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Article

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Journal of Applied Economics

Provided in Cooperation with:
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Suggested Citation: Entele, Birku Reta; Ayalew, Shibiru (2024) : The cost of electricity interruption for manufacturing firms in Ethiopia: Valuing outage by applying stated preference approach, Journal of Applied Economics, ISSN 1667-6726, Taylor & Francis, Abingdon, Vol. 27, Iss. 1, pp. 1-22, https://doi.org/10.1080/15140326.2024.2394715

This Version is available at:
https://hdl.handle.net/10419/314289

Journal of Applied Economics

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/recs20

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To cite this article: Birku Reta Entele & Shibiru Ayalew (2024) The cost of electricity interruption for manufacturing firms in Ethiopia: valuing outage by applying stated preference approach, Journal of Applied Economics, 27:1, 2394715, DOI: 10.1080/15140326.2024.2394715

To link to this article: https://doi.org/10.1080/15140326.2024.2394715

Published online: 26 Aug 2024.

JOURNAL OF APPLIED ECONOMICS
2024, VOL. 27, NO. 1, 2394715
https://doi.org/10.1080/15140326.2024.2394715

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RESEARCH ARTICLE

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The cost of electricity interruption for manufacturing firms in Ethiopia: valuing outage by applying stated preference approach

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ABSTRACT

In sub-Saharan African countries, firms are suffering from frequent, long-lasting and random power outage, which makes planning and production activities difficult. Thus, understanding a firm's cost associated with unreliable power supply is crucial for policymakers and potential investors in the energy sector. To this end, we estimated the economic cost of power interruption to manufacturing firms in selected cities of Oromia Regional State in Ethiopia using a mixed logit model. We collected data from a sample of 600 manufacturing firms. The result shows that a firm's average cost of power interruption is equivalent to ETB 51,777 (~US$976) per month, which corresponds to a nine-fold of their current monthly electricity bill. In addition, the interruption costs amount to 2.22% of a firm's gross monthly revenue. Moreover, we observed a considerable variation in our results, which be partly attributed to company size and type of industry where a company belongs to.

ARTICLE HISTORY
Received 6 August 2023
Accepted 14 August 2024

KEYWORDS
Economic cost; power interruption; manufacturing firms; Ethiopia

1. Introduction

1.1. Background

The accessibility and dependability of electricity services is essential for economic growth, as electricity is an engine of social and economic transformation. Without access to energy services, no nation has advanced beyond a subsistence economy (Kaygusuz, 2011). Energy is necessary for the operation of large industrial machines and promotes the productivity of human capital by supplying electricity to schools, hospitals and modern communication technology. Chronically poor electricity supply is one of the biggest challenges facing businesses in Africa because of its importance to economic development and social well-being (Bos et al., 2018).

Unreliable electricity poses a significant challenge for businesses in Africa. A staggering 78% of African businesses encounter power outages annually, with 41% citing electricity as a major hindrance to their operations – the highest percentage

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globally. On average, African businesses endure over 50 h of power outages per month, resulting in 25 days of lost productivity each year. This surpasses the outage rates of any other continent (Oseni, 2019).

The economic impact of power outages on businesses in developing countries is substantial, primarily due to the increased frequency and duration of these outages. The costs associated with power failures can be categorized as opportunity costs, indirect costs, and direct costs. For example, the opportunity cost to firms of blackouts is that, in addition to the effect of underutilization of capacity, African firms lose about 5% of their annual sales value due to blackouts (Amoah et al., 2019). Projected outage costs range from $2 to $32/kWh depending on firms' vulnerability to blackouts, and estimated direct costs, including estimated backup (self-generation) costs in Africa, are $0. 7/kWh, which is about four times higher when costs are reflected in grid electricity tariffs in countries such as Nigeria ($0.15/kWh) and Uganda ($0.17/kWh) (Oseni, 2019). Ethiopian is not an exception.

Among Ethiopian firms, interruptions resulted in an average loss of about 57 h of economic activity per month. The estimated annual sales loss for the average Ethiopian firms was about 11.4 percent[1] (Ramachandran et al., 2018). Allcott et al. (2016) reported that power shortage reduced the average output of Indian manufacturing firms by about 5 percent. However, the impact on productivity was minimal because most of the inputs could be saved during the downtime. Fisher-Vanden et al. (2015) state that the increase in electricity shortages increased the unit costs of production for Chinese firms by approximately 8 percent. To mitigate the negative effects of power outages, firms in developing countries have used various strategies, such as more flexible production and better storage capacity. One obvious strategy is to invest in backup power generation equipment such as diesel generators. Backup diesel generators are expensive, and it is estimated that in sub-Saharan Africa, self-produced electricity costs three to ten times more than electricity purchased from the grid (Eifert et al., 2008; Foster & Steinbuks, 2009). Even if a firm uses a generator, it still suffers from loss of production because it takes a lot of time and cost to restart the machines after an outage, and self-generated power may not be enough to produce at full capacity (Beenstock, 1991). Research conducted by Ramachandran et al. (2018) indicates that nearly half of the firms in Ethiopia possess generators. These firms have reported experiencing both financial benefits and environmental costs as a result. Diesel generators also have a negative impact on air quality and noise levels. In addition, a backup generator requires a large initial investment cost at the time of purchase, because it is difficult, if not impossible, to obtain a loan for this type of investment in most sub-Saharan countries. Investing in a backup generator is therefore very likely to be suboptimal, as it uses funds that could have been allocated to increase production capacity (Reinikka & Svensson, 2002).

Long-term and sustainable solutions to enhance the country's electricity supply security include investing in generation and distribution capacities and as well as implementing a more flexible pricing model, such as peak load pricing. In fact, under-pricing is one of the main causes of acute shortage of generation capacity in Africa (Collier & Venables, 2012). Long-term electricity security strategies are particularly important in developing countries, where power outages are common and demand is

[1]https://www.enterprisesurveys.org/en/data/exploretopics/infrastructure#sub-saharan-africa–7

constantly increasing. Large infrastructure programs such as grid improvement and modernization require large investment costs and are generally beyond the reach of utilities in sub-Saharan Africa. One way to gradually finance investments is to increase the electricity tariff. This is because energy companies in sub-Saharan Africa are mostly state-owned and choose to keep tariffs very low to appease their urban constituency. The current low electricity rates make the expensive investment required to improve supply economically unfeasible (Collier & Venables, 2012). For example, in Ethiopia the domestic electricity tariff was 0.01 USD/kwh, while in Germany, it was 0.37 USD/kwh and in Nigeria it was 0.06 USD n 2020. In industry, the global average price of electricity was $0.123 per kWh, while in Ethiopia it was $0.023 per kWh, indicating a lower tariff.[2] Implementing a rate increase to finance investments can be a challenging task, as the increase must occur before investments are made. Therefore, it is imperative to assess the willingness of customers to pay for these improvements.

This study examines the willingness of small, medium and large manufacturing firms to pay to improve the reliability of electricity supply. Because we focus on the value of improvements that lead to levels of reliability that currently do not exist, we use a stated preference method: the choice experiment. Most studies to date have used a revealed preference approach, where indirect inferences about costs are made based on firms' actual avoidance costs, such as those spent on backup generators. However, in many developing countries, firms' expenditures on equipment to cope with outages (such as backup generators) can be limited by credit market imperfections, which increases the need to complement revealed preference approaches with stated preference. In Ethiopia, several studies have been conducted to analyze the impact of power outages on various sectors. Abdisa (2018) focused on estimating the cost of power outage using revealed approach, via measuring the cost of power backup to self-generate electricity in response to power outages. Meles (2020) estimated the impact of power outages on households in urban Ethiopia, while Hassen and Degu (2019) examined the effect of Power Outages on Micro and Small Enterprise productivity in urban Ethiopia firms. Carlsson et al. (2020) investigated the cost of power outages for micro, small and medium- sized enterprises in Addis Ababa using a stated preference approach. However, the findings of these studies may not be applicable to the entire Ethiopian context, as they were limited to Addis Ababa's SMEs. There has been a lack of empirical research on the impact of power outage on small, medium and large-sized manufacturing enterprises outside the capital city of Ethiopia. This study aims to fill this gap by examining the effects of power outages on small, medium and large manufacturing enterprises outside Addis Ababa (the capital) and who are facing different power supply situations. We expect that firms operating out of the capital city do have severe power outage and prolonged power outages, significantly affecting their operations. Therefore, this study seeks to answer the following research questions: (1) what are the economic costs of power interruptions for manufacturing firms in Ethiopia? (2) To what extent do power interruptions affect firm performance? (3) What is the average marginal willingness to pay to avoid power interruptions? (4) Is there any difference in marginal willingness to pay (MWTP) to avoid costs of power outages between small, medium, and large-sized enterprises?

[2]https://www.statista.com/statistics/263492/electricity-prices-in-selected-countries/

The remaining part of the study is organized as follows. Section two will focus on the methodology of the study, which will include theoretical model, survey design and elicitation methods, sampling and sample size, and model estimation methods. Section three will delve into the results and discussions of the study. Finally, section four will draw conclusions and policy implications based on the identified results and findings.

2. Methodology

2.1. Choice experiment study

There are different approaches of studying economic loss of power outages by different scholars/authors (Abdisa, 2018; Carlsson et al., 2020; Hassen & Degu, 2019). The choice of the approach depends on whether revealed data are available or not. If the power interruptions and associated variables data are available (revealed) in the market, it could be possible to estimate the cost of power outages to firms using computable general equilibrium model (CGE), input-output model (I-O) or other ordinary econometrics model (Fisher-Vanden et al., 2015). However, in this study, we used the stated preference approach due to its superiority in bringing in data that may not be available in the market. Both the choice experiments (e.g., Carlsson & Martinsson, 2008; Ozbafli & Jenkins, 2016) and contingent valuation methods (e.g., Carlsson & Martinsson, 2007; Moeltner & Layton, 2002) are stated preference methods used to investigate the willingness to pay for improvements in the reliability of electricity supply (Carlsson et al., 2020). In this study, we used the choice experiment method that allows firms to measure their preferences in hypothetical situations using a stated choice survey (Green & Srinivasan, 1990; Louviere et al., 2000). Stated preference data is usually much richer than revealed preference data and thus open opportunities to increase the behavioral capability of a mixed logit model in situations where there is little or no market data information (Carlsson & Martinsson, 2008; Hensher et al., 2005; Ozbafli & Jenkins, 2016; Shin et al., 2014). The questionnaire we used consisted of three parts: (i) general information about the firms, (ii) detailed questions related to the companies, and (iii) the choice experiment. The final questionnaire was developed following multiple focus group studies, which were then followed by a pilot study involving 25 companies. We employed stratified random sampling technique based on industry sector and firm size as criteria to ensure a representative sample that accurately reflects the diversity within the population of interest. Industries included in the survey were categorized in to the food and beverage industry, textile and garment industry, leather product industry, metalwork industry, wood and furniture industry. These industries were treated as strata. Within each stratum, firms of different sizes (small, medium and large) were included in the sample. We sampled small, medium and large manufacturing companies located in Galan, Dukem, Bishoftu, Adama and Shashemene industrial areas. After carefully select 600 companies at random from a pool of over 18,000 registered companies provided by the Oromia Industry and Investment Bureau, we identified the owners or managers of these companies as ideal respondents for our survey. These individuals play a critical role in making decisions regarding investments in production capacity, where the choice of energy sources is of utmost importance.

In the introductory part of the choice experiment, we presented a general overview of power interruptions and discussed various strategies to mitigate them. These strategies included building new dams, upgrading grid networks, improving existing transmission and distribution lines, and improving customer service in the event of technical failures. This was followed by a description of the scenario Table A1 (see Appendix 1). The scenario focuses on a firm's willingness to pay for reducing power outages, considering whether the service provider, which could be the incumbent Ethiopian Electric Utility or potential entrant operator in the form of private or public private partnership, can improve reliability through strategic investments. The main effect of these investments would be to reduce the frequency, duration and time of a firm's power outages. Each respondent was asked to choose the most preferred option among five different choice set. Each set of choice includes the status quo, i.e., the current situation, and four alternatives with improvements in terms of duration, frequency, downtime and ownership of electricity supply. The attribute ownership of power operator is introduced in the choice set with the goal of measuring the firms' attitude and trust towards the incumbent operator (government owned) with regard to electricity service improvement compared to other potential operators (private or public-private partnership) in a hypothetical situation. The trade-off for the firms would be a reduction in these four parameters (duration, frequency, downtime, and ownership) and increased electricity prices. In addition, to facilitate understanding, we also presented an example of a choice set to the respondents after we had read the scenario Table A1 (see Appendix 1). The current situation (the status quo) is obtained from the World Bank Business Survey (WBES) of 2015 for Ethiopia.[3] The fourth column of Table 1 shows the current situation during a typical month consisting of 11 outages, each lasting an average of 5 hours, with an electricity price of 0.67 Ethiopian Birr (ETB) per kWh, with random outage timing and state-owned operator. The attribute levels in the third column show the frequency and duration of blackouts after improvements. Considering five attributes; three attributes

Table 1. Attributes and levels in the choice experiment.

Attributes	Description	Levels	Current situation
Frequency	Frequency of interruptions per month	5, 7, 9, 10	11
Duration	Duration of a typical interruptions in hours	1, 2, 3, 4	5
Time of outage	The time of occurrence of the outage. Day time refers to (6 AM-6 PM) and Nighttime refers to (6:01 PM-5:59 AM)	Daytime Nighttime	Randomly
Power supplier	Entity who supplies and distribute power services to manufacturing firms due to perceived differences in efficiency and customer handling	Government Private Public private partner	Government
Cost (birr/kWh)	Cost of electricity per kWh	0.8, 0.94, 1.08, 1.22	0.67

[3]Ethiopia uses a growing block price strategy for utilities. There are 7 different blocks. The lowest block covers the consumption level from 0 kWh to 50 kWh monthly at a price of ETB 0.27 per kWh. The highest block includes the consumption level above 500 kWh per month at a price of ETB 0.6943 per kWh. Given that most of the companies consume above 500 kWh monthly, the average price at present is ETB 0.67 per kWh. The average wage of a daily industrial worker in out of Addis Ababa was around 200 ETB in the survey period. https://www.nationsencyclopedia.com/WorldStats/ESI-average-duration-power-outages.html

with four levels and one attribute with three levels and one attribute with two levels, the total choice set for an experiment becomes 384; and we used a fractional factorial design to an orthogonal array of hypothetical power supply package.[4] A fractional factorial design is a type of design in a choice experiment that allows practitioners to generate a subset of all possible combinations. There are different types of fractional factorial designs that can be used in constructing discrete choice experiment such as random design, orthogonal design and efficient design. A random design involves selecting a subset of items from a full set without any specific pattern, while an orthogonal design involves selecting a subset where the levels of attributes are not related to each other and the initial parameters are set to zero. The third fractional factorial design is a highly efficient design that involves choosing a subset in a way that maximizes information while also considering prior parameters. Recent studies have demonstrated that practitioners are increasingly utilizing efficient designs that require prior parameters. However, orthogonal and near-orthogonal designs, which are only D-optimal when prior parameters are zero and all alternatives have equal probabilities of being chosen, remain prevalent in choice experiment studies. This is due to the unavailability of these priors in most cases (Bliemer & Rose, 2010). Thus for this study we used an orthogonal fractional factorial design. Using this method, the study ensures maximum efficiency in designing the experiment such as encompassing the principles of level balance, orthogonality, minimal overlap, and utility balance. Lastly, the array is reduced to 16 choice sets and randomly blocked into five choice sets with four alternative services in each set, including the status quo (Table 1).

The structured conjoint survey was administered from January to March 2021. In order to ensure the accuracy of the data, a structured interview method was conducted to the systematically selected respondents, since some of the respondents might not be convenient in understanding the choice scenarios. To make it easier for respondents to choose, we gave them a card showing each choice set Table A1 (see Appendix 1) and we have assisted to clarify things based on their request.

2.2. Sampling and sample size

With regard to sampling and sample size, we used stratified random sampling technique based on industry sector and firm size as criteria. Industries considered in the survey were categorized into food and beverage industry, textile and garment industry, leather product industry, metalwork industry, wood and furniture industry. Within each

Table 2. Sample distribution by sector and firm size.

Sector	Number of registered industries	Small firms (27.2 %)	Medium (40%)	Large (32.8%)	Total sample (3.33%)
Food &Beverage	7200	65	96	79	240
Textile &garment	2400	22	32	26	80
Leather & Leather products	3600	32	48	40	120
Metal & Metal products	2400	22	32	26	80
Wood& furniture	2400	22	32	26	80
Total	18,000	163	240	197	600

[4]A fractional factorial design contains a sub-set of all combinations of levels of attributes.

stratum, firms of different sizes (small, medium and large) were considered in the sample. The size of the firms is based on the number of permanent full-time workers reported and defined as small (5 to 20 employees), medium (21 to 100 employees), and large (more than 100 employees). Accordingly, 163 small, 240 medium and 197 large-sized manufacturing firms were considered in the sample (Table 2).

A total of 600 firms were surveyed from January to March 2021.

2.3. Theoretical models

The random utility theory (McFadden, 1974) is used as a theoretical basis for studying consumer preferences using discrete choice methods. The model assumes that respondents choose their preferred alternatives based on the greatest utility or benefit they perceive. Thus, this study assumes that each consumer/firm perceives the utility associated with each attribute of the options of improved power supply services and selects the one with the highest possible utility.

In the random utility model, the linear utility function is divided into a deterministic component and a stochastic part as follows:

$$U_{nj} = V_{nj} + \varepsilon_{nj} \tag{1}$$

where the subscript n means the nth consumer/firms and j means the jth alternative of the choice situation. U_{nj} is the utility obtained from alternative j by the nth consumer. V represents deterministic utility, while ε represents unobservable utility, which capture excluded factors that may affect the utility of an alternative in V_{nj} and factors that are intrinsically unobservable (Ben-Akiva et al., 1985). In fact, there are various models, such as the generalized multinomial logit (Fiebig et al., 2010), which can capture scale heterogeneity; however, in this study, in addition to capturing coefficient heterogeneity, we also used the mixed logit model due to the simplicity and computational efficiency of its estimation.

2.4. Mixed logit model

Mixed logit is a highly adaptable model that allows for unobserved heterogeneity in estimates, in any random utility model and is commonly used in modeling to enhance power reliability using the stated preference method (Carlsson et al., 2010; Hensher et al., 2005). A mixed logit model divides the unobserved factors into two additional parts:$(\varepsilon_n = \eta_n + \delta_n)$: the stochastic part (η_n) which is correlated over alternatives and heteroscedastic over consumers and alternatives and stochastic part (δ_n), which is IID over alternatives and consumers (Train, 2009). We used simulated maximum likelihood using 500 Halton plots to estimate the model. In the estimates, we used a triangular distribution for the random parameters of all attributes, so that the upper end point is zero and the lower end point is twice of the mean (Hensher & Greene, 2003).[5] This constraint ensures that the cost, duration, and frequency attributes have a negative sign, meaning that increasing any attribute results in disutility. We also investigated the log-

[5]If the distribution is assumed normal, then the subject can have positive and negative utility effects from increasing any attribute, which is not desirable and improbable.

normal distribution as a way to limit the sign of the coefficients, but as is often observed in the literature, we have problems with the convergence of the distribution and fat tails. Thus, the utility of consumer/firm n from choosing option j can be defined as:

$$U_{nj} = X_{nj}\beta_n + \varepsilon_{nj} \tag{2}$$

If an unknown parameter β_n consisting of a vector of coefficients of explanatory variables X_{nj} allows variation across consumers in the tests. To allow the coefficients to vary with respect to consumers in the population, β_n is assumed to have density $f(\beta)$. The choice probability with regard to the random coefficient framework is:

$$P_{nj} = \int L_{nj}(\beta) f(\beta) d\beta \tag{3}$$

Where, $f(\beta)$ is the density function and $L_{nj}(\beta)$ is the logit choice probability at parametersβ:

$$L_{nj}(\beta) = \frac{e^{V_{nj}(\beta)}}{\sum_{k=1}^{K} e^{V_{nk}(\beta)}}$$

$V_{nj}(\beta)$, is the observed part of the utility. If utility is linear in β,$V_{nj}(\beta)$ becomes $\beta' X_{nj}$ and the choice probability takes the form of (Train, 2009);

$$P_{nj} = \int \left(\frac{e^{\beta\prime X_{nj}}}{\sum_{k=1}^{K} e^{\beta\prime X_{nk}}} \right) f(\beta) d\beta \tag{4}$$

The analysis is based on the assumption that the respondent weighs all the features and alternatives and then chooses the best option from the set of options. However, research shows that respondents often use heuristics to make decisions and may not even consider all the features (e.g., Carlsson et al., 2010; Hensher et al., 2005; Scarpa et al., 2009), often referred to as attributes absence. This could be due to a number of reasons, such as unwillingness to pay for the planned improvements, reducing the weight of certain attributes or simply cognitive fatigue. Regardless of the reason, previous research has shown that if respondents do not consider these attributes when making a decision, it can lead to biased estimates. There are several ways to approach this, and here we used responses to a follow-up question that asked people to specifically indicate how much they considered each attribute when making their choices. For each attribute in which the respondent did not participate, we bound the coefficient of that attribute and the respondent to zero when estimating the model (Carlsson et al., 2010). We then estimated the marginal willingness to pay for the two attributes based on the coefficient estimates, which are calculated as the ratio of the attribute coefficient to the price coefficient.

There is a large literature that compares the mixed logit model with other discrete choice models, applying them to empirical studies in various fields. However, some studies argue that the choice of a model depends on the contextual situation of the researcher. For example, if a researcher is interested in revealing the heterogeneity of individual firms to determine the preferences of decision makers, a mixed logic model is preferred (Hensher & Greene, 2003; Train, 2009).

Table 3. Descriptive statistics ($N = 600$).

Variables	Minimum	Maximum	Mean	Std. Dev.
Firm characteristics				
Firm's age in years	2.00	20.00	7.13	3.93215
Number of working hrs. within a day	8	10	8.27	.680
Male employee size	2	146	75	59.891
Female employee size	3	187	92	73.090
Firms average monthly sales (in 1,000 ETB)	27	40000	2335.4	1729.23
Firms' average electricity consumption (in kwh per month)1985	850	2500	1185	1023
Firms monthly profit lost due to power outage	2160	126000	4906.3	3854.53
Firms monthly cost due to power outage	21000	588200	350940	272910.8
Owner characteristics				
Age of respondent in years	25	50	44.5	6.64
Gender of respondent (=1 if owner/manager is male)	0	1	.87	.34
Education level at least college diploma (=1 if yes)	0	1	.67	.49
Business experience in in general (years)	10	34	23.7	7.41
Business experience in current business (years)	2	10	6.3	2.30
Trust in the current electric utility providers (0 if low and 10 if high)	4	7	5.7	.94

3. Results and discussions

3.1. Descriptive statistics

In Table 3, we present descriptive statistics about the sampled companies and their owners. We interviewed owners or managers of 600 firms operating in different parts of the Oromia Regional state excluding the capital Addis Ababa. The conjoint survey was conducted through interviews with selected respondents, who were scheduled in advance. As a result, we achieved a 100% response[6] rate.

Within our sample, the average length of time that a firm has been in business is a minimum of 7 years. Additionally, the average number of male employees is 75, while the average number of female employees is 92. The average monthly revenue is 2,335,400 ETB. The average electricity consumption for the sampled enterprises is 1185 kWh per month. In addition, on average firms profit lost due to power outage is 4906.3 birr per month and general cost due to power outage is 350,940 ETB per month. These overheads may include additional downtime costs such as fuel, generator maintenance costs, and labor costs. This figure shows the extent of the impact of a power outage on the potential performance of companies in general. When comparing costs to monthly sales, businesses lose an average of 15.03 percent of monthly sales. The average age of the owners or managers of the firms are 44.5 years, with the majority being men (87%). Approximately 67% of the owners or managers hold at least a college diploma. In our sample, owners and managers have an average of 23.7 years of general business experience and 6.3 years of experience specifically as an owner or manager at the current firm. When asked to rate their confidence in the current utility on a scale from zero (not at all) to 10 (complete confidence), owners or managers reported a fairly average level of confidence, with an average score of 5.7. We have also gathered detailed information about the business firms and electricity blackout experiences (see Table 4).

[6]According to the EEU, the current electricity generation, transmission and distribution costs amount to approximately USD 0.09 per kWh, while the current electricity tariff ranges from USD 0.04 to USD 0.06 per Kwh. Using $ exchange rate of 52.81 birr by 1 USD, we have calculated 1kwh charge equal to 0.09$ or 4.75 ETB.

Table 4. General characteristics of firms and electricity blackout.

Variables	Categories	Frequency and percentage in brackets	Remarks
Respondents	Manager	440 (73.3)	
	Owner	160 (26.7)	
Legal form of firms	Sole	560 (93.3)	
	Plc	40 (6.7)	
Firm size	Small	163(27.2)	
	Medium	240(40)	
	Large	197(32.8)	
Firm's production interrupted due to power outage	Yes	600(100)	
	No	0	
Measure taken to reduce problem of blackout	Backup generator	440 (84.6)	
	Shifting operation time	80 (15.4)	
Did the operation of firm interrupted due to other problems	Yes	560 (93.3)	
	No	40 (6.7)	
Reasons for interruptions	Lack of raw materials	200 (35.7)	
	Lack of foreign currency	160 (28.6)	
	Shortage of water	200 (35.7)	

Among the firms we sampled, about 93.3 percent were sole-proprietor enterprises whereas about 6.7 percent were private limited companies (Plc). All sampled firms have faced production interruptions due to power outage. In order to mitigate these outages about 84.6 percent of firms have bought backup generator[7] whereas about 15.4 percent of

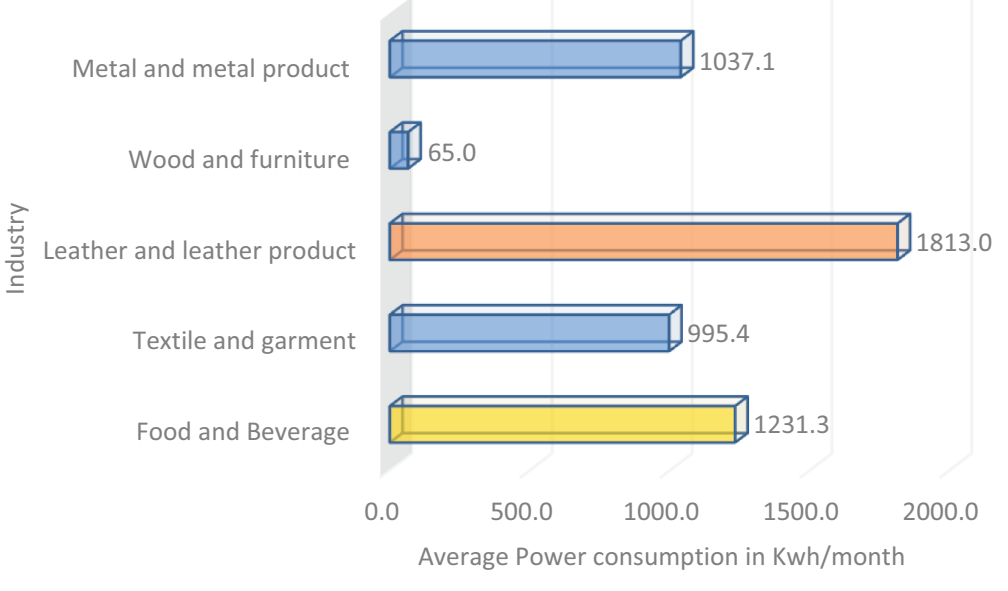

Figure 1. Current power consumption by sector.

[7]Cost of diesel generator to produce a unit of kwh is estimated to be about 3.67 ETB.

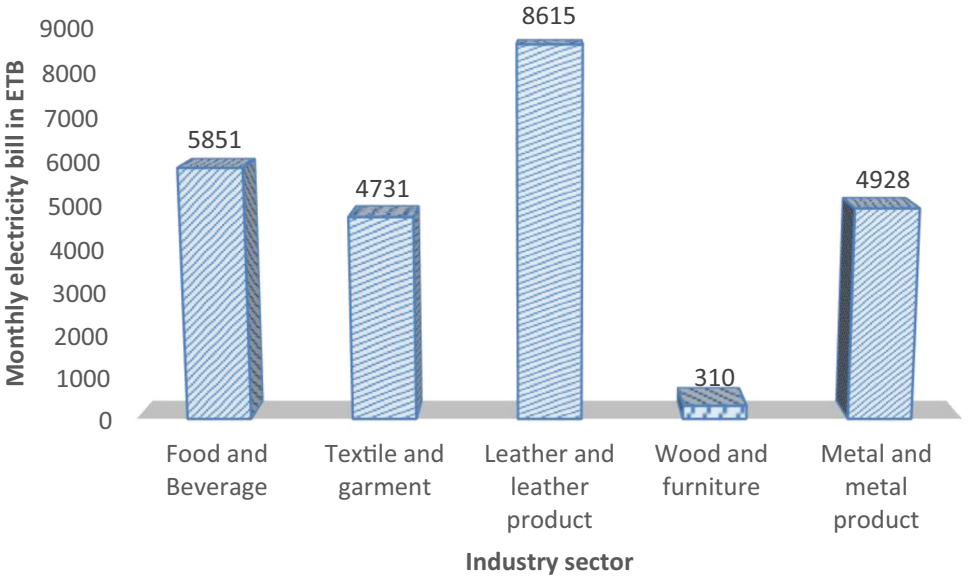

Figure 2. Monthly electricity cost/bill by sector.

Table 5. Effect of power outage on firm performance.

	Average Profit lost due to power outage (ETB/month)	Average Profit lost due to power outage (ETB/year)
Small enterprise	4214.02	50568.28
Medium enterprise	4935.68	59228.14
Large enterprise	5569.20	66830.38

the firms in our sample have been forced to adjust their operation times due to power outage.

Since we have considered different sectors of industries, their level of power consumption and expenditure is heterogeneous. Accordingly, the average power consumption in Kwh per month is depicted in Figure 1 below.

Even though firms are experiencing severe blackout, their current bill expenditure for power consumption varies from sector to sector which directly depends on the amount of power consumption (see Figure 2).

As explained in Table 5, the power outage has a significant effect on firms' performance (on either profit or monthly sales). However, the effect of this power outage may vary depending on the size of the firms. Based on the self-report data, the effect of power outage on firms' profit is summarized as below, see Table 5.

Table 5 illustrates that power outages have a greater impact on large enterprises compared to medium and small-sized enterprises. This disparity may be attributed to the fact that large enterprises have higher power consumption requirements, making it challenging to operate solely on generator backup. As a result, the effects of power outages are more severe for large enterprises than for their smaller counterparts. By the current scenario, a given large enterprise's average profit lost due to power outage is 5,569.20 ETB/month. For medium and small sized enterprises, the average profit lost due

to power outage is 4,935.68 and 4,214.02 ETB/month, respectively. These amounts of profit lost could be improved and regained if the frequency and duration of power outage is improved.

3.2. Econometric analysis

We utilized the Mixed Logit model (MIXL) for our estimation since it was found to provide a better fit to the data using goodness-of-fit criteria such as consistent Akaike information criteria (CAIC), Akaike information criteria (AIC), and log likelihood (LL). Using mixed logit model, the utility of firm n from alternative j can be defined as (Train, 2009);

$$U_{nj} = \beta_{IntFQ} Frequency + \beta_{DUOTGE} Durationotge + \beta_{GOV} Gov'tprovider + \beta_{PPP} PPPprovider + \beta_{DAYTIME} Daytimeotge + \beta_{NIGHTTIME} Nighttimeotge + \beta_{COST} \text{Cost} + \varepsilon_{nj} \quad (5)$$

The estimated result of the Mixed Logit model (MIXL) is shown in Table 6 below.

The result reported in Table 6 shows that the majority of the attributes of power outages remain statistically significant with negative signs. Moreover, almost all the estimated standard deviations of the coefficients are statistically significant, indicating that the model captures unobserved heterogeneity among the respondents. Literally, the result shows that firms prefer less frequent outage, shorter duration of outage, prefer private provider compared to public and public private partner, dislike daytime outage, and prefer to pay less cost for improvement.

With regard to power supplier attribute, we want to value firms' attitude and preference towards providers and check whether power provider ownership matters or not. This is because the level of confidence in the electricity provider might also explain the degrees of WTP for service improvement (Abdullah & Mariel, 2010). Our results show

Table 6. Results of the mixed logit model.

Attributes	Coef.	Std dev.[8]
Frequency	−.572***	.121*
	(.136)	(.059)
Duration	−1.708***	.861***
	(.290)	(.265)
Government provider	−.0773	.778**
	(.274)	(.346)
PPP provider	−1.726***	.003
	(.487)	(.428)
Day Time	−2.025***	.054
	(.605)	(.399)
Night-time	.693	.798**
	(.626)	(.382)
Cost (in ETB/kwh)	−.381**	.322*
	(.161)	(.168)
Log-likelihood	−213.38	
LR chi2(6)	39.81	
Prob > chi2	0.0021	
Observations	600	

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

that firms prefer to get power supply from private operator compared to that of public and public private partner modality. This result reflects their attitudes towards the existing power provider firms (public) related to the imagined private operator had it been in place to provide the services. This is consistent with Townsend (2000), which found that WTPs are lower in those countries where[8] the level of service remains poor even after price increases. Given the chronic nature of outages in Nepal and North Cyprus, most people prefer to invest in coping measures rather than paying more for power service improvement due to the reason that majority of customers have low or very low confidence in their existing electricity provider. These negative attitudes towards the existing service provider and the level of confidence towards the electricity provider need to be considered when appraising the option of power outage service improvement and when considering an increase in tariffs to cover for the investment costs involved.

With regard to time of outage, firms dislike daytime outage significantly taking random blackout as a base. This also seems logical since most of the economic activities are carried out during daytime including labor mobility, transportation, marketing and other services. Because of this, firms do not want to face power interruption during daytime.

The main point of our interest lies in estimating the marginal willingness to pay for the four-outage attributes: frequency, duration, time of outage and provider ownership. The marginal willingness to pay for all attributes is presented in Table 7. Based on the marginal willingness to pay we can convert it to the total cost of interruptions per month. This can be done in such a way that the marginal WTP per month times the existing number of corresponding attribute level[9] in electricity service market gives the total value (cost) of power interruption for firms.[10]

Table 7 shows the marginal willingness to pay and average monthly willingness to pay for each attribute. Companies are willing to pay an average of 1.5 ETB per kilowatt-hour for a unit reduction in the number of monthly outages. This amount corresponds to approximately 223 percent of the current kWh price of electricity. Regarding the

Table 7. Marginal WTP estimates in ETB per kwh/month and total cost of outages (Etb/month).

Attributes	Marginal WTP (ETB per kwh)[9]	Marginal WTP (ETB per month)	Total cost of outages (ETB/month)[10]
MWTP in ETB per kwh			
Frequency	1.50	1777.5	19553
Duration	4.48	5308.8	26544
Government provider	0.20	239.37	239
Public private partnership provider	4.53	5368.05	0
Day time	5.30	6280.5	5006
Evening time	1.81	2144.85	435

[8]The sign of estimated standard deviations is not applicable: assume them to be positive.

[9]Calculated by stata command "*wtp price_kwh $randvars*", following random parameter logit estimation. In order to get Monthly marginal WTP for each attribute, we multiplied marginal WTP coefficient for each attribute by average monthly electricity consumption of the sampled firms (1185 kWh).

[10]Total cost of power outage is then calculated simply by multiplying MWTP estimates for each attribute per month (colomn 3) by existing scenario of corresponding attribute level. Then the column 4 summation give us the total cost of power interruption to firms on average.

duration attributes, companies are willing to pay an average of 4.48 ETB per kilowatt-hour to reduce the average outage by one hour. Compared to the current electricity tariff, it is 668 percent of the price per kilowatt-hour of electricity. Regarding the attribute of downtime, companies are willing to pay an average of 5.30 ETB per kilowatt-hour to reduce a one-unit daytime power outage. In terms of power provider ownership, companies are willing to pay 0.20 ETB/kwh to replace the current state energy provider and 4.53 ETB/kwh to avoid a potential PPP supplier. The later finding seems to be odd but this is due to the fact that the firm's attitude towards fully or partially government owned operators is not preferred to the private provider. We then calculated the marginal WTP of each attribute in ETB per month using the average monthly electricity consumption of the sampled firms (1185 kWh). The results of this analysis are shown in column 3 of Table 7. We also estimated willingness to pay for the total downtime cost per month. To do this, the total amount is added by multiplying the marginal WTP estimate by the total number of power outages, the marginal WTP estimate by the average duration, the marginal WTP estimates for provider ownership by the number of current providers, and the marginal WTP estimates for the time of outage by the average frequency of time of outage per month. This estimate is then multiplied by the average monthly electricity consumption (1185 kWh/month) to get the measure in ETB per month. The total monthly cost of power outage for the average firm is ETB 51,777 ($976).[11] This means a nine fold increase from the current average monthly electricity bill for firms. Outage costs is estimated to be 2.22 percent of a firm's monthly sales.

In short, the marginal willingness to pay (MWTP) and the total cost of power interruption per month to firms is calculated using the following equations.

$$MWTP_{per\ month} = \beta_{each\ attribute\ level} \times Average - electricity - consumtion(1185Kwh/month)$$

$$Total\cos t - of - outage/month = \sum MWTP_{for-each-attribute-coefficient} \times number - of - current\ scenario\ of - each\ out\ age\ attributes$$

This finding is in line with the finding of Carlsson et al. (2020) who have investigated the cost of power outage in the case of Addis Ababa, Ethiopia. However, in the current study, we have considered broader attributes of power outage including time of outage and ownership of provider and the area of the study is also out of the capital where we believe that the problem of power outage is more severe for manufacturing firms. Thus, regardless of the time differences, study area differences and inflation issues, the firms' monthly cost of power outage on average is estimated to be 51,777 ETB/month whereas study by Carlsson et al. (2020) found that the average cost of power outage was 2293 ETB.

3.3. Observed heterogeneity in preferences

So far, we looked at sample means only. As a result, decision-makers have only a limited understanding of how to prioritize energy-sector investments. In fact, it is essential that decision-makers are aware of and understand the potential variation in blackout costs

[11]The summation of each product of marginal WTP coefficient by average monthly consumption of power in kwh (1185 kwh) times the current scenario of outage attributes.

based on the characteristics of the firms. To illustrate this, let us look at two key characteristics of firms: size and sector type. This allowed us to generate different models for different categories of firms.

3.3.1. Firm size

Firm size is one aspect that correlates with outage costs, and this criterion could be important for decision makers when planning investments. For example, small businesses (5–20 employees) may[12] not have sufficient financial resources to invest in backup generators, while[13] medium-sized (21-100 employees) and large (more than 100 employees) firms are more likely to have the financial resources to do so. On the other hand,

Table 8. Results of the mixed logit model for different firm sizes.

	Small enterprises		Medium enterprises		Large enterprises	
	Coef.	Std dev.[12]	Coef.	Std dev.	Coef.	Std dev.
Frequency	−.513*	.002	−.572***	.327*	−.834***	.224 *
	(.271)	(.221)	(.191)	(.178)	(.251)	(.103)
Duration	−1.388**	.741**	−2.017***	.218*	−1.398 ***	.915*
	(.623)	(.279)	(.234)	(.103)	(.381)	(.492)
Govt provider	1.585**	1.486*	−1.299***	.389**	−.628*	.075*
	(.763)	(.789)	(.473)	(.173)	(.360)	(.043)
PPP provider	−.549***	.857	−2.524***	.452	−1.906**	.025
	(.099)	(2.233)	(.621)	(.312)	(.925)	(.538)
Day Time	−2.837*	.027	−1.412**	.435	−1.822*	.005
	(1.720)	(.567)	(.575)	(.556)	(1.009)	(.616)
Night-time	.203	.0009	3.280***	.453	.691*	2.317***
	(1.192)	(.405)	(.623)	(.531)	(.345)	(.882)
Cost (in ETB/kwh)	−.632*	.122*	−.189*	.214 *	−.296*	.256*
	(.328)	(.058)	(.094)	(.109)	(.160)	(.140)
Log-likelihood	−55.88		−126.76		−73.64	
LR chi2(6)	24.99		286.32		34.62	
Prob > chi2	0.0001		0.0000		0.0051	
Observations	163		240		197	

Standard errors in parenthesis. ***, **, *denotes significance at 1%, 5% and 10% levels, respectively.

Table 9. Marginal willingness to pay (MWTP) estimates by firm sizes.

Attributes	Small	Medium	Large
MWTP in ETB per kwh			
Frequency	0.81	0.47	2.82
Duration	2.2	1.61	4.73
Government provider	2.51	1.43	2.12
Public private partnership provider	0.87	0.99	6.45
Day time	4.49	2.39	6.16
Night time	0.32	0.76	2.34
MWTP in ETB per month[13]			
Frequency	807.57	474.82	4122.84
Duration	2193.40	1616.80	6915.26
Government provider	2502.47	1432.88	3099.44
Public private partnership provider	867.39	996.30	9429.90
Day time	4476.53	2402.82	9005.92
Night time	319.04	766.47	3421.08
Total cost of power outage per month in ETB	25985.3	16810.5	90899.18

[12]The indication of estimated standard deviations is not applicable: assume them to be positive.

[13]Average power consumption of small, medium and large manufacturing firms is estimated to be 997, 1004.5, and 1462.5 kwh per month, respectively. We multiplied this average power consumption by each attributes marginal willingness to pay to get MWTP in ETB per month for each attribute.

medium and large firms can be very dependent on electric services, so that even the use of backup generators will not meet their needs during a power outage. In this case, these groups may suffer higher downtime costs than small businesses. The estimated model for the three groups are presented in Table 8 and the corresponding MWTP estimates in Table 9.

The mixed logit result for firm sizes shows that the majority of the attributes of power outages remain statistically significant with negative signs for all firm sizes. Furthermore, almost all the estimated standard deviations of the coefficients are statistically significant, indicating that the model captures unobserved heterogeneity among the respondents. With regard to power provider attribute small firms prefer government provider unlike other medium and large enterprises. This may be related to the attitude towards private vs government provider in terms of trust and price expectation. Small firms may be price sensitive and they cannot afford to invest on alternative power supply so that with all its drawbacks they tend to prefer government provider over the others. With regard to all other attributes, the results seem to be similar and are as expected with regard to sign.

Table 9 shows that small firms have the highest marginal willingness to pay in ETB per kWh for frequency, duration, government owner operator, daytime outage attributes compared to medium-sized enterprises. By the same fashion, the total cost of power outage per month in ETB is highest for small firms (25985.3 birr per month) compared to that of medium-sized enterprises (16810.5 birr per month). This may be due to the reason that small firms may not be able to afford to invest in alternative energy backups while those of medium-sized are able to invest on alternative energy sources. On the other hand, large-sized enterprises do have the highest marginal willingness to pay for all attributes compared to both small and medium-sized enterprises. The average cost of power outage per month for large manufacturing enterprises is 90,899.9 birr per month.

We tested the differences using *t*-statistics. For the duration, frequency, government ownership and daytime outage attributes, the MWTP differences are statistically significant at 5 percent, for all comparison between small, medium and large-sized enterprises. The differences in MWTP for the public private partnership as an operator and nighttime outage attribute are statistically significant only for the difference between medium and large enterprises.

At the bottom of the table, we can see the estimated MWTP per month in Birr for each firm size category. As these figures are calculated by multiplying MWTP birr/kWh by the average monthly power consumption for each group, we see a different trend when comparing the groups. Contrary to the claims of Carlsson et al. (2020), medium-sized companies have the lowest monthly MWTP in Birr and the lowest monthly power outage costs in Birr for all indicators. On the other hand, large companies have the highest MWTP in Birr and the highest monthly downtime costs in Birr across all attributes. These differences in average electricity consumption between groups are the main driver of the pattern observed in the MWTP Birr per months. Therefore, the costs of power outages are substantially higher for larger firms, and relatively lower for medium-sized firms, compared to smaller firms.

3.3.2. Industry sector

The production process and electricity dependence may vary between industries, which in turn affects downtime costs. For this reason, we break down our sample

Table 10. Marginal willingness to pay for attributes by industry sector measured in ETB/kwh.

Attributes	Food and beverage industry	Textile and garment industry	Leather and leather product industry	Wood and furniture industry	Metal and metal product industry
MWTP in ETB per kwh[14]					
Frequency	1.1	0.028	1.31	2.29	7.13
Duration	4.6	3.109	3.3	3.61	11.21
Government provider	.41	3.95	1.85	4.61	14.32
PPP provider	3.18	4.63	.07	8.03	24.93
Day time	2.52	2.25	6.7	3.81	11.83
Night time	2.84	4.21	.24	6.30	19.57
MWTP in ETB per month[15]					
Frequency	1354.41	27.87	2375.03	149.17	7391.01
Duration	5663.92	3094.79	5982.90	234.66	11626.92
Government provider	504.83	3931.94	3354.05	299.66	14847.52
PPP provider	3915.49	4608.83	126.91	521.76	25852.15
Day time	3102.84	2239.71	12147.10	247.66	12271.04
Night time	3496.85	4190.75	435.12	409.61	20295.25
Total cost of power outage per month in ETB by sector	46905.79	22348.23	69163.45	3394.37	168183.16

into five sub-groups based on the classification used by the Central Statistical Office of Ethiopia: food and beverage, textiles and clothing, leather and leather products, metal and metalwork manufacturing product, and wood and furniture industry. The result of the mixed logit model displayed in Table A2 (see Appendix 2), shows that attributes of power outage such as frequency, duration and cost per kWh are statistically significant with negative signs across all industry sectors. Furthermore, most of the estimated standard deviations are statistically significant for the coefficients, suggesting that the model is capturing unobserved heterogeneity within the industry. The marginal willingness to pay (MWTP) is also estimated as depicted in Table 10.

By the same token, we estimated both the marginal willingness to pay in birr per kWh and the marginal willingness to pay in birr per month for each of the industry sectors. Column 6 in the top panel shows that firms in the metal and metal processing sector have the highest MWTP per kWh for all the attributes. For instance, for the firms in the food and beverage sector, the MWTP per kWh corresponds to a 1.1 percent, 4.6 percent, and 2.52 percent increase in the electricity price to reduce the average number of outages from 11 to 10 in a month, to reduce the average duration of an outage from 5 to 4 hours and to reduce a daytime outage once per month, respectively.

The bottom panel of Table 10 shows that MWTP in birr per month for each sector is calculated by multiplying MWTP per kWh by the average monthly power consumption of the sectors. The result shows that the wood and furniture industry sector have the lowest cost of power outage in birr per month followed by textile and food and beverage sectors. On the other side, the metal and metal product industry and the leather and leather processing industry have the highest cost of power outage in birr per month considering all attributes.

[14]Calculated by stata command "*wtp price_kwh $randvars*", similar to Table 9.

[15]The average power consumption in Kwh per month for metal and metal product, wood and furniture, Leather and leather product, Textile and garment and Food and beverage industries, respectively, are 1037.1, 65, 1813, 995.4, 1231.3. We multiplied this average power consumption by each attributes marginal willingness to pay to get MWTP in ETB per month (cost of power outage) for each industry.

4. Conclusion and policy implications

Firms in many developing countries suffer from blackouts, which are characterized by random, frequent and prolonged power outages that make it difficult to plan and execute production operations. Thus, understanding the costs associated with unreliable electricity supply is particularly important for policy makers and new investors planning to invest in the energy sector. In the past, a different approach was used to estimate the costs of power outages for businesses. Most studies to date have used the revealed preference method. However, in many developing countries, firms' expenditure on equipment to cope with outage (such as backup generators) may be limited by credit market imperfections, increasing the need to supplement revealed preference approaches with stated preference. A detailed and in-depth analysis of the subject is lacking in sub-Saharan Africa, and especially in Ethiopia, where unreliable electricity service is one of the most important obstacles to economic growth and industrialization.

This study estimated the economic costs of power outages for manufacturing enterprises in Ethiopia using stated preference approach. The survey covers small, medium and large enterprises, including various industries such as food and beverages, textiles and clothing, leather and leather products, metal and metal products, and wood and furniture. To do this, we performed a choice experiment and estimated using the mixed logit model. The electricity service improvement scenario implemented in our choice experiment included four different components: number of outages experienced per month, average duration of a typical outage, and time of outage per month and ownership type of electricity producer. The study notes that manufacturing companies located outside the capital city incur significant economic costs due to power outages. The average cost of outages for a firm is ETB 51,777 ($976) per month, nine times the current average monthly electricity bill. Downtime costs also account for 2.22 percent of the firms' monthly sales. Our results show considerable heterogeneity by firm size and industry sector.

The obtained results suggest several policy implications that should be considered by relevant authorities. The costs of power outages have been found to be significant and companies are generating their own electricity to deal with power shortages. In addition, firms are willing to pay to avoid disruptions. This shows that there is a market for more reliable energy source, suggesting the investment on more power plants and distribution system (allocation efficiency) to produce reliable electricity. This can be achieved in several ways. One could be to eliminate subsidies and establish optimal tariffs that are cost recovering for new grid investment. Because the electricity tariff rate of Ethiopia is too low (0.01 USD per kWh), compared to other African countries. This can also attract international and private investors to the sector. The government should also introduce policies that encourage the private sector to participate in power generation and distribution.

In addition to building more power plants and distribution system, the government should optimize diversification of source of electricity in order to liberate our industries from rain fed energy sources and improve reliability. So far, 90 percent of Ethiopia electricity generation is from hydro followed by 7.6 percent from wind. In the event of insufficient rainfall, there will be a shortage of electricity, leading to disruptions in production for businesses.

The government may eliminate the electricity interruption by investing on the distribution and monitoring system. This can be done by reforming on the tariff rate, exploring new markets, source diversification and service provision automation. If the blackout must exist for some forced reasons, there should be a blackout schedule and prior notification so that firms can adjust their operation schedules to minimize costs associated with unscheduled/random interruptions. The study presents valuable insights and policy implications for companies dealing with frequent power interruptions. However, it is important to note that the data used in the study was limited to only 600 firms. Therefore, it is recommended that future researchers consider a larger sample size in order to obtain more comprehensive results and implications. This will allow for a more thorough understanding of the issue at hand and provide recommendations that are more robust for firms facing similar challenges.

Acknowledgments

We would like to thank and acknowledge Adama Science and Technology University for supporting this research work.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This work was supported by the Adama Science and Technology University under Grant number 14th cycle of ASTU.

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Data availability statement

Data is available and will be provided based on request.

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Appendix 1: Sample choice/rank card

We ask respondent to make rank or choice among different power supply alternatives. Each alternatives describes the frequency of outages, duration, time of outages and owner of the electricity supply during a typical month, as well as the cost of electricity in Birr per kWh. Rank the alternative options you are most likely to like (first) to least popular, including the status quo.

Table A1. Rank/Choice set 1.

Power Alternatives	Frequency of outage/month	Duration of outage	Time_of _outage	Power supply owner	Price_per_kwh (birr)	Rank/choice (1st, 2nd,3rd,4th)
Alt 1	7 times	1 hour	Daytime	Public private partnership	1.08	
Alt 2	5 times	2 hours	Nighttime	Private	1.22	
Alt 3	9 times	3 hours	Daytime	Government	0.94	
Alt 4	Existing electricity service					

Appendix 2: Estimates by industry sector

Table A2. Mixed logit model for different industry sector.

	Food and beverage industry		Textile and garment industry		Leather and leather product industry		Metal and metal product industry		Wood and furniture industry	
	Coef.	Std dev.	Coef.	Std dev.	Coef.	Std dev.	Coef.	Std dev.	Coef.	Std dev.
Frequency	−.384**	.205*	−.019	.192	−.517*	.002	−.667**	.212	−.677**	.970*
	(.188)	(.098)	(.192)	(.204)	(.277)	(.236)	(.263)	(.203)	(.273)	(.443)
Duration	−1.591***	.555*	−2.086***	1.208*	−1.298***	.691	−1.055***	.228*	−1.065***	.428*
	(.362)	(.295)	(.283)	(.674)	(.461)	(.518)	(.225)	(.112)	(.235)	(.211)
Govt provider	.142	.005	2.653***	.664*	.726	.071	1.370**	.654*	1.360**	.753*
	(.384)	(.715)	(.659)	(.324)	(.529)	(1.431)	(.652)	(.314)	(.642)	(.374)
PPP provider	−1.108	.004	3.108***	.312*	.026	.669	−2.363*	.322*	−2.368*	.319*
	(.707)	(.411)	(.766)	(.163)	(.785)	(.948)	(1.311)	(.153)	(1.308)	(.159)
Day Time	−.877	.016	−1.511***	.621*	−2.634***	.32095	−1.120	.321	−1.124	.221
	(.834)	(.395)	(.503)	(.313)	(.925)	(.864)	(.911)	(.314)	(.909)	(.213)
Night Time	.989	.968*	−2.827***	.934*	.096	.474	1.861*	.635	1.859*	.535*
	(.907)	(.498)	(.672)	(.524)	(.828)	(.422)	(.960)	(.587)	(.957)	(.286)
Cost (ETB/kwh)	−.348**	.287*	−.671***	.716**	−.393*	.235*	−.096*	.626*	−.295*	.426*
	(.129)	(.143)	(.179)	(.289)	(.188)	(.117)	(.343)	(.299)	(.142)	(.199)
Log likelihood	−104.28		−111.58		−45.23		−52.33		−50.33	
LR chi2(6)	52.28		220.45		10.95		82.30		79.30	
Prob > chi2	0.0020		0.0000		0.0073		0.0000		0.0000	
Observations	240		80		120		80		80	