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**Abstract** Public electricity provision in Africa has been marred by under investment and frequent power outages. One of the strategies often adopted by firms to cope with this poor public supply is investment in backup generation. This strategy is not without cost however. Extant literatures on outage cost estimation have shown that firms possessing certain characteristics have a higher tendency to invest in backup generation. What is less known, however, is whether those firms suffer lesser or higher unmitigated outage losses (costs). Using cross-sectional data from 6854 firms currently operating in 12 African countries, this study investigated the extent to which firms' characteristics might create incentives for auto-generation and whether these incentives lead to lesser unmitigated outage costs. We used three different methods including marginal cost, incomplete backup and subjective evaluation techniques. The results reveal that large firms, firms engaging in exports, and those using the Internet for their operation still suffer higher unmitigated outage costs despite having a higher propensity of investing in backup generation. The results further reveal that unmitigated costs still account for the larger proportion of the total outage costs despite high prevalence of backup ownership among the firms. This reflects the inefficiency in backup generation due to small backup capacity held by firms. Our estimates also indicate that ignoring firms' characteristics such as size and the nature of operation (e.g. export promotion, internet usage, etc.) may result in underestimation of outage losses. The analysis further suggests that firms can still benefit significantly even when the current subsidised tariffs are replaced by cost-reflective rates that ensure stable electricity supply. The net outage cost (having adjusted for a cost-reflective tariff) incurred by firms are large enough to expand their scope of operation and hire more workers, suggesting the macroeconomic effect could be significant.

**Keywords** Africa, Backup, Electricity, Firms, Outage costs, Two-Limit Tobit

**JEL Classification** L6, L81, L94, N77, Q4

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# The Economic Costs of Unsupplied Electricity: Evidence from Backup Generation among African Firms

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## Abstract

Public electricity provision in Africa has been marred by under investment and frequent power outages. One of the strategies often adopted by firms to cope with this poor public supply is investment in backup generation. This strategy is not without cost however. Extant literatures on outage cost estimation have shown that firms possessing certain characteristics have a higher tendency to invest in backup generation. What is less known, however, is whether those firms suffer lesser or higher unmitigated outage losses (costs). Using cross-sectional data from 6854 firms currently operating in 12 African countries, this study investigated the extent to which firms' characteristics might create incentives for auto-generation and whether these incentives lead to lesser unmitigated outage costs. We used three different methods including marginal cost, incomplete backup and subjective evaluation techniques. The results reveal that large firms, firms engaging in exports, and those using the Internet for their operation still suffer higher unmitigated outage costs despite having a higher propensity of investing in backup generation. The results further reveal that unmitigated costs still account for the larger proportion of the total outage costs despite high prevalence of backup ownership among the firms. This reflects the inefficiency in backup generation due to small backup capacity held by firms. Our estimates also indicate that ignoring firms' characteristics such as size and the nature of operation (e.g. export promotion, internet usage, etc.) may result in underestimation of outage losses. The analysis further suggests that firms can still benefit significantly even when the current subsidised tariffs are replaced by cost-reflective rates that ensure stable electricity supply. The net outage cost (having adjusted for a cost-reflective tariff) incurred by firms are large enough to expand their scope of operation and hire more workers, suggesting the macroeconomic effect could be significant.

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## 1. Introduction

The importance of electricity to the economic development of any nation cannot be overemphasised. Access to reliable electricity supply increases the productivity and welfare of society. To business enterprises, electricity serves as an indispensable input. Apart from its necessity for running many industrial machines, its contributions to the productivity of human capital are enormous. Virtually all business activities, especially industrial units, require constant and effective flow of electricity. Similarly, efficient functioning of the electricity system sometimes determines the comfort of workers

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and their productivity. A banker feeling serious heat due to lack of electricity to power fans or air conditioners for instance, may find it uncomfortable to attend to customers. This consequently reduces productivity. Besides serving as an input in production processes, electricity also contributes greatly to product marketing. In many cases, electricity plays important roles in storing finished goods ahead of demand, and therefore enhances consumers' satisfaction by assisting in making the goods available to consumers when needed; this also helps in building a firm's image and protects firm's reputation because customers can be assured of having their demand met.

Given the above, it suffices to say that poor electricity supply or lack of quality and effective electricity service delivery is a bane to economic development. It restricts economic growth and development, as well as the socio-economic welfare of the people. Poor electricity supply affects business activities in many ways. First, it affects firm's productivity as in many cases other inputs may be idle when there is no electricity to power them. The use of Information Communication Technology (ICT) for different purposes requires an effective and efficient flow of electricity. In addition to this is the huge damage to materials and equipments that a power outage of long duration that occurs during production process may cause in some firms; an outage of about 40 minutes will cause molten ore in electronically heated ovens to harden. This may consequently damage the ovens, destroys the materials and also results in huge restart costs. More so, an outage of few minutes at an emergency unit of a specialist hospital may result in loss of life. Second, many firms rely on the use of the Internet to communicate their customers (e.g. emails), to advertise their products, and for electronic payments, which can only be efficient if there is effective electricity supply. Lastly, many raw materials and some finished products require a constant flow of electricity for their storage, and any power cuts would result in a huge business loss; this may have considerable effects on people whose livelihoods depend on the business.

Poor electricity supply has proved to be the major constraint to the business sector[2] in Africa and has contributed to the low productivity and poor competitiveness of the manufacturing sector in the continent. This is evidenced in some studies examining the impacts of electricity on the performance of business enterprises in Africa. Unreliable electricity supply has a significantly negative impact on a firm's total factor productivity (Arnold, Mattoo, & Narciso, 2008; Escribano, Guasch, & Pena, 2009), while the possession of a generator has a significant positive effect (Arnold et al., 2008). Indirect costs (of which energy costs account for the largest share) are a major factor responsible for the low productivity of enterprises in Africa (Eifert, Gelb, & Ramachandran, 2008). A study of 17 micro-enterprises (12 carpentry and 5 tailoring workshops) in Kenya has also found that the use of electricity

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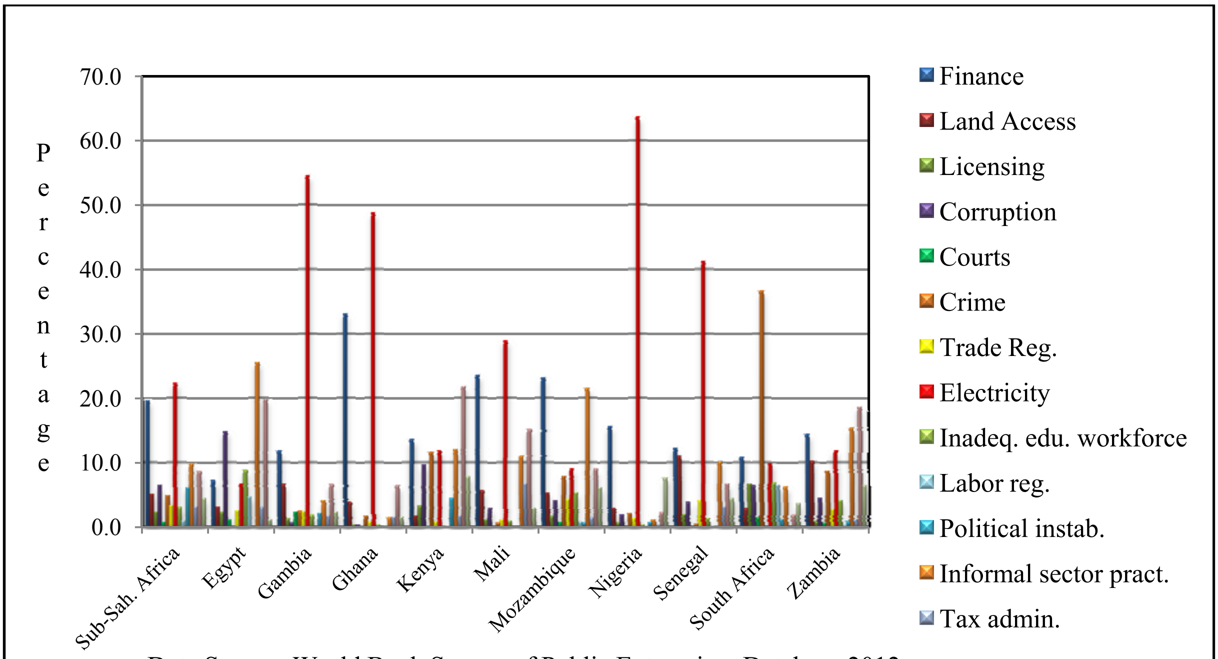
[2] A report by ADB (2009) shows that lack of a reliable electricity supply was by far the most binding constraint to doing business in Nigeria for more than 80% of the firms surveyed.

can raise productivity per worker by approx. 100-200% for carpenters and by 50-170% for tailors, depending on the item being produced (Kirubi et al., 2009).

Between 2006 and 2010, more than 50% of the Sub-Sahara African firms identified electricity as a major constraint to their businesses compared to just 27.8% that named transportation as the most critical problem in the World Bank Surveys of Business Enterprises (World Bank, 2012)[3]. In 2007, about 25% of firms in Sub-Sahara Africa identified electricity as the biggest obstacle followed by financial constraint identified by 20% of the firms (Figure 1).

Figure 1: Percentage of Firms Identifying each of the Constraints as the Biggest Obstacle in 2007



Data Source: World Bank Survey of Public Enterprises Database 2012

Furthermore, an average Sub-Sahara African firm suffers the loss of economic activities for about 77 hours a month due to power outages. The situation is even more pathetic in some countries and more worrisome when compared with other developing regions of the world. In 2007 for instance, an average firm in Nigeria experienced an outage of 8.2 hours 26.3 times in a typical month. This translates to loss of economic activities for 216 hours (9 days), on average, in every month, assuming no palliative measure. Meanwhile, an average firm in East Asia & Pacific experiences power outages of less than 15 hours a month. Similarly, a typical firm in Latin America & the Caribbean only suffers electricity cuts of about 6 hours a month (World Bank, 2012).

Given the prevalence of power outages, firms in Africa have adopted different strategies to cope with this poor electricity supply. Some of these response adjustments include choice of business, choice of location, output reduction, factor substitution and self generation. While all these strategies are observable among African firms, the most commonly adopted strategy by firms is investments in

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[3] In 2007, the percentage of firms identifying electricity as a major constraint in Ghana was 86%.

alternative generation (i.e., complementary capital). Many electricity users – both households and firms – now find it necessary to make their own generation in part or in whole to make up for the inadequate provision resulting from the inefficiencies of the public power system. As a matter of fact, many end users of electricity (from small to large enterprises) now operate small to medium-sized plants with capacities ranging between 1 MW and 700 MW for own generation (Karekezi & Kimani, 2002). Self generation has been on the increase and own generation now accounts for more than 20% of generation capacity in some countries in Africa (Foster & Steinbuks, 2009).

A great issue of concern with this strategy is that while investment in a generator enables firms to continue their operations in the event of power outage; it undermines firms' capacity to finance other productive investments. Reinikka & Svensson (2002) find that unreliable and inadequate electric power supply significantly reduces investment in productive capacity by firms in Uganda. Firms invest in auto-generation when the public provision is unreliable. The direct cost of this action, however, is that less productive capital is installed. In addition to this there are diseconomies of scale in self generation. A joint report by the UNDP/World Bank in 1993, for instance, estimated the cost differential between self generation and public provision for large industrial firms in Nigeria to be between 16 – 30% (World Bank, 1993). However, previous studies might have over-exaggerated the cost-differential between own generation and national grid because they ignored the fact that the currently operated tariffs of public utility in Africa are highly subsidised.

Auto-generation does not necessarily mitigate the electrical impact of losses due to the unreliability or lack of full capacity of the own generator. Unmitigated outage losses (or costs) are the losses (e.g. damage to equipment stock, loss of output, restart costs, etc) suffered by a firm due to the inadequate or lack of proactive measures against the incident of power outages. Unmitigated outage losses are equal to the total outage losses if no portion of the potential losses or damages due to power outages is mitigated – e.g. when a firm had not invested in backup generation. For a firm that has invested in auto-generation, unmitigated outage losses/costs are the portion of the losses/costs that the firm is unable to alleviate due to the inadequate backup capacity or the unreliability of the backup.

Although the use of a backup generator is common among African firms given poor public provision of power, a number of studies have argued that firms' size and export promotion significantly influence the decision to own a generator (Adenikinju, 2003, Steinbuks & Foster, 2010). In other words, larger firms and those that own International Standard Organisation (ISO) certification do self-generate more than others. However, what is less known is whether larger firms – considering their tendency for backup capacity – suffer more or less unmitigated outage loss (cost) compared to smaller firms. Similarly, it is (still) not clear whether firms holding ISO certificates suffer less or more unmitigated losses. Besides, the effect of the use of the Internet on backup generation and how it affects unmitigated outage losses have not been examined. We investigate these issues using data on the year 2007 backup generation by 6854 business enterprises in 12 African countries. We first re-examine the roles of firms' size and export promotion as well as the use of the Internet on backup generation. We then investigate how those factors affect unmitigated loss (cost) using the method proposed by Beenstock *et al.* (1997). Specifically, we concentrate on the following questions:

- What is the relationship between firm size, export promotion (e.g. ISO certificate ownership), internet operation and unmitigated outage loss?
- To what extent does investment in backup generation mitigate outage loss? In other words, are firms able to mitigate most of their outage costs by investing in backup generation?
- Is own generation (measured in terms of outage cost) still costly compared to public utilities under a cost-reflective tariff regime?

The rest of this study is structured as follows. Next section presents the theoretical framework and hypotheses tested in this study. Section 3 presents some of the previous blackouts experienced in the world. Section 4 reviews the literature while Section 5 presents the methodology explored in the analysis. Section 6 presents the overview of data followed by discussion of empirical results in Section 7. The last section concludes.

## 2. Theoretical Framework and Hypotheses

### *2.1. Theoretical Framework*

Making an investment decision is critical to business activities as it relates to or affects the overall business objectives. The profitability level of a firm depends on how good or bad its investment decision is. While a good investment decision increases the profitability and enhances the financial viability of firms, poor choice of investment reduces the financial capability and sometimes causes firms to be liquidated. Investment in fixed capital, often referred to as business fixed investment, has both the relative costs and (expected) benefits that often influence firm's decision to embark on such spending. The user or rental cost of investment is affected by the price of capital, the real interest rate and the depreciation rate[4]. The real cost of a unit of capital to a firm is the ratio of rental cost to the price of a unit output produced from the capital installed. On the other hand, the benefit of a unit of capital is the marginal product of output derived from adding it to the production process. Like the cost, the extent to which a firm benefits from capital investment depends on the existing capital level,

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[4] In relative term, the real cost of capital depends on the relative price of a capital good, the real interest rate, and the depreciation rate.

the amount of labour employed and the level of technology. A rational firm would invest in capital if the marginal product of capital exceeds or equals the associated marginal cost, and vice versa (Jorgenson, 1963). In other words, in making an investment decision, firms would equate the expected marginal benefit from that investment to the marginal cost of the investment.

Investing in backup generation is not costless and therefore has to be taken judiciously. A firm experiencing power outages would have to consider the marginal benefit of investing in backup and the marginal cost of purchasing and running the plant. For instance, a firm experiencing frequent power outages would have to decide whether (1) to invest in backup generation and be able to continue operations in the event of outages but at the required costs, or (2) not to invest in backup generation and shut down operations during power outages. A firm can choose the first option if it considers it to be a rational decision to own a generator in order to be able to continue operations during outages. On the contrary, another firm may consider the second alternative to be its rational and optimal decision. The latter might consider the costs of owning and operating a generator (i.e., the user cost) to be too high compared to the gain from continuing operations in the events of outages. Investment in new capital stock with respect to changes in its determinants may be limited if the fixed adjustment costs are too great to justify the potential gains (Nickell, 1978). Therefore, a rational firm would equate at the margin the expected cost of generating a kWh of its own electricity to the expected benefit from that kWh (Bental & Ravid, 1982). That gain consists of the continued operation that the self-generated electricity makes possible, and the damage to equipment stock that would have been caused by a power outage.

Decisions to invest in energy related goods can be driven by many non-economic factors as long as those factors influence the marginal benefits of such investments. Company size, sectoral and regional differences, and other organisational factors play important roles as economic drivers in explaining firms' lighting investment decisions (Decanio & Watkins, 1998; DeCanio, 1998). The level of gain from investing in backup generation (i.e., the marginal benefit or marginal product of a unit backup) can be driven in part by certain organisation's characteristics. The number of workers in a firm, for instance, may influence the marginal productivity of backup generator. Purchasing a backup generator alone does not earn direct benefits to a firm; it is meant to power the available capital or machines whose productivity in turn depends on the human capital available to the firm.

Traditionally, size of firms is considered an important factor that influences the behaviour of firms or organisations. A number of management literatures, for instance, have shown that organisational size plays important roles in the investment decisions of firms. Bøhren *et al.* (2007); Gugler *et al.* (2007); and Raza *et al.* (2012) found that the size of firms positively and significantly affects the level of investments and cash flow-investments sensitivity. The existence of a positive relationship between the firm's size and the level of investment can be linked to the ability of large firms to attract more funds to finance investments compared to smaller firms.

Many business organisations (both large and small) now make use of the Internet for their operations in order to become more productive and competitive. The use of the Internet (synonymous with technological innovation in neo-classical theory) for business operations enhances the connections between firms, their suppliers and consumers; this in turn increases productivity and competitive advantage. A number of studies have focussed on the impacts of the Internet on existing business models (see Cronin *et al.,* 1994; Hoffman & Novak, 1997). Fuller and Jenkins (1995) conduct an experimental study on the learning and business transformation process of small business adoption. They found that the information richness of the environment in which the firm operates, the necessity for collaboration in order to compete, and the business cultures present in electronic communication play important roles in the use of the Internet by business enterprises. Similarly, a study by Poon & Swatman (1997) presents the results from a case study of 23 Australian small businesses which were both the early adopters and current users of the Internet. They found that firms predominantly use the Internet as a medium of communications, advertising and as a document transfer channel. Also, the study revealed that management enthusiasm and perceived benefits are the driving forces for the use of the Internet by businesses.

Although a firm can benefit by investing in own generation, investment in a backup generator does not always guarantee complete outage mitigation. In some cases, a firm may hold backup and still suffer outage loss; this may be in form of restart cost and/or loss due to the inability of the backup capacity to generate and supply the total required power load of the firm. Beenstock *et al.* (1997) found that firms in Israel still incur unmitigated outage cost despite investing in backup generation. Although the unmitigated portion of the total outage cost per kWh in their study is lower than the cost of generating a kWh of own power, this may reflect the omission of the other factors (e.g., firm's characteristics) that may affect the amount of unmitigated cost as well as a firm's incentive to invest in backup.

While a firm's characteristics may add to its incentive to invest in backup due to the perceived high marginal productivity, they can equally play significant roles in determining the level of outage cost or loss suffered by a firm. A larger firm, all things being equal, that experiences a power outage of two hours would suffer more loss compared to a smaller firm which experiences the same duration of outage. Similarly, effective usage of the Internet depends on continuous supply of electricity. A firm whose operations depend on the use of the internet would suffer more outage loss, ceteris paribus, as outage would affect its performance. Furthermore, an event of a power outage that prevents a firm from meeting the international quality standard would reduce the firm's competitive advantage and results in higher outage losses compared to a firm without such certification. Considering both the negative effect (in terms of the possible high outage costs) and the positive effect (in terms of the incentive to invest in backup due to high marginal productivity) of firms' characteristics would result in some interesting questions that are needed to be answered: To what extent do these characteristics affect the incentive to invest in backup technology? How do they affect the power outage costs, especially unmitigated outage costs? In other words, do firms that possess particular characteristics suffer more or less unmitigated outage costs compared to their counterparts?

## *2.2. Hypotheses*

All over the world, the issue of (un)reliability of the power system has been a great source of concern to both the regulators and other players (including consumers) in the sector. An unreliable power system poses serious challenges to the socio-economic and political structure of an economy. Some of these challenges include loss of welfare, pressure on governance, and loss of output among others. Because of these challenges however, the affected consumers (especially industrial users) usually provide alternative measures in order to curtail the effects of the poor public provision on their economic activities. A prominent measure usually taken by firms is the generation of own electricity. Firms invest in backup generation in order to continue operations during power outages. Therefore, it is reasonable to expect the firms owning generators be able to curtail a greater portion of outage costs through this action. Thus, our first hypothesis is

***Hypothesis 1****: Although power outages impose substantial costs on business enterprises, the greater proportion of these costs is curtailed by investing in backup generation. In other words, the value of unmitigated cost in total cost per kWh unsupplied is very small.*

Compared to smaller firms, larger firms are more likely to exercise demand for backup generator and have less relative unmitigated costs compared to smaller firms. Furthermore, competitive advantage, reduction in business operating costs and increased productivity enjoyed by firms from the use of the Internet for their operations have greatly increased internet usage among business enterprises. Firms use the Internet to communicate with their suppliers and for marketing and sales purposes. However, the use of the internet can be greatly hindered by constant power outages. Since the efficient usage of the internet requires an effective electricity supply, any power outage that affects firms' internet usage would result in decreased productivity, loss of sales and profits. Considering these effects however, firms that use the Internet would probably invest more in backup generation and therefore suffer less outage costs.

Firms are often issued an International Standard Organisation (ISO) certificate. ISO certificate is a written assurance (certificate) given to a firm by an independent body, indicating that the products, processes and services offered by a holding firm meet the specific requirements as stated by the International Standard Organisation. A number of studies have identified significant potential benefits for organisations holding ISO certificates. A 2011 survey from the British Assessment Bureau showed that 44% of their certified clients had won new business as a result of becoming certified to the quality management standard (British Assessment Bureau (BAB), 2011). Similarly, a study from Cornell University's Centre for Hospitality Research found that Spanish hotels that are certified to ISO 14001 environmental management standard are more profitable than those without (Segarra-Oña *et al.*, 2011). It is therefore logical to expect that the need to meet the international quality standard in order to prevent the withdrawal of the ISO certificate would influence the internationally certified firms to invest in backup generation compared to firms without such certification. Therefore, it is hypothesised that:

***Hypothesis 2****: All else being equal, larger firms, firms using the internet for their operation and those that hold an ISO certificate suffer lower unmitigated costs relative to others, because they invest more in backup generation.*

Previous studies on the estimation of outage costs to firms in an African context have all concluded that the outage costs suffered by firms are greater than the prices of electricity supplied from the public grid. However, it is not clear whether this conclusion was driven by the fact that the current electricity prices in Africa are heavily subsidised. Since the willingness to pay for reliability at a cost-reflective tariff by firms would likely be influenced by whether outage costs incurred by firms are more than the new tariffs or not, we hypothesise and test the rationality of own generation under a cost-reflective regime as:

***Hypothesis 3****: Firms would incur outage cost higher than the cost (price) of electricity from the public grid when prices are cost-reflective; thus, it is irrational for firms to generate own electricity even under a cost-reflective tariff regime.*

## 3. Historical Blackouts in the World

Table 1 presents a summary of some major blackouts previously experienced in the world. Among the previous outages, only the incident in the Philippines was caused by a factor similar to the main cause of power outages in Africa. While the causes of major outages in Europe and North America have been attributed to natural disasters or technical faults, the massive blackouts in the Philippines (1992-1994) was caused by inadequate generating capacity. The inadequate capacity brought by poor implementation of energy planning and obsolete power plants resulted in outage averaged 8-12 hours per day. The estimated economic loss of this outage ranges from US$600 million –US$800 million per annum (Austria, 1999). Meanwhile, Toba (2004) has estimated the economic benefits of ending of power crisis in the Philippines. The study estimated the net benefit of reform and privatisation that ended the crisis to be between US$10.4 billion and US$11.8 billion at 1999 prices. The major components of this benefit were the avoided cost for quickly ending the power crisis and the improvement in operating efficiency. The study further showed that consumers and investors were the beneficiaries of the reforms that ended the crisis, and concluded that the reform with the private sector participation increased social welfare.

Like that of the Philippines, the major cause of power outages in Africa is inadequate installed and generating capacity which resulted from poor planning and implementation. Due to inadequate installed capacity, electricity generation is always low and subsequently causes supply to fall below demand. Inadequate generation results in low power supply and constant blackouts. The continent's generating capacity is the lowest among the regions in the world and in many cases is less than the installed capacity in some countries. Africa accounts for only 2.65% of the world generating capacity in 2008. Out of this total capacity, South Africa alone contributed about 36%. At 133.78 gigawatts (GW) in 2010, the entire generating capacity in the continent is less than half of that of Japanese generating capacity. Excluding South Africa, the total generating capacity is less than 80 GW, and is about 5GW short of the installed capacity in Spain (EIA, 2009). Moreover, more than 40% of this installed capacity is not currently generated due to poor maintenance and sometimes vandalisms of equipments.

Table 1: Some Historical Blackouts in the World

| Country, year | Type of incident | Consequences in the power system | Social consequences | | |
|---|---|---|---|---|---|
| | | | Number of end-users interrupted | Duration, energy not supplied | Estimated costs to whole society in 2010 prices |
| Sweden/Denmark, 2003 | Disconnector short circuit followed by double busbar short circuit | Loss of all lines and generation separation of Southern Sweden/Denmark, voltage collapse | 1.6 million in Sweden and 2.4 million in Denmark | 2.1 hours, 18 GWh | (US$206.22 – 256 million) |
| France, 1999 | Two consecutive storms, extreme wind | Extensive outages, 0.4 % of the total network length damaged | 1.4-3.5 million | 2 days - 2 weeks, 400 GWh | (US$14.13 billion) |
| Italy/Switzerland 2003 | Overloading lines between Switzerland and Italy | Collapse of the entire Italian electric power system | 55 million | 18 hours | n.a |
| Sweden, 2005 | Storm Gudrun, extreme wind | Extensive damage of overhead lines in Southern Sweden | 0.7 million | 1 day - 5 weeks, 111 GWh | (US$526 million) |
| Central Europe 2006 | Busbar fault at a substation in Germany | Disturbances in the whole interconnected grid in Europe | 15 million households | Less than 2 hours | n.a |
| London, 2003 | Poor Protection Relays | Disturbance of 720 MW line in South London | 410,000 people | 37 minutes | n.a |
| Philippine, 1992-1994 | Insufficient generation capacity | Interruption in Countrywide electricity supply | Entire country | 8-12 hours daily | US$1.89-$2.52 billion per annum |
| US/Canada, 2003 | Tree flashovers | Disturbance in interconnected grid in North America | 50 million people | 16 hours – 1 week | US$8.3-$11.9 billion |

*Source:* (Bialek, 2004; Cowie *et al*., 2004; Ekraft-System, 2003; Larsson & Danell, 2006; Lu *et al.*, 2006; Makarov *et al*., 2005; NERC, 2004; Silvast & Kaplinsky, 2007; UCTE, 2004; US-Canada Power System Outage Task Force, 2003, 2004).

## 4. Literature Review

The literature on the economics of power outages has so far been dominated by two different but related issues. The first has to do with the cost of unsupplied electricity to the consumers (see Andersson & Taylor, 1986; Beenstock et al., 1997; Bose et al., 2006; Lacommare & Eto, 2006; Pasha et al., 1989; Sanghvi, 1982; Serra & Fierro, 1997), while the second has focused on the optimal reliability of electricity supply (Munasinghe, 1981; Sanghvi, 1983). These issues are related because the consumer facing an unreliable power supply will insure himself against possible power outages by investing in backup generators and related equipment to cover, in whole or in part, the loss induced by power outages.

A study by Bental & Ravid (1982) was the first to point out that the costs of power outages to a firm can be estimated using data on backup generators. The study assumed that decision makers in a firm act rationally and hedge to insure themselves against part or total damages that can be caused by power cuts, by investing in backup generating plants. They further assumed that firms are competitively risk-neutral, and thus will equate at the margin, the expected cost of self generation of a kWh to the expected benefit from that kWh. They compute the marginal cost of unsupplied electricity for the US and Israel. Their results indicate that outage cost varies proportionally with reliability (low outage time); outage cost tends to be higher in the US where reliability is higher than in Israel where reliability is lower. Beenstock (1991) proposed a refinement of the methodology proposed by Bental & Ravid (1982). The study distinguished between the absolute, mitigated and unmitigated costs of power outages, and also incorporated risk aversion phenomenon in computing the cost of power outages. Contrary to Bental & Ravid (1982), the study found that, based on self constructed or assumed data, the cost of outage varies inversely with the levels of reliability of electricity supply and that expenditure on generator is sensitive to outage risks. Of course, consumers would be willing to invest in backup as service becomes less reliable but would face a discontinuity at a point when risks associated with additional loss of service or interruption appear to be insignificant.

The use of backup data to infer the cost of power supply reliability was pioneered by Matsukawa & Fujii (1994). They empirically examined the consumer preferences for reliability in electricity supply using data on backup investments among the Japanese firms using large computer systems. Utilising a probabilistic discrete choice model, the study found that customers faced a trade-off between the price and reliability of the power system. Their results indicate that demand for backup varies inversely with the reliability of electricity supply and the user cost of backup investments. They also showed that the characteristics of customers such as the type of business and levels of electricity consumption significantly affect the choice of backup equipments. The major problem with their methodology is the omission of information on the quantity of backup which may have important implications for their findings. This problem was corrected in a study by Beenstock *et al.* (1997). They built on the methodology proposed by Beenstock (1991) and applied it to data on investments in backup generators and uninterruptible power supplies (UPS) to empirically examine the implied cost of power outages on Israeli industrial and public sectors. Based on a neutrality assumption about the behaviour of the firms and the public sector, they estimated two-limit Tobit models of demand for backup to simulate the mitigated and unmitigated cost of power outages in the sectors. They found that the demand for backup and the total cost of outages varies inversely with reliability of service, while the marginal cost per kWh of unsupplied electricity varies directly with service reliability. In other words, the decision to invest in backup and the total outage cost increases as power outage increases but the marginal cost of this outage declines, possibly due to investments in backup that have already taken place which mitigates the incremental effects of any additional outage duration.

Pasha *et al.* (1989) quantify the economic cost of power outages using a surveyed data on a sample of 843 firms in industrial sector of Pakistan. They estimated the overall cost of outages to be about 8.8% of the value added by the industrial sector in 1984-85. Their results showed that the shares of planned and unplanned outages in these costs are about 65% and 35% respectively. Their analysis further indicates that industries that are most severely affected by outages are food, beverages and tobacco, textiles, metal and metal products, and machinery and equipment. The study further estimate the multiplier effects of the industrial outages' cost to be 1.34 and concluded that power outages in the industrial sector led to 1.8% reduction in overall GDP in 1984-1985.

However, while this analysis might provide a good insight about the multiplier effects of power outages in an economy, it has suffered from some major flaws. The analysis was principally based on the loss reported directly by the surveyed firms (i.e. self assessment). Such self-assessment data obtained from business are often inaccurate and may not actually represent the true cost of outages. For instance, firms may exaggerate their reported outage costs in order to impress the utility company and the regulator or the government about the need for more reliable electricity. Or they may do that so that they can disproportionately shift the burden of a little increase in tariffs to consumers of their products thereby making economic profits. For example, the utility company or the regulator may raise the electricity tariff, based on the reported outage costs, in order to improve reliability in the system. If this happens, firms may use this as an opportunity to significantly increase the price of their products (by claiming that the increasing tariff rates have significantly raised their cost of production), thereby making economic rents. Another reason that may account for the bias in the reported loss is the difficulty in measuring the output of some businesses/sectors. For example, it is difficult to measure the output of some firms (e.g., hospitals, police, hostelry, etc.) and any reported loss in the event of an outage may be incorrect. Furthermore, such data based on self assessment may be unreliable given the possibility that interviewees may be unaware of the costs or may be unable to devote sufficient time to carefully complete the questionnaire.

A variant of revealed preference method have been used by Caves *et al.* (1992) to infer the cost of outages from the decision of large industrial consumers to participate in interruptible service programs (i.e. curtailable schemes) introduced by a US utility in the early 1980s. The participants were assumed to experience outage costs that were less than the discounts they receive in return for their participation in the schemes. However, this methodology ignores the possible effects of backup investments on the decision of firms to participate in curtailable services. While backup investment may be a cheaper and a preferred option for some firms, other firms may find both backup and curtailable schemes necessary. Backup investments are not 100% reliable and also have fixed cost that has to be spread on the units of output produced, depending on the scale of operation, which may make it unaffordable to small firms. While backup investment may be a cheaper (e.g. large firms may find it cheaper but not always the case) and a preferred option for some firms, other firms may find both backup and curtailable schemes necessary especially when considering the incomplete reliability of backup investment. Thus, a complete analysis of this type would involve a concurrent treatment of backup investments and participation in curtailable schemes service.

Despite the low reliability of electricity supply in developing countries, empirical studies on the economic costs of power outages in Africa are still very limited, probably due to the lack of appropriate data that could be used for such research. As a matter of fact, the methods employed by the few existing studies on this issue in African context have been very limited and could not provide proper understanding of the costs of outages. Steinbuks & Foster (2010) have studied the causes of in-house electricity generation and its costs among 8483 firms in 25 African countries using a panel data from 2002 – 2006. They estimated two binary choice models of generator ownership and its capacity. They found that the size of the firm and export regulation play more important roles than reliability of supply in the decision to invest in backup generator. Using the Bental & Ravid (1982) proposed method, their estimates of costs of power outages show that firm incurs more cost to generate its own electricity than the price paid for a kWh of electricity supplied by utilities. However, the study could not find a significant difference between the costs and benefits of own generation, probably because the study ignored other benefits that can result from self generation.[5] Table 2 summarises some of the previous studies on the cost of power outages.

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[5] Their analysis of benefit was only based on reduction in lost sales due to self generation. They did not account for other important benefits such as reduction in damage to equipments, raw materials, restart costs, etc which may sometimes constitute the largest components of outage costs.

Table 2: Summary of Some Previous Studies on the Estimation of Cost of Power Outages

| Study | Scope | Method/Data | Focus | Findings/Outage cost estimates in 2007 prices |
|---|---|---|---|---|
| Bental & Ravid (1982) | US & Israel | Data on firms' average outage duration in 1980.<br>-US: 10 hours p.a.<br>-Israel: 70 hours p.a.<br>Marginal cost approach. | Computation of marginal outage costs. | Reliability varies directly with outage costs.<br>Outage cost: Israel - US$0.40/kWh<br>US – US$2.23/kWh |
| Pasha *et al.* (1989) | Pakistan | Nationwide random survey of 843 firms in 1984/85<br>Reported loss data<br>- Planned outages<br>- Unplanned outages | Computation of output loss due to power outages,<br>Computation of the multiplier effects of firms' loss due to outages on the overall economy. | Overall outage cost accounts for 8.8% of industrial output value added. Off which<br>- Planned outages: 65%<br>- Unplanned outages: 35%<br>Outage multiplier: 1.34<br>Overall impact on GDP: 1.8% reduction<br>Outage costs per kWh:<br>- Planned: $0.58<br>- Unplanned: $1.02 |
| Caves *et al.* (1992) | US | Use of data on interruptible service schemes.<br>- 8 participants<br>- 11 non-participants | Estimation of shortage cost. | None of the parameter estimates was significant.<br>Expected outages costs decrease as the size of the interruption increases.<br>Shortage cost (Utility): $4.63 - $5.58/kWh.<br>Outage cost for Industry: $6.97-$34.85/kWh. |
| Matsukawa & Fujii (1994) | Japan | 1988 Survey of backup among industrial & commercial consumers with large computers by CRIEPI, Japan<br>Mailed questionnaires<br>- Sample: 2,200<br>-Complete questionnaire Returned: 236<br>Discreet choice model | Computation of outage costs using back-up data,<br>Evaluation of the factors affecting the demand for back-up. | Demand for backup varies inversely with reliability & user costs of backup investments<br>Customers face trade-off between price & reliability of power supply<br>Customers characteristics have significant effects on backup investment<br>Outage cost: $50.72 - $236.17/KW |
| Beenstock *et al.* (1997) | Israel | Surveying of 794 business and public sectors.<br>-Data on backup<br>-Reported losses<br>-Firms characteristics<br>Two-limit tobit model. | Separation of total outage cost from unmitigated cost,<br>Comparison between the computed costs from revealed datasets and subjective datasets analyses | Outage cost - $9.21/kWh Unmitigated cost- $3.45/kWh<br>Total annual cost – $45.34/KW<br>Back-up rate – 33 percent<br>Reliability varies inversely with demand for backup and total outage cost, but varies directly with marginal cost per kWh unsupplied. |
| Steinbuks & Foster (2010) | Africa | Use of firms' datasets on back-up & sale losses<br>- 25 countries<br>- 8483 firms<br>- dataset between 2002 & 2006<br>Probit & tobit models<br>Marginal cost method | Computation of outage costs,<br>Investigation of drivers of auto-generation,<br>Evaluation of cost-benefits with focus only on sale loss reduction. | Impact of power unreliability on demand for generator is limited<br>Outage cost varies directly as reliability<br>The cost-benefit of self generation is not significant<br>Outage cost: $0.13 - $0.76/kWh |

## 5. Methodology

Many empirical studies have attempted to measure the cost of power outages to businesses (industrial sector) using different methodologies. These methodologies can be generally categorised into two: estimates based on macro data, and studies based on micro analysis of individual plants. One of the most popular and pioneering is the use of macro data by Telson (1975) to compute the upper and lower bounds on cost estimates of unsupplied electricity. The upper bound is approximately the ratio between GNP and total electricity consumption while the lower bound is the aggregate wage bill per unit of electric energy consumed. Among the studies that have used similar techniques include the literatures on value of lost load (VOLL) such as Leahy & Tol (2011), Tol (2007), Willis & Garrod (1997), de Nooij *et al.* (2007). The macro approach benefits from its simplicity and ease of implementation compared to many other methods.

Despite the advantages enjoyed by this approach however, its implicit assumption of no substitution between electricity and other factors of production is questionable. The use of (value added of) output-energy ratio in each sector as an estimate for the output lost due to unserved energy unit clearly demonstrates that the industries that are less electricity-intensive would have the largest loss per unit of energy unsupplied. Furthermore, such computations only estimate average cost of unserved energy, whereas the interest should be on (1) the marginal cost, since an electric utility has to decide on additional capacity or marginal cost or worth of reliability; (2) the curtailable risks (or mitigated costs) by customers, since the amount of loss that consumers are able to curtail through their actions in the event of an outage would definitely have impacts on their willingness to pay for extra reliability from the grid; and (3) the unmitigated costs, because the amount of loss the customers are unable to prevent through their actions would affect their decisions in evaluating how much more reliability is necessary for their businesses.

The first sub-category of studies on micro analysis of individual plants are usually based on questionnaires where firms are either asked to report the losses suffered from outages and the average outage duration experienced in a typical period, or to estimate the costs to their companies during typical interruption scenarios. Such reported loss components often include lost sales, damage to goods or raw materials, damage to equipment, etc. Among these literature are Munasinghe & Gellerson (1979), Pasha *et al.* (1989), Raesaar *et al.* (2006), and Tishler (1993). Analyses based on such reported data are often referred to as *subjective evaluation* because the estimates are normally prone to severe inaccuracies. Firms may have good reasons to overstate or ignorantly understate their losses.[6] Furthermore, it is often very difficult to aggregate the different estimates that may ensue from individual plants; and therefore, it may be difficult to formulate policy based on such estimates.

The last category is based on the principle of *revealed preference or investment method* in which the costs of outage are inferred from the actions taken (e.g. captive power generation) by firms to reduce the economic costs of power interruptions. In comparison with the methods previously cited, this one allows for the estimation of the marginal cost of an unserved kWh of energy, the total cost of unserved energy, the mitigated and unmitigated costs (or losses), and it is free from (or less prone to) over or undervaluation problems. Among the studies that support this approach are Adenikinju (2003), Beenstock (1991), Beenstock *et al.* (1997), Bental & Ravid (1982), Matsukawa & Fujii (1994), and Steinbuks & Foster (2010). The present study explores this approach in two different forms. First, it uses the marginal cost method version to compute the cost of unserved energy (as in *Adenikinju, 2003; Bental & Ravid, 1982; Steinbuks & Foster, 2010*). Second, it computes other outage costs (unmitigated and total) using a better methodology that allows for incomplete backup following Beenstock *et al.* (1997). Lastly, the study also computes outage cost estimates using the subjective evaluation method (as in *Pasha et al., 1989*) for comparative purposes. We also allow for the effect of incomplete backup in the subjective evaluation technique by including backup rates. As earlier stated, the latter may overstate or understate the costs of outage because the analysis relies on the reported outage losses by respondents, given the previously stated reasons.

### *5.1. Revealed Preference (Investment) Approach*

In every case, power interruptions impose economic loss on businesses, though some functions of a business (or some businesses) may be more vulnerable to power outages than others. That is, an outage of a given duration may impose large losses on certain parts of a business (or on certain firms) while other parts (or other businesses) may be less affected or left virtually unscathed. For example, an emergency unit of a specialist hospital would require constant flow of electricity for running its blood bank, ECHO machine, CTC scan, X-ray machines etc, and any power interruption would result in great losses, while the parking department of the hospital may be left virtually unscathed or suffer minor inconvenience. Similarly, expensive raw materials may be wasted as a result of power outages in an iron and steel producing firm, while a book distribution business may only suffer some minor inconvenience. Firms are rational and have an incentive to take alternative measure by investing in auto-generation to mitigate, in whole or in part, the damage that may result from power outages. In most cases, given the rationality of the firms' managers, they always

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[6] The reasons for businesses to overstate or understate their losses are already discussed under literature review.

prioritise those functions of their businesses that are most vulnerable to outages when deciding to invest in backup technology. In other words, rational managers would back up that part of the load that serves the business most vulnerable units.

### *5.1.1. Marginal Cost Method*

Investing in backup generation is expensive and may not be economically viable if it is not well planned. Firms have to choose the optimal amount of backup power by considering its energy load and the damage the remaining unserved energy would cause. Therefore, the firm's problem is to decide and choose the optimal degree of backup that minimises the sunk costs incurred in procuring generation capacity as well as the damage that would result from power interruption. A competitive risk-neutral firm will maximise the expected benefits from generating a kWh from its plant by equating at the margin, the expected cost of generating the kWh to the expected benefit from that kWh. This benefit consists of the continued production (even if partial) made possible by self-generated electricity, and the reduction or prevention of other costs, such as damage to equipment, loss of reputation due to inability to meet customers' demand, etc, that would have resulted from power interruption. The marginal cost of own-generation serves as an estimate for marginal outage cost because the expected marginal gain from auto-generation equals the expected loss from the kWh not supplied by the utility provider.

Following earlier literature, the equation that computes the marginal cost of power outage is:

$$C'(G)_{kWh} = \frac{b'(G)}{\pi} + v \qquad (1)$$

Where $G, \pi\ and\ v$ are generator capacity, outage time and variable cost per kWh respectively. Equation (1) can be used to compute the marginal cost of self-generation using data on the firm's acquisition and running cost of own-generating capacity, and the duration of power outages. To achieve this result, values for $b', \pi,$ and $v$ must be obtained.

### *5.1.2. Incomplete Backup Method*

The method proposed by Beenstock *et al.* (1997), unlike the marginal cost method, account for the possible losses that a firm may incur due to incomplete backup in the event of power interruption[7]. Thus, the method allows for separate estimation of the total and unmitigated outage costs. The underlying functional heterogeneity in the risk exposure to power interruptions of different

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[7] In most cases, investment in backup capacity does not guarantee 100 percent reliability. Thus, a company that invests in own generation may still suffer some losses because of the inability to completely back up its load. This is also linked to the earlier statement that firms will at least try to back up the most vulnerable functions of its establishment.

business' units simply implies that rational managers will likely ensure continuous electric service to the most vulnerable units by investing in backup generation. The optimal level of scale of this backup would mostly depend on the level of vulnerability, the capital and the operating cost of backup generator, and the expected outage time. Similarly, mitigated and unmitigated losses depend on the backup size. In other words, the greater the backup capacity, the higher will be the mitigated loss, and the smaller will be the unmitigated loss in the event of an outage.

Defining $X$ as a point on the loss distribution incurred due to power outage, and assuming that the portion of the loss below $X$ (i.e., the maximum affordable loss) is not backed up while the loss above it is backed up, a competitive risk neutral firm will minimise its total yearly cost of outages – i.e. user cost of backup plus the unmitigated loss – with respect to $X$. At the optimum, the firm will equate the cost of a marginal kW that is not backed up $(X^*\pi)$ to the marginal cost of backup $(P)$, which is assumed to be constant. Thus, the following equation holds for the optimal level of $X$:

$$X^* = {}^{P}/_{\pi}$$

There will be some backup if $E > G\left({}^{P}/_{\pi}\right) > 0$ and there will be complete backup when $G\left({}^{P}/_{\pi}\right) = E$, where $G$ and $E$ are respectively backup capacity and electricity load of the firm.

Assuming an exponential loss distribution of form $f(x) = k\lambda e^{-\lambda x}$, where $k$ is a scale variable, Beenstock *et al.* (1997) have shown that the optimal demand for backup is

$$G^* = Eexp^{\left(-\lambda P/_{\pi}\right)} \tag{2}$$

This implies that the demand for backup varies inversely with the cost of backup $P$, but directly with the firm's load $E$, and the unreliability of the power supply, $\pi$. Firm knows the loss distribution $f(x)$, and the mean outage time $\pi$. Equation 2 may be rewritten to express the underlying mean value of an outage loss (see Beenstock *et al.*, 1997) as

$$\frac{P}{\pi ln\left({}^{E}/_{G}\right)} = \frac{1}{\lambda} \equiv \mathrm{E}(y) \tag{3}$$

and can be parameterised as:

$$y_i = \beta \mathrm{Z}_i + u_i \tag{4}$$

Where $\beta$ is a row vector of parameters; Z is a vector of observable variables hypothesised to determine the underlying mean value of an outage loss (i.e, ${}^{1}/_{\lambda}$). $u_i = \varepsilon_i + \omega_i$; $\varepsilon \sim N(0, \sigma_\varepsilon^2)$ represents unobserved heterogeneity in losses across firms; and $\omega \sim N(0, \sigma_\omega^2)$ captures the optimisation error by firms. Lastly, $cov(\varepsilon, \omega) = 0$ indicates that the unobserved heterogeneity is independent of firms' tendency to invest in too small or too much backup relative to the optimal level.

Firms may report during the survey that they do not suffer losses in the event of power interruptions for some few possible reasons. They can be naturally immune to outage losses (given the nature of their businesses) in which case they do not need to invest in backup, or they are fully backed up (i.e., $G = E$). Firms may invest in complete backup because it is optimal (e.g., there may be economies of scale in backup investment), due to optimisation error, or due to indivisibility in backup investment. Similarly, the same reasons apply to those firms that do not invest in backup.

Rationally, there are four possible cases regarding the investment in backup generation and outage losses. These are cases of incomplete backup (i.e., there is backup and reported outage losses), no backup but there are outage losses, complete backup (i.e., backup and zero outage losses) and lastly natural immunity to outages (i.e., no backup and no losses).[8]These four possible cases imply that the dependent variable $y$ in Eq. (4) is a censored variable, censored from below at zero and from above at $\alpha$, where $\alpha$ is an unknown positive parameter above which only complete backup is economically valuable. Thus, the latent variable $y^*$ is defined as

$$y^* = \begin{cases} 0 \quad if\ \beta Z + \varepsilon + \omega < 0 & i.e.,\ no\ backup \\ y \quad if\ 0 < \beta Z + \varepsilon + \omega < \alpha & i.e., incomplete\ backup \\ \alpha \quad if\ \beta Z + \varepsilon + \omega > \alpha & i.e., complete\ backup \end{cases} \tag{5}$$

The estimates of parameters $\beta$ in Eq. (4) are obtained by regressing $y$ on the observed variables $Z$ using "two-limit tobit" estimation (see Maddala, 1983 pp. 160-162). The estimate of the mean outage loss for firm $i$ will be ${}^{1}/_{\hat{\lambda}} = \hat{\beta} Z_i + \hat{\varepsilon}_i$ and the unmitigated loss of an outage can be inferred, given the estimate for $\lambda_i$, as[9]:

$$\hat{L}_i = \frac{ln\left({}^{E_i}/_{G_i}\right)}{\hat{\lambda}_i} \tag{6a}$$

while the total outage cost to a firm $i$ can be estimated as

$$\hat{C}_i = P_i G_i + \pi_i \hat{L}_i \tag{6b}$$

Thus, Eq. (7) computes the expected unmitigated outage loss to a firm $i$, having classified the firm into any of the four categories discussed above using their backup-outage losses information, as:

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[8] A possible irrational case could be when a firm still invests in backup despite being naturally immune to power outage. This irrational case is ignored in this empirical study.

[9] Readers are referred to Beenstock *et al.* (1997) for detailed procedures involved in this method.

$$\hat{L}_i = \pi \mathrm{E}\left\{\left[1 - exp\left(-\hat{\lambda}_i P\big/_{\pi}\right)\right]\Big/\left[\hat{\lambda}_i - (P/\pi)exp\left(-\hat{\lambda}_i P\big/_{\pi}\right)\right]\right\} \tag{7}$$

### *5.2. Subjective Evaluation Method*

As noted earlier, this method estimates the cost of outages from the losses suffered due to electricity outages by firms. During the survey, firms are asked to report the values of the losses they suffer due to power outages. The reported loss data are then regressed on the outage duration and the other characteristics of the firm. A key element of these characteristics of the firms is the backup rate, which captures the impacts of backup investment on outage losses. All things being equal, a firm with more backup are likely to suffer smaller unmitigated loss. Eq. (8) relates the firms' total loss to a set of variables that may account for variation in losses across firms

$$L_{it} = \psi \mathrm{H}_{\mathrm{it}} + \mu_{it} \tag{8}$$

$L_{it}$ = Reported loss due to an unsupplied kWh to customer $i$ of duration $t$,
$\mathrm{H}_{it}$ = A matrix representing the characteristics of consumers and outages,
$\psi$ = A row vector of unknown parameters,
$\mu_{it}$ = Random error term.

The dependent variable $L$ is a restricted variable considering the fact that some firms may report zero loss, either because they have natural immunity to outage or because they have fully backed up their loads. Using zero as the lower limit and setting the upper limit at $\overline{\mathrm{A}}$ (where $\overline{\mathrm{A}}$ represents the maximum loss set by the author to control for "protest responses" in the reported losses, and in this case it is set at –\$100 per kWh. This restriction is to control for a number of instances where the reported losses may be unreasonably large. As noted earlier, the respondents (firms) may report unusually high losses to register their discontent with the public utilities. So, to control for these instances, we set the upper limit at \$100 per kWh. This amount is considered high enough considering the trends of the reported outage losses. In fact, less than 5% of the firms reported outage losses of \$100 and above.[10] Thus, we can estimate Eq. (8) using a two limit Tobit estimator as

$$L = \begin{cases} L = \overline{\mathrm{A}} \;\; if\; \psi\mathrm{H} + \mu \geq \overline{\mathrm{A}} \\ \psi\mathrm{H} + \mu \quad if\; 0 < \psi\mathrm{H} + \mu < \overline{\mathrm{A}} \\ 0 \qquad if\; \mu \leq -\psi\mathrm{H} \end{cases}$$

Finally, the unmitigated outage cost for an average firm $i$ can be computed as follows

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[10] Upper limit of \$80 and \$120 per kWh are also considered but do not yield significantly different estimates. This is because those firms which reported values greater than \$100 recorded significantly higher values above this threshold.

$$\hat{L}_i = \mathrm{H}_i\hat{\psi}(\theta_{2i} - \theta_{1i}) + \hat{\delta}_\mu(\Theta_{1i} - \Theta_{2i}) + (1 - \theta_{2i})\bar{\mathrm{A}} \quad (9)$$

Where

$\theta_{1i}$ = Cumulative standard normal density function at $-\hat{\psi}\mathrm{H}_i/\hat{\delta}_\mu$ ,

$\theta_{2i}$ = Cumulative standard normal density function at $(\bar{A} - \hat{\psi}\mathrm{H}_i)/\hat{\delta}_\mu$ ,

$\Theta_{1i}$ = Standard normal density function at $-\hat{\psi}\mathrm{H}_i/\hat{\delta}_\mu$,

$\Theta_{2i}$ = Standard normal function at $(\bar{A} - \hat{\psi}\mathrm{H}_i)/\hat{\delta}_\mu$,

$\hat{\delta}_\mu$ = Standard deviation of $\hat{\mu}$.

### 6.1. Overview of Data

The major data used for this empirical analysis comes from the 2007 World Bank Enterprise surveys of 6854 firms currently operating in 12 African countries[11]. Word Bank Enterprise surveys capture business perceptions of the obstacles to their growth, the relative importance of various constraints to increasing employment and productivity, and the effects of a country's investment climate environment on the international competitiveness of its firms. The surveys use a stratified random sampling methodology. However, because there are more small and medium firms than large ones in most countries, the surveys generally oversample large enterprises. Notwithstanding, the major advantage of this database is its provision of both the managers' opinions on the (un)reliability of electricity supplies and the economic data relevant for structural microeconomic analysis.

The unit cost of generating a kWh of electric energy, $b'$, is a function of the price schedules for generators, tax, depreciation rules, and the interest rates. Original price schedules in national currencies and data on year of acquisition are taken from the enterprise surveys database for those countries where such data are reported. The original price schedules are deflated using the corresponding value of the country's GDP deflator before converted into dollars at the prevailing exchange rate, adjusted for price volatility using World Bank Atlas method. For those countries whose data on generator prices are not available, the converted data for other countries are adopted taking into account the firm's size and the sector. We then compute the capital cost (in 2007 dollars) per kW of installed capacity using the projected data from the World Bank (2006) assuming thermal generation, no tax rules, and 10% internal rate of return.[12]

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[11] The countries include Algeria, Egypt, Gambia, Ghana, Kenya, Mali, Morocco, Mozambique, Nigeria, Senegal, South Africa and Zambia.

[12] The reported data from the enterprise surveys show that most firms in Africa do not have access to external source of finance. Thus, internal rate of return might be a better measure of opportunity cost of capital.

The operating cost $v$, is computed by multiplying the unit cost of fuel by the generator's fuel efficiency (fuel consumption per kWh). Assuming that the firms' industrial plants rely on thermal generation, the unit cost of fuel is approximated by an average per litre of diesel fuel; the fuel prices are obtained from the 2007 GTZ International Fuel Prices (World Bank, 2007). The data on fuel efficiency was obtained from the Web sites of two leading manufacturers of generators –Wärtsilä and Cummins. The data on outage time $\pi$, are obtained from the information on monthly outage frequency and average duration reported by firms in the enterprise surveys. Although the data on national average outage time are not officially available, we assume a value of 8 hours per day.[13] Data on employments and the weekly operating hours are obtained from the survey of enterprises.

The data on electricity loads are not directly available from enterprise surveys but the costs of electricity are reported. To derive the data on firms' loads, we first convert the reported electricity costs into electricity using the data on electricity prices. We then converted the results into kW using the average annual operation hours reported in the survey. For the non-backup firms that reported zero outage loss the converted electricity figures were taken as their loads. For 100% backup firms – i.e., firms with backups that reported zero outage loss – we adjust for the electricity generated from backups to derive their electricity loads. For those with incomplete backups and those without backups but suffer outage loss, we adjust for their electricity consumption with the electricity they would have consumed if they had not experienced power outage using their reported outage time. The data on electricity prices are obtained from the regulators and from a 2009 study of electricity tariffs used in Africa by UPDEA. Other variables are dummies used to capture firms' export promotion (proxy by whether a firm has International Quality Certificate – ISO Certificate), and to reflect technological differences across firms as well as their usage of the Internet for operation[14].

Figure 2 presents the percentage distribution of the reported outage time and outage losses when controlling for outage time. The figure shows that, contrary to expectation, the country that accounts for the largest percentage of the outage time is not necessarily the country that experiences the largest outage loss. Nigeria accounts for 32.36% of the reported average outage time but accounts for only 3.72% of the average outage loss. On the contrary, South Africa which accounts for 0.85% of the reported outage time accounts for 23.74% of the average outage loss. This suggests that the distribution of outage losses might not only be influenced by outage time but may also depend on other factors such as the size of the firms, export promotion, nature of operation, etc. For

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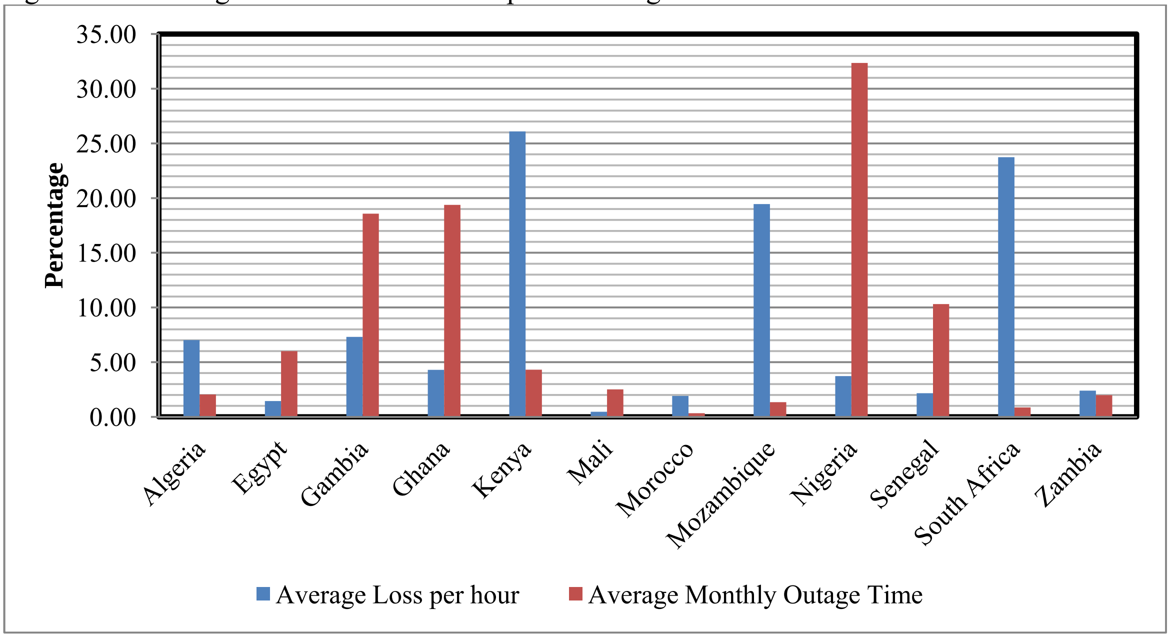
[13] We also assume 9 hours outage time to examine how cost of outage changes with respect to reliability, see Table 3.

[14] Firms using internet (e.g., emails or own websites) for their operations are likely to rely more on electricity and this may reflect in their decisions to invest in backup.

instance, a larger firm that experiences an outage of 2 hours may suffer greater loss compared to a smaller firm that experiences a power outage of 3 hours duration, ceteris paribus.

Figure 2: Percentage Distribution of the Reported Outage Time and Losses in 2007



Data Source: World Bank Surveys of Business Enterprises 2007

## 7. Discussion of Empirical Results

### *7.1. Revealed Preference – Marginal Cost Method*

Table 3 presents the estimated (marginal) costs of unsupplied kWh of electricity obtained from Equation (1)[15]. The results show that the cost of generating own electricity ranges between $0.16 in Algeria and $0.58 in Zambia. The results further indicate that as the system becomes less reliable, (marginal) cost of unsupplied electricity reduces over the range of 2% and maximum of 9%. A plausible explanation for this is that, an unreliable system is characterised by huge investments in backup so that an additional rise in unreliability results in less (marginal) cost per unit due to huge backup investments already made. In all the countries (including Algeria and Egypt where fuel is heavily subsidised), the cost of own generation is substantially higher than the cost of electricity supplied from the public grid. This may reflect the diseconomies of scale in own generation due to the small backup generators widely used by firms compared to the large power plants being utilised in the public grid. On the other hand however, these high cost differentials might be because the public electricity grid is highly subsidised in Africa. This issue is investigated further later.

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[15] Recall that as earlier stated, Equation (3) does not account for additional outage cost that may result from incomplete backup.

Table 3: Estimated Costs of Unsupplied Electricity and Public Grid Prices per kWh, 2007 US$ Prices

| Country | (A) variable cost | (B) unit cap cost (8 hrs) | (C)=(A)+(B) own generation (8 hrs) | (D) unit cap cost (9hrs) | (E)=(A)+(D) own generation (9hrs) | % change in cost due to less reliability | % gen share of electricity | Public price |
|---|---|---|---|---|---|---|---|---|
| Algeria | 0.05 | 0.11 | 0.16 | 0.10 | 0.15 | -7.43 | 7.40 | 0.06 |
| Egypt | 0.04 | 0.26 | 0.30 | 0.23 | 0.28 | -9.48 | 14.80 | 0.05 |
| Gambia | 0.25 | 0.19 | 0.44 | 0.17 | 0.42 | -4.85 | 32.30 | 0.20 |
| Ghana | 0.24 | 0.22 | 0.46 | 0.20 | 0.44 | -5.32 | 29.50 | 0.11 |
| Kenya | 0.30 | 0.06 | 0.36 | 0.05 | 0.35 | -1.87 | 14.70 | 0.12 |
| Mali | 0.30 | 0.26 | 0.56 | 0.23 | 0.53 | -5.16 | 6.50 | 0.24 |
| Morocco | 0.24 | 0.32 | 0.56 | 0.28 | 0.52 | -6.37 | 16.00 | 0.14 |
| Mozambique | 0.34 | 0.22 | 0.57 | 0.20 | 0.54 | -4.42 | 10.48 | 0.10 |
| Nigeria | 0.25 | 0.23 | 0.48 | 0.20 | 0.45 | -5.27 | 60.90 | 0.05 |
| Senegal | 0.33 | 0.25 | 0.57 | 0.22 | 0.55 | -4.74 | 24.70 | 0.21 |
| South Africa | 0.18 | 0.36 | 0.54 | 0.32 | 0.50 | -7.40 | 15.10 | 0.04 |
| Zambia | 0.40 | 0.18 | 0.58 | 0.16 | 0.56 | -3.47 | 19.50 | 0.03 |

### *7.2. Revealed Preference – Incomplete Backup Method*

Table 4 presents the results of the two-limit –Tobit estimation of Equation (4). It should be noted that the dependent variable in Eq. (4) is a transformation of the rate of backup $\left(G/_{E}\right)$ per unit user cost $\left(P/_{\pi}\right)$ where the latter is equal in equilibrium, to the maximal loss. Thus, the estimated parameters from Eq. (4) bear the interpretation of semi-elasticity of demand for backup:

$$lnG = lnE - \left(P/_{\pi}\right)/\beta Z + error\ term \qquad (10)$$

That is, the demand for backup varies directly with electricity consumption, inversely with the user cost of backup $(P)$, directly with outage time $(\pi)$, and with the heterogeneous firm's characteristics. We capture the observed heterogeneity by the firm's load, and by firm's characteristics such as sizes, export promotion (proxy by ISO certificate holding), use of the Internet for firm's operation and by a series of sectoral dummies designed to account for technological differences.

The first five explanatory variables, as expected, indicate that the demand for backup varies directly with load, export promotion, firm's size, and the use of internet facilities by firms. In other words, the results show that larger firms, those that hold international standard certificate and those whose activities involve the use of the Internet are likely to demand more backup. This is not surprising given that a firm with export promotion (i.e., holding international quality standard) is likely to back up its system in order to meet the international quality standard. Similarly, since the use of the Internet requires efficient running of electricity, firms which use internet services for their day to day operations (e.g., marketing, procurements, etc) will likely demand for backup against the occurrence of power outages.

Table 4: Estimation of Equation (4) by Two Limit Tobit

| Variable | Coefficient | *P-value* | Variable | Coefficient | *P-value* |
|---|---|---|---|---|---|
| Intercept | -0.88*** | 0.00 | Plastics | 0.22* | 0.06 |
| Load | $2.74 \times 10^{-7}$* | 0.06 | Retails | 0.29** | 0.01 |
| Export Promotion | 0.15*** | 0.00 | Textile | 0.16 | 0.14 |
| Small | -0.18*** | 0.00 | Wood & Furniture | 0.08 | 0.50 |
| Large | 0.25*** | 0.00 | Algeria | 0.40*** | 0.00 |
| Internet | 0.09*** | 0.00 | Egypt | 0.12*** | 0.00 |
| Chemicals | 0.37*** | 0.00 | Gambia | 0.89*** | 0.00 |
| Construction | -0.03 | 0.96 | Ghana | 0.36*** | 0.00 |
| Electronics | 0.31** | 0.01 | Kenya | 0.57*** | 0.00 |
| Fabrications | 0.11 | 0.35 | Mali | 0.32*** | 0.00 |
| Food | 0.28** | 0.01 | Mozambique | 0.12* | 0.05 |
| Garments | 0.34 | 0.38 | Nigeria | 1.27*** | 0.00 |
| Information Technology | 0.37*** | 0.00 | Senegal | 0.80*** | 0.00 |
| Machine & Equipment | 0.31** | 0.01 | South Africa | 0.06 | 0.19 |
| Metal | 0.26** | 0.02 | Zambia | 0.01 | 0.47 |
| Non-Metal | 0.26 | 0.03 | | | |
| Other Manufacturing | 0.15 | 0.14 | | | |
| $\hat{\sigma}_u = 0.51$ | $\hat{\sigma}_\varepsilon = 0.26$ | $\hat{\alpha} = 0.85$ | | | |
| (0.010) | $\hat{\sigma}_\omega = 0.44$ | | | | |
| | (0.008) | | | | |

N= 5920 of which 3767 censored from below and 457 censored from above.

Note: Base country: Morocco; base sector: Other retails; Hotels & Restaurants dropped due to collinearity. Operation hours removed from the model because it negatively affects the performance of the model.

Source: World Bank, Enterprise Survey Database.

Furthermore, larger firms and firms that require more electricity are likely to invest more in backup to mitigate outage losses. Overall however, firms' size, export promotion and internet usage play major roles in firms' decision to invest in backup. In terms of a country's demand for generator, the results suggest that, all things being equal, firms operating in Nigeria, Gambia, Senegal and Kenya are likely to invest more in own generation. This reflects the contributions of the above factors on the demand for backup in those countries. The parameter $\alpha$ was estimated by choosing the value of $\alpha$ that maximized the likelihood function through a search procedure. An estimate of 0.85 suggests that because of indivisibilities and installation costs, firms begin to invest in complete backup once it is worth investing in 85% backup capacity.

### *7.3. Subjective Evaluation*

The estimates from Equation (8) based on Two-Limit Tobit estimation of the reported outage losses are presented in Table 5. We include backup rates to capture the effects of backups on outage losses. This allows us to account for the effects of incomplete backup on outage losses. As expected, the first eight variables yield the expected signs and they (except the use of the internet) are highly significant. The coefficient on load (though small) indicates that firms which depend more on electricity for their activities are likely to be more vulnerable to power outages. Also, a larger firm has a higher probability of suffering more outage loss compared to smaller firms.

Similarly, firms that experience outages of long duration and those holding quality standard certificates are more likely to suffer more outage loss. In the same vein, a firm operating for long hours is more likely to suffer more loss. All things being equal, a firm that operates for longer hours per day is likely to witness more outages and therefore suffers more outage loss than a firm which operates for fewer hours.

The negativity of the coefficient on backup rate has two implications. First, it indicates that a firm that owns or shares a generator has low probability of suffering outage loss. The second is that the higher the backup rate, the lower the outage loss to be suffered by a firm, ceteris paribus. The significance of the parameter on backup rate indicates that having a backup has significant effects in reducing outage loss. Surprisingly however, the results indicate that the construction industry suffer more loss from power outages than other industry. This reflects the low demand for backup generation by construction firms (see Table 4). Construction firms might consider electricity less important for their operations and therefore do not border to invest much on backup generation. So, when outage occurs, parts of their activities that may require electricity will be left undone. This effect can be more pronounced when the next process which does not depend on electricity can not be carried out until those parts that are dependent on electricity are completed.

Table 5: Estimation of Equation (8) by Two Limit Tobit (TLT)

| Variable | coefficient | *p-value* | Variable | coefficient | *p-value* |
|---|---|---|---|---|---|
| Intercept | -9.65 | 0.25 | Textile | -2.26 | 0.78 |
| Internet | 1.54 | 0.15 | Wood & Fur. | 0.10 | 0.99 |
| Small | -5.37*** | 0.00 | Algeria | -12.71*** | 0.00 |
| Large | 12.82*** | 0.00 | Egypt | -12.39*** | 0.00 |
| Duration | 0.38*** | 0.00 | Gambia | 12.92** | 0.01 |
| Operation Hours | 0.06*** | 0.00 | Ghana | 1.65 | 0.56 |
| Backup Rate | -10.76*** | 0.00 | Kenya | 20.51*** | 0.00 |
| Load | $6.4\text{x}10^{-5}$*** | 0.00 | Mali | -9.98*** | 0.00 |
| Export Promotion | 3.87*** | 0.00 | Mozambique | -6.12** | 0.04 |
| Chemicals | 9.17 | 0.26 | Nigeria | 11.72*** | 0.00 |
| Construction | 47.06* | 0.07 | Senegal | 7.39** | 0.01 |
| Electronics | 9.10 | 0.29 | South Africa | -3.71 | 0.14 |
| Fabrications | 0.12** | 0.01 | Zambia | -1.33 | 0.63 |
| Food | 3.67 | 0.64 | $\sigma$ | 24.44 | 68.85[a] |
| Garments | 1.35 | 0.87 | | | |
| Machine & Equip. | 5.60 | 0.50 | | | |
| Metal | 4.85 | 0.55 | | | |
| Non-Metal | 3.57 | 0.66 | | | |
| Other Mfg. | -0.07 | 0.99 | | | |
| Plastics | 6.21 | 0.75 | | | |
| Retails | -2.17 | 0.80 | | | |

Note: N= 4359 of which 1649 censored from below and 100 censored from above.

[a] t-value. Base country: Morocco; base sector: Hotel & Restaurants; Information Technology dropped due to collinearity.

One puzzle with the estimates reported in Table 5 is that our empirical might be subject to selection biases or endogeneity problems from unobserved heterogeneity in firms' behaviour.[16] Specifically, the key variable (backup rate) might be endogenous. One reason is that omitted variables like motivation or managerial ability both might influence the decision to invest in backup capacity and firm's outage loss and might not be sufficiently captured by other control variables. If the last statement is true, therefore, a causal interpretation of the results in Table 5 is not warranted. In order to deal with possible or test for the existence of endogeneity problem that might affect our estimates, we apply Newey's (1987) two-step estimation procedure. While finding appropriate identifying variables is in many cases a prohibitive challenge, we use data measuring manager's years of experience in the industry as the instrument. This variable satisfies the necessary conditions. Preliminary analyses show that manager's experience is correlated with backup rate but not correlated with the dependent variable (outage loss per kWh unsupplied) in Table 5.

The results from the two-step estimation procedure show that the use of instrumental variable does not improve the performance of the model.[17] Although the results reject the hypothesis that all the instruments are jointly zero at 1% level of significance, all the variables change to being individually insignificant. With regards to the treatment, the 2SLS estimation confirms the Tobit results partly: there is no difference in the sign of the parameter on backup rate; however, the coefficient is larger and insignificant. Overall, however, the Wald test of exogeneity of the instrumented variable (i.e., backup rate) indicates that the test statistic is not significant, suggesting that the null hypothesis of no endogeneity cannot be rejected. In other words, the estimates in Table 5 are valid.

It is also important to point out that this study relies more on the estimates from the incomplete backup method given some possible biases in self reported losses as pointed out previously. The estimates from subjective evaluation are mainly used for comparative purposes. Therefore, a possible problem of endogeneity (even if there is any) in the model in Table 5 should not be a serious issue for this study.

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[16] We acknowledge the anonymous reviewer for suggesting to us to test for endogeneity in the model.

[17] The results from this estimation procedure are available upon request from the authors.

### *7.4. Unmitigated Outage Costs*

The computed expected unmitigated outage costs based on both the incomplete backup method (Table 4 and Eq. 7) and the subjective evaluation (Table 5 and Eq. 9) are reported in Table 6[18]. The table also includes the total outage costs based on the incomplete backup method. Based on the subjective evaluation technique, the unmitigated costs of unsupplied kWh of electricity range from US$2.78 (Algeria and Mali) to US$3.32 (Kenya). Using the incomplete backup method however, the unmitigated cost per kWh of unserved energy ranges from US$0.37 in Egypt to as high as US$2.39 in Nigeria. The total cost per kWh (i.e. both unmitigated and mitigated) ranges between $0.62 (Zambia) and US $3.32 (Nigeria). Moreover, the results show that the unmitigated costs still account for a significant proportion of outage costs ranging between 45.7% and 72.0% of the total cost per kWh. Therefore, we reject the first hypothesis that the unmitigated cost accounts for a lower proportion of the outage cost per kWh. The last column of the table further shows that an average firm in Africa incurs between US$1,752.0 and US$9,694.4 per KW due to power outages.[19]

Table 6: Cost (US$) of Unsupplied Electricity based on Incomplete Backup and Subjective methods, 2007 Prices

| | Unmitigated costs per kWh | | Estimates based on Incomplete backup method | | |
|---|---|---|---|---|---|
| Country | Incomplete backup | Subjective evaluation | Total expected cost per kWh | % of unmitigated cost per kWh | Total annual cost per KW $ |
| Algeria | 0.57 | 2.78 | 1.23 | 46.3 | 3591.6 |
| Egypt | 0.37 | 2.91 | 0.81 | 45.7 | 2365.2 |
| Gambia | 1.31 | 3.10 | 2.33 | 56.2 | 6803.6 |
| Ghana | 0.49 | 3.00 | 0.97 | 51.0 | 2832.4 |
| Kenya | 0.93 | 3.32 | 1.80 | 51.6 | 5256.0 |
| Mali | 0.40 | 2.78 | 0.79 | 51.0 | 2306.8 |
| Morocco | 0.43 | 3.07 | 0.84 | 51.2 | 2452.8 |
| Mozambique | 0.38 | 2.92 | 0.60 | 63.3 | 1752.0 |
| Nigeria | 2.39 | 3.07 | 3.32 | 72.0 | 9694.4 |
| Senegal | 0.99 | 3.03 | 1.90 | 52.1 | 5548.0 |
| South Africa | 0.43 | 2.97 | 0.83 | 51.8 | 2423.6 |
| Zambia | 0.39 | 2.96 | 0.62 | 63.0 | 1810.4 |

### *7.5. Relationship between Outage Costs and Firms' Characteristics*

In Table 4 and 5, we found that export promotion, firms' size and the use of the Internet for operation significantly influence firms' decision to invest in backup generation. In Table 7 and 8, we compare the unmitigated ouatge costs suffered by firms possessing the aforesaid characteristics with those that do not. Our results reveal that – despite having high propensity for backup – firms

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[18] The estimates are based on outage time of 8 hours daily. 8 hours outage duration is assumed throughout this study for the purpose of making comparison with the previous studies on Africa and to compare the estimates from the various methods explored in this study.

[19] This is based on the assumption of 8 hour outage time per day.

holding an international quality standard certificate (export promotion), larger firms, and those that use the Internet for their operation still suffer greater unmitigated outage losses than others. The unmitigated outage cost increases with firm size in all the countries. In terms of the magnitudes, the unmitigated costs range from \$0.12 for small firms in Mozambique to \$3.20 for large firms in Nigeria (Table 7).

Table 5: Unmitigated Cost (US\$) per kWh Based on Incomplete Backup According to Firms' Characteristics, 2007 Prices

| | Small | Medium | Large | ISO Firms | Non-ISO | Internet | No Internet |
|---|---|---|---|---|---|---|---|
| Algeria | 0.45 | 0.63 | 0.91 | 0.83 | 0.56 | 0.63 | 0.47 |
| Egypt | 0.21 | 0.35 | 0.57 | 0.60 | 0.32 | 0.49 | 0.27 |
| Gambia | 0.92 | 1.43 | 2.69 | 2.63 | 1.07 | 2.04 | 1.03 |
| Ghana | 0.35 | 0.60 | 1.06 | 1.05 | 0.45 | 0.76 | 0.40 |
| Kenya | 0.61 | 0.90 | 1.33 | 1.27 | 0.86 | 1.05 | 0.67 |
| Mali | 0.32 | 0.65 | 1.05 | 0.71 | 0.37 | 0.61 | 0.32 |
| Morocco | 0.18 | 0.36 | 0.63 | 0.65 | 0.39 | 0.48 | 0.23 |
| Mozambique | 0.12 | 0.40 | 0.67 | 0.48 | 0.20 | 0.44 | 0.17 |
| Nigeria | 1.26 | 2.71 | 3.20 | 3.00 | 2.52 | 2.91 | 2.41 |
| Senegal | 0.86 | 1.21 | 2.01 | 1.54 | 0.95 | 1.23 | 0.85 |
| South Africa | 0.22 | 0.41 | 0.75 | 0.64 | 0.31 | 0.47 | 0.26 |
| Zambia | 0.14 | 0.32 | 0.58 | 0.47 | 0.25 | 0.37 | 0.20 |

Small: 1-19; medium: 20-99; large: 100+

Similar to firms' size, firms operating at international quality standard level suffer unmitigated outage costs of between \$0.47 and \$3.00 inclusive, while the unmitigated costs for non-international quality standard firms range from \$0.20 to \$2.52. Firms using the Internet for their operation also suffer outage costs from \$0.37 to \$2.91 compared to others with outage costs raanging between \$0.20 and \$2.41 (Table 7). Similar trends are reported in Table 8 using the subjective evaluation method. Given this evidence therefore, we reject the hypothesis 2 that larger firms, firms holding international quality standard certificate and those using the Internet for their operation suffer lesser unmitigated loss because they tend to invest more in backup generation.

Table 8: Unmitigated Outage Costs (US $) Based on Subjective Evaluation According to Firms Characteristics, 2007 Prices

| Country | Small | Medium | Large | ISO | Non-ISO | Internet | Non-Internet |
|---|---|---|---|---|---|---|---|
| Algeria | 2.70 | 2.80 | 3.00 | 2.87 | 2.77 | 2.81 | 2.72 |
| Egypt | 2.79 | 2.88 | 3.09 | 3.08 | 2.88 | 2.99 | 2.86 |
| Gambia | 3.04 | 3.15 | 3.42 | 3.22 | 3.08 | 3.20 | 3.07 |
| Ghana | 2.95 | 3.03 | 3.26 | 3.20 | 2.99 | 3.09 | 2.98 |
| Kenya | 3.17 | 3.29 | 3.52 | 3.45 | 3.29 | 3.37 | 3.20 |
| Mali | 2.75 | 2.87 | 3.10 | 2.89 | 2.77 | 2.85 | 2.76 |
| Morocco | 2.93 | 3.00 | 3.17 | 3.13 | 3.06 | 3.09 | 2.94 |
| Mozambique | 2.86 | 2.99 | 3.18 | 3.00 | 2.90 | 3.01 | 2.89 |
| Nigeria | 3.04 | 3.13 | 3.38 | 3.23 | 3.06 | 3.13 | 3.06 |
| Senegal | 3.00 | 3.07 | 3.28 | 3.18 | 3.02 | 3.06 | 3.01 |
| South Africa | 2.83 | 2.95 | 3.18 | 3.09 | 2.90 | 3.00 | 2.84 |
| Zambia | 2.87 | 2.97 | 3.17 | 3.05 | 2.94 | 3.01 | 2.90 |

One puzzle from the above findings is why firms having a higher propensity to invest in backup capacity continued to suffer higher unmitigated outage costs.[20] The reason simply is that although firms with certain characteristics have a propensity to invest in backup generation, they in most cases make partial investments which still make them vulnerable to power outages. Table 8a below shows the distribution of backup status of firms across the countries. Between 76% and 100% of firms that have invested in backup generation make partial investments and complement their energy needs from the services from the national grid. If a firm invests in its own generation, it can still suffer more unmitigated outage costs if the investment is partial depending on the proportion of the firm's energy loads the investment is able to cover. Although larger firms have a higher tendency of investing in backup generation, they can still suffer more unmitigated outage costs than smaller firms if their investments are partial and could not cover the larger proportion of their potential outage losses.

Table 8a further shows that even in countries with a higher distribution of firms with investments in backup capacity, the backup rates are still very low. On average, none of the countries has up to 50% backup rates. The implication of this low backup capacity is that even if certain firms (due to their characteristics) tend to invest more in backup capacity, they might still suffer significantly from power outages due to low installed backup capacity relative to their energy needs. There are several reasons why firms might decide to run significantly less than 100% backup. First, firms may decide to invest in small backup capacity and complement it with the energy from the national grid because it is cheaper. The costs of electricity supplied from the national grid are significantly lower than the own-generation costs (see Table 11). Another reason for running less capacity could be due

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[20] Thanks to an anonymous referee for suggesting to us the need to further explore this issue.

to financial constraints. That is, firms may go for less backup capacity if they do not have adequate financial capacity to invest in 100% backup generation.

Table 8a: Distribution of Backup Capacity and Estimated Unmitigated Outage Costs per kWh (US$)

| | % of firms with backup | | | | Backup rate (%) | | | % of firms with backup | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Country | Overall | Complete | Partial | Costs | Overall | Backup firms only | Sector | Overall | Complete | Partial | Costs |
| Algeria | 36.38 | 18.71 | 81.29 | 0.57 | 10.37 | 28.75 | Chemicals | 39.83 | 23.40 | 76.60 | 0.57 |
| Egypt | 23.40 | 14.79 | 85.21 | 0.37 | 6.64 | 28.38 | Construction | 33.33 | 0.00 | 100.0 | 1.10 |
| Gambia | 62.50 | 5.00 | 95.00 | 1.31 | 18.59 | 29.75 | Electronics | 45.26 | 7.00 | 93.00 | 0.78 |
| Ghana | 19.07 | 1.28 | 98.72 | 0.49 | 4.58 | 24.05 | Fabrications | 16.14 | 2.17 | 93.83 | 0.33 |
| Kenya | 48.64 | 0.00 | 100.0 | 0.93 | 6.86 | 14.10 | Food | 35.81 | 8.22 | 91.78 | 0.88 |
| Mali | 19.87 | 0.00 | 100.0 | 0.40 | 2.82 | 14.19 | Garments | 23.24 | 4.18 | 95.82 | 0.55 |
| Morocco | 16.78 | 23.38 | 76.62 | 0.43 | 6.03 | 35.96 | Info. Tech. | 82.24 | 0.00 | 100.0 | 3.67 |
| Mozambique | 11.41 | 13.16 | 86.84 | 0.38 | 2.36 | 20.74 | Mach &Equip | 44.00 | 6.82 | 93.18 | 2.22 |
| Nigeria | 70.71 | 1.70 | 98.30 | 2.39 | 30.53 | 43.17 | Metal | 44.36 | 6.78 | 93.22 | 0.96 |
| Senegal | 34.70 | 24.41 | 75.59 | 0.99 | 13.77 | 39.57 | Non-Metal | 28.32 | 16.33 | 83.67 | 0.57 |
| South Africa | 19.21 | 10.95 | 89.05 | 0.43 | 4.20 | 21.89 | Other Mfg | 30.55 | 7.45 | 92.55 | 0.77 |
| Zambia | 8.77 | 5.41 | 94.59 | 0.39 | 2.11 | 24.03 | Other Retails | 21.19 | 12.00 | 88.00 | 0.45 |
| | | | | | | | Plastics | 27.27 | 12.82 | 87.18 | 0.56 |
| | | | | | | | Retails | 42.53 | 1.31 | 98.69 | 2.73 |
| | | | | | | | Textile | 26.90 | 12.26 | 87.74 | 0.36 |
| | | | | | | | Wood & Furniture | 45.97 | 6.19 | 93.81 | 0.10 |

### *7.6. Comparison of the Estimates from Different Methods*

Table 9 presents the results from the three outage cost estimation techniques. As expected, the results from the marginal cost method are significantly lower than the estimates from the other two techniques. This is because the marginal cost technique does not account for outage losses due to the inadequate backup capacity. That is, the marginal cost method only estimates the portion of an outage cost that a firm is able to mitigate by investing in backup generation. Similarly, the results from the subjective evaluation method are higher than those from the incomplete backup estimation technique. Subjective evaluation estimates are based on the reported outage losses by firms which might lead to biased results. Bias might occur because firms might overstate their reported outage losses to impress the regulators or the policymakers that they are seriously suffering from power outages. They might do that to evade taxes by declaring high outage losses and low profits. Therefore, estimates from the incomplete backup method are more reliable because the method accounts for unmitigated outage costs, and it is also based on the revealed preferences rather than subjective estimates.

Table 9: Estimated Outage Costs (US$) per kWh from the Three Different Techniques, 2007 Prices

| Country | Estimated total outage cost ($) per kWh | | | Unmitigated outage costs ($) per kWh | |
|---|---|---|---|---|---|
| | Marginal cost method | Incomplete Backup | Subjective evaluations | Incomplete backup | Subjective evaluations |
| Algeria | 0.16 | 1.23 | 3.44 | 0.57 | 2.78 |
| Egypt | 0.30 | 0.81 | 3.35 | 0.37 | 2.91 |
| Gambia | 0.44 | 2.33 | 4.12 | 1.31 | 3.10 |
| Ghana | 0.46 | 0.97 | 3.48 | 0.49 | 3.00 |
| Kenya | 0.36 | 1.80 | 4.19 | 0.93 | 3.32 |
| Mali | 0.56 | 0.79 | 3.17 | 0.40 | 2.78 |
| Morocco | 0.56 | 0.84 | 3.48 | 0.43 | 3.07 |
| Mozambique | 0.57 | 0.60 | 3.14 | 0.38 | 2.92 |
| Nigeria | 0.48 | 3.32 | 4.00 | 2.39 | 3.07 |
| Senegal | 0.57 | 1.90 | 3.94 | 0.99 | 3.03 |
| South Africa | 0.54 | 0.83 | 3.37 | 0.43 | 2.97 |
| Zambia | 0.58 | 0.62 | 2.96 | 0.39 | 2.96 |

Table 10 reports the estimated unmitigated cost per kWh across the various sectors of the economy based on both the incomplete backup and subjective evaluation methods. Based on the incomplete backup method, the estimates show that Information Technology and Machine & Equipment sectors incur more unmitigated cost per kWh due to power outage than others despite having high demand for backup. This reflects the inefficiency of autogeneration by firms due to small backup capacity. Although Infromation Technology firms have a higher tendency to run backup generation, for instance, none of them runs a complete (100%) backup capacity. Based on the subjective evaluation, however, construction firms are the most hit by poor power supply. Overall, the estimates from the subjective evaluation are substantially higher than those form the incomplete backup method. This further confirms the possibility that firms might not be able to accurately estimate the losses they suffer from power outages, or they might deliberately overstate their reported outage losses either to use it as an excuse to increase their product prices or to register their discontent with the utility providers.

Table 10: Estimates of Unmitigated Cost per kWh Across Sectors, 2007 US$ Prices

| Sector | Incomplete backup | Subjective evaluation | Sector | Incomplete backup | Subjective evaluation |
|---|---|---|---|---|---|
| Chemicals | 0.57 | 3.09 | Other Retails | 0.45 | 2.82 |
| Construction | 1.10 | 4.19 | Plastics | 0.56 | 3.04 |
| Electronics | 0.78 | 3.10 | Retails | 2.73 | 2.80 |
| Fabrications | 0.33 | 2.93 | Textile | 0.36 | 2.97 |
| Food | 0.88 | 3.01 | Wood & Furniture | 0.10 | 3.04 |
| Garments | 0.55 | 2.92 | | | |
| Information Technology | 3.67 | - | | | |
| Machine & Equipments | 2.22 | 2.95 | | | |
| Metal | 0.96 | 3.06 | | | |
| Non-Metal | 0.57 | 2.98 | | | |
| Other Manufacturing | 0.77 | 2.98 | | | |

### *7.7. Outage Costs and the Public Grid Tariffs under Cost-Reflective Scenarios*

Here, we turn to the third hypothesis that *firms would incur outage cost higher than the cost (price) of electricity from the public grid even when prices are cost-reflective; thus, it is irrational for firms to generate own electricity even under a cost-reflective tariff regime*. Using the data on the true costs of provision sourced from the Africa Infrastructure Country Diagnostic (AICD) online database[21] and the estimated outage cost per kWh from the incomplete backup method, we test that the cost of own generation is higher than the true cost of buying a kWh from the national grid. The results show that the outage cost (used as the proxy for own generation cost) per kWh is significantly higher than the true cost of provision from the national grid (Table 11). That is, the cost of mitigating a kWh unsupplied is (still) significantly higher than a cost-reflective tariff that is based on the actual provision cost. Therefore, the third hypothesis which states that it is irrational for a firm to generate own electricity even under a cost-reflective tariff because it is more costly cannot be rejected.

Table 11: Difference Between Outage Cost & The True Provision Cost per kWh, in US$ 2007 Prices

| | | | | Difference btw Outage cost & provision cost | | |
|---|---|---|---|---|---|---|
| Country | Outage Cost per | Current tariff rate | True provision cost[a] | per kWh ($) | Per kW | T-test[b] |
| Algeria | 1.23 | 0.06 | n.a | - | - | |
| Egypt | 0.81 | 0.05 | n.a | - | - | |
| Gambia | 2.33 | 0.20 | n.a | - | - | |
| Ghana | 0.97 | 0.11 | 0.12 | 0.85 | 2482 | 30.263*** |
| Kenya | 1.80 | 0.12 | 0.14 | 1.66 | 4841 | 60.054*** |
| Mali | 0.79 | 0.24 | 0.34 | 0.45 | 1314 | 20.176*** |
| Morocco | 0.84 | 0.14 | n.a | - | - | |
| Mozambique | 0.60 | 0.10 | 0.11 | 0.49 | 1431 | 16.631*** |
| Nigeria | 3.32 | 0.05 | 0.10 | 3.22 | 9402 | 10.694*** |
| Senegal | 1.90 | 0.21 | 0.25 | 1.65 | 4818 | 47.769*** |
| South Africa | 0.83 | 0.04 | 0.06 | 0.77 | 2248 | 39.715*** |
| Zambia | 0.62 | 0.03 | 0.07 | 0.55 | 1606 | 20.021*** |

[b] Test of significant difference between outage cost and the true cost of provision. *** indicates significant at 1% level.

[a] True provision costs ($) per kWh (2003-2008) were sourced from: http://www.infrastructureafrica.org/models/canned/

Figure 3 shows the estimated costs of power outage per kWh based on the incomplete backup method, the current prices of electricity from the public grid and the true costs of provision. In most countries, the price of the electricity from the public utilities is so low that the cost of outage is as high as 6 to 66 times the public tariff. Even in Mali where the current tariff is the highest, the cost of unsupplied kWh is about 3 times the currently operating tariff.

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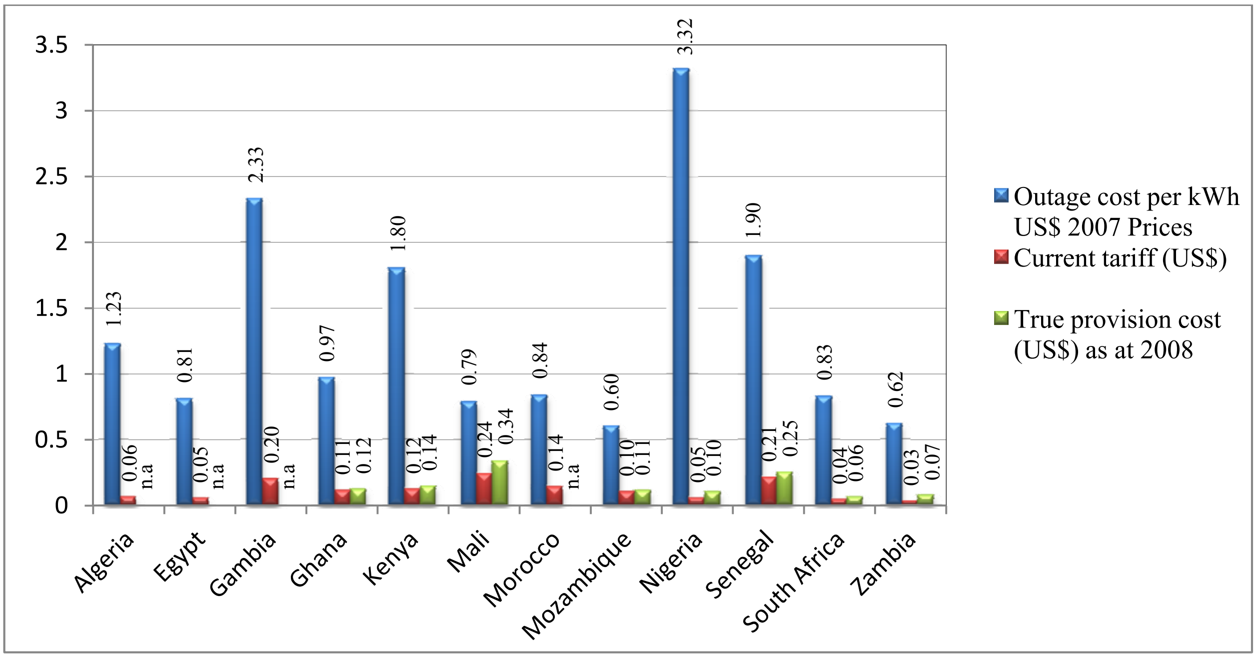
[21] see http://www.infrastructureafrica.org/models/canned/

The currently operating heavily subsidised tariffs in most African countries have been one of the reasons for the low installed and generating capacity that results in frequent power outages in the continent. Installed and generating capacity has been very low because many Independent Power Producers have refused to enter the market claiming that the tariff rates do not guarantee their returns. However, given that own generation costs (outage costs) are significantly higher than the provision costs, it suggests that the utility regulators should raise the currently operating industrial tariffs to reflect the true generating and supply costs. This will encourage the private investors to invest in the power sector and therefore reduces the problem of inadequate electricity supply faced in the continent.

Figure 3: Cost of Power Outage, Current Tariff and Cost-Reflective Tariffs in US$ per kWh



Note: n.a – indicates data not available

## 8. Summary and Conclusion

Several studies have demonstrated that firms possessing certain characteristics are more likely to demand backup (i.e., invest in own generation) when facing an unreliable electricity supply. What is less known, however, is whether those firms suffer lesser or higher unmitigated outage losses (costs) compared to firms without those characteristics. This study examined whether larger firms, firms engaging in exports (i.e., holding ISO certificate), and those using the Internet for operation suffer lesser unmitigated outage losses because they were able to invest in auto-generation. The study has extended the existing literature on costs of power outage estimation in several ways. First, it re-examined how firms' characteristics might influence the decision on own generation, and how that might affect outage costs. Second, we extended the analysis to examine whether electricity from the public grid is cheaper for the consumers (firms) than self generation when a cost-reflective pricing system is allowed. Lastly, we combined three different methods to compute the costs of power outages in order to make a comparative analysis.

We found that though firms possessing certain characteristics have a higher tendency to invest in auto-generation, they still suffer higher unmitigated outage losses (costs) compared to firms that do not possess those characteristics. For instance, although larger firms are more likely to invest in backup, they still suffer higher unmitigated outage costs compared to smaller firms despite having a higher propensity of investing in auto-generation. Similarly, firms holding the International Standard Organisation (ISO) certificates and those using the Internet for their operations suffer more outage losses despite having a higher tendency to invest in backup generator. This is due to less backup capacity often run by most of those firms.

The results from the three estimation techniques also showed that the cost of an unsupplied kWh of electricity is significantly higher than the cost of electricity from the public grid. In comparison, the estimates based on the incomplete backup method and those based on subjective evaluations are significantly higher than the estimates obtained from the marginal cost method. This suggests that the past studies on Africa, whose estimated outage costs had been obtained without allowing for additional losses due to incomplete backup, have underestimated the costs of unserved energy. Steinbuks and Foster (2010), using the marginal cost method of revealed preference approach, estimate the outage costs between \$0.13 and \$0.76 (2007 prices) per kWh for African firms for surveys of complete firm subsectors. Using a revealed preference method, that accounts for incomplete backup, our estimates range between \$0.60 and \$3.32 per kWh at 2007 prices. For all the countries reported in their studies which also feature in the present study, the previously estimated outage costs reported in their paper are significantly lower than ours.

Lastly, we found that the cost of mitigating a kWh of electricity (measured by outage cost per kWh) is significantly higher than a cost-reflective tariff, suggesting that firms can still benefit substantially from a cost-reflective tariff that ensures reliability.

A number of conclusions that inform thinking about energy policy can be drawn from the analyses conducted in this study. The estimated costs of unsupplied electricity show that power outages impose substantial costs on the economy. For instance, after adjusting for a cost-reflective tariff, an average firm in Africa incurs a net outage cost of between US\$1,314 and \$9,402 per kW annually. This amount is substantial enough for some firms to expand their scope of operation and increase employment opportunities. This suggests that a stable electricity supply may have strong impact in reducing poverty and promoting economic activities. Apart from the loss of jobs related to poor power supply, another cost that was not properly captured in the above analysis is environmental and health problem (cost) due to self generation. The use of diesel generators by firms results in noise pollution and environmental hazards through carbon emissions. Considering the impacts of these on global warming and health, governments need to find a way of solving the problems posed by poor electricity supply in the continent.

Since the cost of power outage to consumers (firms) is still higher than the expected cost-reflective tariff, the government should be more committed to its reform policy and should embark on the removal of subsidy on industrial and commercial electricity tariffs to encourage the private investors' participation in the industry. This will solve the problem of inadequate generating capacity and also reduce the capacity constraints posed to firms by poor power supply. The reduction in capacity constraints would likely increase employment opportunities in the private sector. Moreover, the withdrawal of subsidy on the electricity tariff would reduce energy waste and encourage energy efficiency among users. Also, government can use the amount realised from subsidy removal to finance other important projects. One way forward is that the government may gradually increase supply to the private sector at cost-reflective rates, while retaining supply to other consumers at the current tariff. This will reduce the shocks and mass protests that a sudden removal of the overall subsidy across consumers may attract.

This study is not without its limitation however. The conversion of the reported electricity expenditure by firms to obtain their corresponding electricity demand may not be perfect. Given that some countries operate different pricing systems, such as two-part pricing where a fixed amount is first charged to consumers before the evaluation of the cost of electricity consumed per kWh. The use of price to divide the expenditure to obtain electricity consumption in such a case may not be accurate. However, such an effect is assumed to be insignificant because such fixed charges are usually small.

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