we include a measure of reported water shortages, reported at firm level for a sub-set of our sample, in our second stage regression. In each case water shortages were found to be statistically insignificant determinants of firm sales. Second, to assess whether conflicts might be influencing firm sales we create a measure of conflict within 100km of each city using the UCDP GED dataset. In each case the conflict variable was not a statistically significant determinant of firm sales.

6. Conclusions

In this paper we quantify the effect of power outages on firm sales taking into account endogeneity concerns by instrumenting for power outages. Our instrument choice is motivated by Africa's increasing reliance on hydropower and the relationship between the stream-flow to a river that serves a hydropower plant and the power generated by that plant. As our results indicate, we do indeed find evidence of endogeneity indicating the importance of carefully addressing such endogeneity concerns. We also find that power outages have a significant impact on firm sales for firms without generators but find no effect for firms with generators. This latter finding perhaps suggests that the operation of firm-owned generators is not sufficiently expensive to impact upon firms' performance. For firms without a generator, our 2SLS estimates indicate that if the average hours of outage could be reduced to that of the average South African firm in the sample, this would result in an increase in sales of 83%, or roughly $36 million in 2005 PPP. Similarly, if the *number* of outages fell by 73% (roughly the difference between an average firm and its South African counterpart) this would result in an increase in total sales of 117% for firms without a generator. The magnitude of these effects is notably larger than those estimated using OLS. The impact of outages does not differ in a statistically significant manner for small and large firms or for labor and capital intensive firms. We do find that non-exporters are affected by outages whereas exporters are not, perhaps reflecting the impact that outages may have on the local market and supply chain. We also find outages to have a statistically significant negative impact on firm profits and firm TFP.

Our results have two broad policy implications. Perhaps the most obvious is that African states with available funds should continue to invest in the upgrading of their energy infrastructure. The result would be a general increase in sales for all firms in the economy, especially for those firms without access to back-up generation, which is 45.7% of the firms in our sample. Furthermore, many other positive impacts are likely to derive from such an investment, not least since the public sector and hence the wider population will also benefit from a more stable power supply. Second, until such investments have been made and electricity supplies have become truly dependable African states should look to increase the availability of firm-owned generators and to improve the ability of firms to purchase or lease generators, for instance by providing greater access to credit.

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Figure 1: Average hours of outage per year

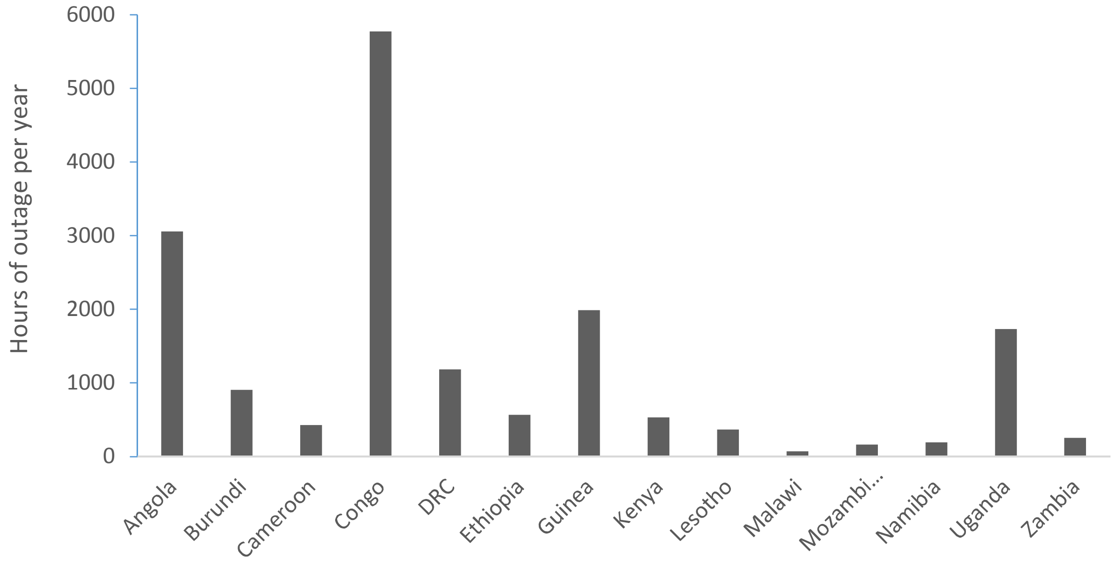

Figure 2. Reported losses and total hours of outages (industry averages)

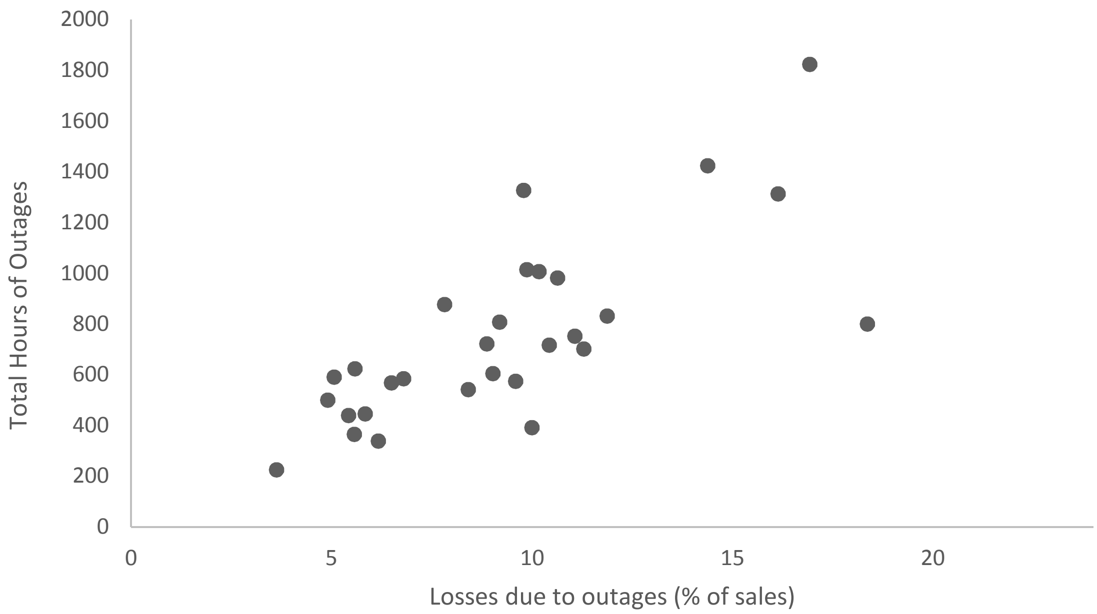

Figure 3. Reported losses and the extent to which outages form an obstacle to firms (industry averages)

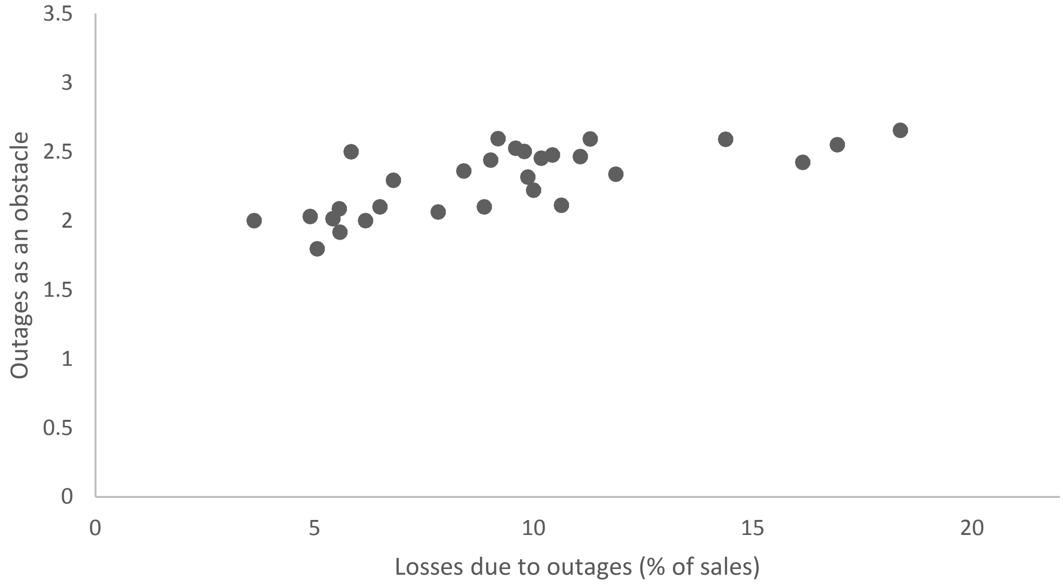

Table 1: Summary statistics for hydropower plants in Africa

	Number of power plants	Installed Capacity (MW)	Share of HP
Angola	67	1,319.41	66.84%
Burundi	32	42.283	82.93%
Cameroon	27	1,032.86	71.71%
Congo	11	196.408	50.41%
DRC	90	2,631.66	97.66%
Ethiopia	60	932.373	74.20%
Guinea	21	929.52	70.59%
Kenya	65	1,917.90	52.62%
Lesotho	14	79.546	97.69%
Malawi	18	337.161	84.44%
Mozambique	27	2,439.33	89.52%
Namibia	12	450.76	57.68%
Uganda	30	1,094.18	77.89%
Zambia	32	1,906.61	92.04%

Source: PLATTS WEPP database. Column (1) shows the number of power plants. Column (2) shows the total installed capacity in MW. Column (3) shows the share of MW of installed capacity due to hydropower and column.

Table 2: Power plants and radiuses by African country

	50 km	100 km	200 km	300 km	Country size, km²
Angola	0	6	12.58	24.98	1,246,700
Burundi	7.24	17.96	22	22	27,384
Cameroon	1.97	5.66	10.77	19.23	475,442
Congo	3.33	4	5.67	7	342,000
DRC	2.31	2.96	5.03	8.32	2,345,409
Ethiopia	3.08	4.89	11.15	17.18	1,104,300
Guinea	2.48	5.52	12.52	14.04	245,836
Kenya	3.32	11.71	22.78	29.96	581,309
Lesotho	**2**	2	8	8	30,355
Malawi	4.05	5.79	7.29	9.68	118,484
Mozambique	2.24	2.85	4.47	5.18	801,590
Namibia	2.3	2.3	2.18	3.73	825,615
Uganda	4.7	7.64	9.79	15.33	241,038
Zambia	4.54	5.55	7.35	10.5	752,618

Notes: Column (1) presents the average number of power plants within a 50km radius of the cities in that country. Columns (2), (3) and (4) provide the same statistics for a 100 km, 200km and 300 km radius respectively. Column (5) provides information on the size of the country.

Table 3: OLS baseline estimation results

	(1) All firms Total Sales	(2) All firms Total Sales	(3) No generator Total Sales	(4) No generator Total Sales	(5) Generator Total Sales	(6) Generator Total Sales
Number of PO	-0.09*		-0.17**		0.01	
	(0.05)		(0.07)		(0.07)	
Hours of PO		-0.05*		-0.05		-0.04
		(0.03)		(0.04)		(0.04)
Generator Ownership	0.50***	0.49***				
	(0.09)	(0.09)				
Small	-1.18***	-1.18***	-1.15***	-1.16***	-1.17***	-1.17***
	(0.10)	(0.10)	(0.14)	(0.14)	(0.14)	(0.14)
Large	0.72***	0.70***	0.89*	0.86*	0.62**	0.62**
	(0.17)	(0.17)	(0.36)	(0.36)	(0.20)	(0.20)
Very large	1.96***	1.96***	1.45**	1.43**	2.15***	2.14***
	(0.25)	(0.25)	(0.44)	(0.44)	(0.31)	(0.31)
Exporter	0.83***	0.84***	0.69**	0.70**	0.87***	0.88***
	(0.14)	(0.14)	(0.23)	(0.23)	(0.17)	(0.17)
Credit	0.40***	0.41***	0.69***	0.69***	0.20	0.21
	(0.10)	(0.10)	(0.14)	(0.14)	(0.14)	(0.14)
Publically owned	0.09	0.08	0.54**	0.54**	-0.16	-0.16
	(0.13)	(0.13)	(0.20)	(0.20)	(0.17)	(0.17)
Foreign ownership	0.96***	0.96***	0.95***	0.97***	1.02***	1.02***
	(0.14)	(0.14)	(0.24)	(0.23)	(0.18)	(0.18)
Firm age	0.36***	0.37***	0.20**	0.20**	0.51***	0.51***
	(0.05)	(0.05)	(0.06)	(0.06)	(0.08)	(0.08)
Constant	13.47***	13.39***	14.58***	14.16***	13.09***	13.35***
	(0.44)	(0.41)	(0.70)	(0.67)	(0.76)	(0.72)
Country dummies	Yes	Yes	Yes	Yes	Yes	Yes
Industry dummies	Yes	Yes	Yes	Yes	Yes	Yes
Number of obs.	2525	2525	1205	1205	1320	1320
R^2	0.64	0.64	0.75	0.75	0.52	0.52

Notes: OLS estimation with robust standard errors in parentheses. The dependent variables is the log of total sales expressed in PPP 2005$, the explanatory variables of main interest are the log of number of power outages per year and the log of the hours of power outages per year. All regressions include country and 2-digit industry dummies. ***, ** and * =significance at the 1%, 5% and 10% level respectively.

Table 4: First stage regression, baseline specification, single instrument

	(1) All firms Number	(2) All firms Hours	(3) No generator Number	(4) No generator Hours	(5) Generator Number	(6) Generator Hours
Yearly Mean Anomaly	-2.03***	-2.08**	-2.58***	-3.78***	-1.60***	-1.37*
	(0.53)	(1.03)	(0.53)	(0.94)	(0.57)	(0.83)
Wooldridge Score Test	3.63*	3.48*	12.23***	12.97***	0.18	0.14
F-Statistic (Stock - Yogo)	14.98	4.04	23.29	16.19	7.83	1.5
Kleibergen-Paap Wald statistic	15.64***	4.23**	24.89***	17.3***	8.34***	2.81*
Anderson-Rubin Wald Chi^2	4.06**	4.06**	17.58***	17.58***	0.18	0.18

Notes: First stage regression for the baseline specification. The dependent variables are either the log of the number of outages per year or the log hours of outages per year. Standard errors in parentheses. ***, ** and * =significance at the 1%, 5% and 10% level respectively.

Table 5: Second stage regression, baseline specification, single instrument, dependent variable = Total Sales

	All firms				No Generator				Generator			
Number of PO	-1.09** (0.55)		-1.16** (0.57)		-1.46*** (0.50)		-1.61*** (0.43)		-0.99 (1.07)		-0.42 (1.02)	
Hours of PO		-1.36 (1.0)		-1.08 (0.76)		-1.18** (0.52)		-1.10*** (0.36)		-1.42 (2.01)		-0.49 (1.32)
Generator Ownership			0.73*** (0.16)	0.77*** (0.24)								
Small			-1.15*** (0.21)	-1.19*** (0.17)			-1.04*** (0.21)	-1.09*** (0.18)			-1.17*** (0.29)	-1.19*** (0.26)
Large			0.80* (0.36)	0.44 (0.37)			0.98 (0.54)	0.56 (0.46)			0.67 (0.35)	0.55 (0.36)
Very large			1.87*** (0.29)	1.66*** (0.35)			1.55*** (0.42)	1.33* (0.62)			2.11*** (0.27)	2.03*** (0.36)
Exporter			0.70** (0.21)	0.90*** (0.24)			0.59** (0.22)	0.69* (0.34)			0.82** (0.31)	0.91*** (0.24)
Credit			0.40** (0.12)	0.51** (0.18)			0.65*** (0.19)	0.77*** (0.20)			0.21 (0.13)	0.27 (0.26)
Publically traded			0.16 (0.18)	0.05 (0.22)			0.52** (0.17)	0.59** (0.21)			-0.11 (0.24)	-0.20 (0.22)
Foreign ownership			0.84*** (0.23)	0.75** (0.29)			0.60 (0.38)	0.56 (0.39)			1.03*** (0.16)	1.02*** (0.19)
Firm age			0.34*** (0.08)	0.46*** (0.09)			0.21* (0.08)	0.36*** (0.10)			0.48*** (0.14)	0.52*** (0.10)
Country & Industry dummies	No	No	Yes	Yes	No	No	Yes	Yes	No	No	Yes	Yes
Number of obs.	2775	2775	2525	2525	1205	1205	1205	1205	1320	1320	1320	1320

Notes: 2SLS estimation with standard errors clustered at the city-level in parentheses. The dependent variable is the log of total sale expressed in PPP $2005. All regressions include country and 2-digit industry dummies. ***, ** and * =significance at the 1%, 5% and 10% level, respectively.

Table 6 Extensions and Robustness (for firms without generators)

	Large Firms		Small Firms		Labor Intensive		Capital Intensive		Exporters	
	Total Sales	Total Sales	Total Sales	Total Sales	Total Sales	Total Sales	Total Sales	Total Sales	Total Sales	Total Sales
Number of PO	-2.32**		-1.41***		-1.61*		-1.73***		-4.08	
	(1.09)		(0.40)		(0.95)		(0.57)		(2.98)	
Hours of PO		-1.61***		-0.86**		-0.69*		-1.18***		1.38
		(0.60)		(0.34)		(0.42		(0.40)		(0.98)
n	349	349	856	856	626	626	528	528	86	86
Z test (number)	0.78				0.11					
Z test (hours)	1.09				0.97					

Table 6 (cont.)

	Non-Exporters		Alternative Dep.Var.		Alternative Dep. Var.		Non-Hydro Placebo		No Reservoirs	
	Total Sales	Total Sales	TFP	TFP	Profits	Profits	Total Sales	Total Sales	Total Sales	Total Sales
Number of PO	-1.41**		-0.97**		-1.95**		0.66		1.53**	
	(0.41)		(0.38)		(0.71)		(1.69)		(0.35)	
Hours of PO		-0.86**		-0.72**		-1.37***		0.45		-1.09***
		(0.28)		(0.30)		(0.65)		(1.09)		(0.28)
n	952	952	971	971	952	952	1213	1213	1205	1205
1st stage yearly mean anomaly							1.23	1.82	-2.61***	-3.65***
							(0.78)	(1.35)	(0.72)	(0.95)

Highlights

- power outages have a significant impact on African firm sales
- sales by firms with their own generators are not affected
- the impact of outages is larger when endogeneity is taken into account
- power outages also affect firm profits and total factor productivity