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Research Paper

Self-generation and outage losses: A firm-level analysis for emerging and developing Asian countries

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ABSTRACT

Access to reliable and affordable electricity is critical to economic development in emerging and developing Asia. However, many firms in these regions face challenges in obtaining consistent and affordable electricity from the grid, leading them to invest in self-generation technologies. This paper examines the strategic decision of firms to self-generate electricity and the economic losses incurred during power outages. Using survey data from the World Bank Enterprise Survey (WBES) of 5639 manufacturing firms in seven Asian countries, we identify factors driving the decision to self-generate and assess the impact of self-generation on mitigating economic losses during power outages. An endogenous switching regression model is employed to account for self-selection bias. The results show that firms experiencing more outages and higher electricity costs are more likely to invest in self-generation. Larger, older, and exporting firms also show a higher propensity to self-generate. In addition, the results indicate that firms that invested in self-generation would have experienced, on average, outage losses that were 88 percent higher than their actual losses if they had not invested. Conversely, firms without self-generation could have reduced their actual outage losses by on average 5 percent by implementing self-generation strategies. Overall, our results indicate that self-generating firms in Asian emerging and developing countries are particularly vulnerable to losses from power outages and underscore the importance of self-generation as a strategic choice for these firms.

1. Introduction

One of the United Nations Sustainable Development Goals is to ensure access to affordable, reliable, sustainable and modern energy for all (SDG-7). This includes access to reliable and affordable electricity, which is particularly crucial for economic development and growth in emerging and developing countries (see, e.g., Shahbaz et al., 2017; Falentina and Resosudarmo, 2019). However, many firms operating in these regions face challenges in obtaining reliable and affordable electricity from the grid, especially during periods of peak demand or when the electricity supply is interrupted (see, e.g., Oseni and Pollitt, 2015; Abeberese, 2020; Kupzig, 2023). As a result, firms may choose to invest in self-generation technologies to ensure a reliable and stable supply of electricity (see, e.g., Steinbuks and Foster, 2010).

The decision to self-generate electricity is not without cost, as it requires a significant upfront investment and ongoing maintenance expenses (see, e.g. De Nooij et al., 2007). However, in some cases, self-generation may be the most cost-effective option for firms, particularly if grid electricity is unreliable or expensive. The decision to self-generate is thus a critical strategic choice for firms operating in emerging and developing countries, with potentially significant implications for their profitability and competitiveness.

Moreover, the reliability of the electricity supply can have a significant impact on a firm's performance during times of electricity outages. Outages can disrupt production, damage equipment, and result in lost revenue, and firms may incur additional costs to mitigate the effects of these outages (see, e.g., Scott et al., 2014; Abeberese, 2017; Seidler et al., 2018). In emerging and developing countries, where the electricity infrastructure is often inadequate and prone to disruptions, the impact of outages on firm performance can be particularly severe. Few studies have investigated the impact of self-generation on mitigating the economic losses for firms specifically in Africa (see, e.g. Steinbuks and Foster, 2010; Oseni and Pollitt, 2015; Abdisa, 2020; Abeberese et al., 2021; Kupzig, 2023).

Against this background, this research paper aims to contribute to the existing literature by examining the decision of firms to self-generate electricity and the losses due to power outages in the context of Asian emerging and developing countries. To the best of our knowledge, this is

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the first study to focus specifically on Asian emerging and developing countries in this area. Specifically, we seek to answer the following research questions:

1. What factors drive the decision to self-generate in emerging and developing Asia?
2. What is the impact of self-generation on mitigating economic losses due to power outages in emerging and developing Asia?

To address these research questions, we use survey data from the World Bank Enterprise Survey (WBES) that entails 5639 manufacturing firms from seven Asian emerging and developing countries. The survey collects data on firms' electricity consumption, self-generation technologies, and experience with electricity outages, as well as firm-level characteristics such as industry, size, and ownership structure. As for the econometric modeling, we follow Abdisa (2020) and apply an endogenous switching regression model. This approach allows us to estimate the effect of various factors on the firm-self-generation decision and the impact of outages on firm performance by at the same time accounting for self-selection in the decision to invest in self-generation.

The rest of this paper is organized as follows. Section 2 reviews the literature on outages and firm productivity, and self-generation and outage losses. The data is presented in Section 3, followed by a description of the empirical model in Section 4. Section 5 presents and discusses the empirical results. Finally, Section 6 summarizes and concludes the paper.

2. Literature review

Power outages are a common problem in many developing and emerging countries, and their impact on firm performance can be significant. The existing literature on power outages and firm performance can be broadly divided into two strands of research. First, one that deals generally with the impact of power outages on firm performance and possible strategies to reduce the negative impact of power outages on firm operations. Second, one that deals specifically with the drivers of self-generation and the impact of self-generation on mitigating economic losses due to power outages.

Among the most recent studies in the first strand of research is that of Fisher-Vanden et al. (2015), which examines the impact of power shortages on the productivity of industrial firms in China. Using a panel dataset of 23000 energy-intensive firms from 1999 to 2004, the authors find significant input factor substitution and an 8 percent increase in unit production costs as a result of power shortages. Similarly, Allcott et al. (2016) investigate the impact of electricity shortages on Indian manufacturers. Using a unique dataset on electricity supply and demand, the authors find that electricity shortages significantly reduce firms' productivity and output. The authors estimate that the average reported level of electricity shortages reduces revenues and producer surplus by 5–10 percent. The authors also find that larger firms are more often invested in self-generation than smaller firms, which results in smaller firms being more affected by shortages.

Furthermore, Cole et al. (2018) examine the relationship between power outages and firm performance in Sub-Saharan Africa using firm-level survey data for 14 countries. The authors find that power outages significantly reduce firms' sales, with a much stronger effect for firms without self-generation than for firms with self-generation. Reducing the average outage level of firms in Sub-Saharan Africa to the average outage level of firms in South Africa is estimated to increase sales by about 85 percent overall and by about 117 percent for firms without self-generation.

In addition, Abdisa (2018) uses survey data on manufacturing firms in Ethiopia and finds that power outages significantly increase production costs and reduce firm performance, particularly for small firms. The author also finds input factor substitution and investment in self-generation as a strategic response to power outages. Finally, using survey data on manufacturing firms in Senegal, Cissokho (2019) finds that power outages have a significant negative impact on the productivity of small and medium-sized enterprises (SMEs) in Senegal, but firms with generators can mitigate this negative impact, shifting the burden to SMEs that may lack the financial resources to acquire generators.

In summary, this strand of research demonstrates the negative impact of power outages on firm performance. It also highlights the need to improve the reliability of electricity supply to enhance firm productivity in developing and emerging economies. Furthermore, it shows that firms use different strategies to reduce the negative impact of power outages on their operations, with the use of generators being one of the most common.

In the second strand of research, Steinbuks and Foster (2010) examine the factors that influence firms' decisions to generate their own electricity in Africa. Using data from 25 African countries, the authors find that firms are more likely to generate their own electricity when there are frequent power outages. In addition, larger firms, older firms, and exporting firms are more likely to generate their own electricity. While the authors find that the costs of self-generation are high, their results also indicate that the benefits of self-generation are substantial, with the value of lost load being more than three times lower for self-generating firms than for non-self-generating firms.

Oseni and Pollitt (2015) examine the impact of power outages on African firms, focusing on outage loss differentials between self-generating and non-self-generating firms. Using data from a survey of more than 2600 firms in eight Sub-Saharan African countries, their results indicate that firms with self-generation would have experienced a 1–183 percent increase in outage losses if they had not invested in self-generation, while firms without self-generation could have reduced their outage losses by 6–46 percent if they had invested in self-generation. In addition, the results indicate that in the case of very frequent power outages, self-generating firms may still experience higher outage losses than non-self-generating firms due to their high dependence on electricity and limited self-generation capacity. Furthermore, with respect to investment in backup generators, the results show that larger firms and those engaged in export activities are more likely to have backup generators.

Similarly, using data from the WBES covering 13 Sub-Saharan African countries, Abdisa (2020) examines the effectiveness of self-generation investments in reducing outage losses and compares the difference in outage losses between firms that invested in self-generation and those that did not. The results, based on more than 3000 firm observations, indicate that investments in self-generation have indeed led to a reduction in outage losses for firms that have made this strategic choice. However, despite this reduction, firms with self-generation still face comparatively higher unmitigated outage losses than their counterparts without such investments. Specifically, firms that invested in self-generation would have experienced outage losses from 36–100 percent higher than their actual losses if they had not made the investment. Conversely, firms without self-generation could have reduced their actual outage losses by 2–24 percent by employing self-generation strategies. With regard to investment in backup generators, the results again indicate that in particular large firms are more likely to invest.

Abeberese et al. (2021) analyze the productivity losses and firm responses to electricity shortages in Ghana. Using panel data from a survey of about 800 small and medium manufacturing firms across various sectors, the authors find that power outages lead to significant productivity losses. In addition, when examining strategies to mitigate the adverse effects of power outages, the authors find that shifting production to less energy-intensive products is an effective approach. However, contrary to previous studies, they find no mitigating effect associated with the use of generators.

Finally, Kupzig (2023) investigates the impact of power outages on firm productivity and the role of generator ownership in mitigating the negative effects of electricity shortages in East Africa. Based on about

400 firm observations from Kenya, Tanzania, and Uganda, the author finds that power outages lead to significant productivity losses, which can largely be mitigated by self-generation. However, the results also imply that self-generation per se has a negative impact on productivity, suggesting that investments in self-generation are only profitable if the average duration of power outages is relatively long.

In summary, all but one of the studies in the second strand of research show that firms that have invested in generating their own electricity have been able to significantly reduce their losses due to power outages. The results also suggest that larger and exporting firms are more likely to generate their own electricity. However, all of these studies focus exclusively on firms in Africa. Therefore, this study focuses on Asian emerging and developing countries and examines the factors that influence the decision of firms in these countries to generate their own electricity, and how self-generation in these countries affects the economic losses caused by power outages.

3. Data

The empirical analysis in this study is based on firm-level data for 5639 business enterprises operating in seven emerging and developing Asian countries, drawn from the WBES. Starting with thirty countries defined as emerging and developing Asia by the International Monetary Fund (see, e.g. International Monetary Fund, 2023), the remaining seven countries were selected based on data availability for all variables used in the study and a threshold of at least 100 observations per country after all dropouts due to missing information.

Table 1 provides an overview of the average annual outage time in days, the average annual outage loss in percent of annual sales, and the share of firms owning a generator for the seven considered countries.

Overall, the figures show great heterogeneity between countries. Power supply unreliability ranges from an average annual duration of power outages of about 4 days in Sri Lanka to nearly 42 days in Bangladesh. Interestingly, by far the worst electricity reliability in Bangladesh is not accompanied by the highest percentage of generator ownership. While only about 44 percent of firms in Bangladesh report owning a generator, this figure is much higher in other countries, such as 87 percent and 84 percent in Myanmar and India, respectively. Nevertheless, the observed lowest percentage of companies owning a generator is still relatively high with about 42 percent in Indonesia.

In terms of the economic impact of unreliable power supply, Myanmar has the highest average annual loss due to power outages. On average, Myanmar firms reported losing about 7 percent of their annual sales due to power outages. The Philippines, India, and Bangladesh follow with an average annual loss of about 5–6 percent. Only in China do firms report a relatively low average annual sales loss of about 1 percent.

Overall, these figures indicate that the unreliability of power supply and its economic consequences are an important issue in most of the Asian countries considered. To investigate whether and to what extent investment in self-generation capacity can limit economic losses from power outages, we empirically analyze the difference in outage losses between firms with and without self-generation using an endogenous switching regression model (see Abdisa, 2020). In our model, we account for a number of firm characteristics and, in particular, for possible self-selection in the firm's decision to invest in a generator.

Table 1
Country-level statistics.

Country	Average annual outage time in days	Average annual outage loss in % of annual sales	Share of firms owning a generator in %
Bangladesh	41.60	4.65	43.53
China	5.02	1.35	50.97
India	23.47	4.69	83.81
Indonesia	6.48	4.44	42.26
Myanmar	15.86	7.41	86.97
Philippines	4.82	5.80	45.76
Sri Lanka	4.40	4.21	42.98

Table 2 presents descriptive statistics for the variables included in our model. The statistics are presented for all firms, for firms with self-generation, and for firms without self-generation. In addition, the differences in means between firms with self-generation and firms without self-generation are provided.

The selection of variables is based on previous literature on outage losses and self-generation (see, e.g., Abdisa, 2020; Oseni and Pollitt, 2015) and data availability. Of the 5639 firms in our sample, 4154 (74 percent) own a generator and thus belong to the group of firms with self-generation. The remaining 1485 firms (26 percent) do not own a generator and are therefore assigned to the group without self-generation. This large number of self-generating firms indicates the economic importance of unreliable electricity supply in the countries considered.

The outcome variable used in this study is the annual outage loss measured in thousand US-dollars. Since the WBES records all financial data in local currency units (LCUs), all monetary variables are converted to US-dollars using the country's 2010 purchasing power parities. The average annual outage loss for firms with self-generation is 302 thousand US-dollars, while it is only 116 thousand US-dollars for firms without self-generation. This information reveals a systematic difference between firms with and without self-generation, which can also be observed for other firm characteristics such as the number of employees, electricity costs, export activities, age, and manager experience. In particular, the mean values for the number of employees and the electricity costs indicate that firms with self-generation are larger and more dependent on electricity supply than firms without self-generation.

Following Oseni and Pollitt (2015), the reliability of electricity supply is measured by the number of days per year that a firm experienced power outages. The variable *Outages* is constructed from the values reported in the WBES survey for the average number of power outages per month and the average duration of power outages in hours. Multiplying these two values gives the average monthly outage duration in hours. Further, multiplying by twelve months and dividing it by 24 hours gives the average annual outage time in days. From Table 1, it can be seen that this value averages about 23 days, both for self-generating as well as for non-self-generating firms.[1]

In addition to the variables directly related to electricity demand and supply (such as electricity costs and firm size measured by the number of employees), we also include a number of variables that account for other structural differences between the firms in our model. The variable *Exporter* equals one if a firm exports more than 50 percent of its total sales and zero otherwise. Similarly, the variable *Foreign ownership* equals one if a firm is partly or totally owned by a foreign individual, company, or organization and zero otherwise. Finally, we also include the age of the firm and the manager's experience, both measured in years, as well as a number of country and sector controls in the form of country- and sector-specific dummy variables in our analysis.

4. Model specification

Defining our model specification, we follow previous research in the area of power outages and self-generation by Abdisa (2020) and use a two-stage endogenous switching regression model (see Maddala, 1983, pp. 223–228). In this approach, it is assumed that the decision for self-generation is not exogenously determined but is caused by self-selection.

[1] To avoid measurement errors and extreme values in the self-reported information on annual outage loss and annual outage time, the obtained values for all outage variables are winsorized at the 95th percentile (cf. Oseni and Pollitt, 2015).

Table 2
Descriptive statistics of firms with and without self-generation.

Variable	All firms		Firms with self-generation		Firms without self-generation		
	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	Difference
Annual outage loss in % of annual sales	4.72	5.66	4.55	5.59	5.21	5.83	0.66***
Annual outage loss in thousand US-dollars	302.92	585.87	369.65	638.44	116.26	340.61	-253.39***
Annual outage time in days	23.04	21.83	23.04	21.28	23.06	23.29	0.02
No. of employees	113.97	325.54	136.18	357.88	51.84	197.38	-84.34***
Electricity costs in thousand US-dollars	525.50	11,552.33	658.35	13,447.13	153.90	892.12	-505.45**
Exports (yes = 1)	0.08	0.27	0.09	0.29	0.04	0.19	-0.06***
Foreign ownership (yes = 1)	0.02	0.15	0.02	0.14	0.03	0.17	0.01
Age in years	19.69	14.01	20.04	14.21	18.73	13.40	-1.31***
Manager experience in years	15.16	9.56	14.76	9.33	16.25	10.09	1.49***
No. of observations	5639		4154		1485		

Note: ***, ** and *: Significant at the 1%-, 5%- and 10%-level.

A firm invests in a generator if the expected return minus the cost of self-generation (Y_G^*) exceeds the expected return without self-generation (Y_N^*). That is, $G_i^* = 1$ if $Y_G^* > Y_N^*$ and $G_i^* = 0$ otherwise. The perceived expectation of the firms cannot be observed directly, but it can be modeled as a function of the observed firm characteristics that influence the firms' decision to invest in self-generation. Accordingly, the first stage of the model consists of a selection equation for investing in a generator:

$$G_i^* = \alpha Z_i + \mu_i \; with \; G_i = \begin{cases} 1 \; if \; G_i^* > 0 \\ 0 \; otherwise, \end{cases} \tag{1}$$

where G_i is a binary variable that equals 1 if a firm invested in a generator and 0 otherwise. Z_i is a vector of firm characteristics that influences the firms' decision to invest in a generator,α is a vector of unknown parameters to be estimated and μ_i is the error term.

In the second stage of the model, two outcome equations are specified, one for firms that invested in a generator and one for firms that did not invest in a generator:

$$Y_{Gi} = \beta_G X_i + \epsilon_{Gi} \quad if \quad G_i = 1, \tag{2a}$$

$$Y_{Ni} = \beta_N X_i + \epsilon_{Ni} \quad if \quad G_i = 0, \tag{2b}$$

where Y_{Gi} and Y_{Ni} are the outcome variables, i.e, the outage losses of firms with a generator and without a generator, and X_i is a vector of exogenous variables that influence the outage losses. β_G and β_N are vectors of unknown parameters to be estimated and ϵ_{Gi} and ϵ_{Ni} are the error terms.

While this specification accounts for a selection bias caused by observed factors, it does not account for a selection bias due to unobserved factors. Therefore, the endogenous switching regression model also includes the inverse Mills ratios obtained from the estimation of Eq. (1) in the second stage. The second-stage equations are then given as:

$$Y_{Gi} = \gamma_G X_i + \sigma_{G\mu}\lambda_{Gi} + \omega_{Gi} \quad if \quad G_i = 1, \tag{3a}$$

$$Y_{Ni} = \gamma_N X_i + \sigma_{N\mu}\lambda_{Ni} + \omega_{Ni} \quad if \quad G_i = 0, \tag{3b}$$

where Y_{Gi}, Y_{Ni} and X_i are as defined before. With $\phi(.)$ and $\Phi(.)$ denoting the density and cumulative density function of the standard normal distribution, $\lambda_{Gi} = \phi(\alpha Z_i)/\Phi(\alpha Z_i)$ and $\lambda_{Ni} = \phi(\alpha Z_i)/[1 - \Phi(\alpha Z_i)]$ are the inverse Mills ratios obtained from the estimation of Eq. (1).γ_G, γ_N, $\sigma_{G\mu}$ and $\sigma_{N\mu}$ represent unknown parameters to be estimated and ω_{Gi} and ω_{Ni} are the error terms. The model defined in Eqs. (1) and (3a), and (3b) is estimated by full information maximum likelihood (FIML) following Lokshin and Sajaia (2004).

To identify the model, the selection equation in the first stage should contain the same variables as the equations in the second stage plus at least one instrumental variable that directly influences the investment decision for or against a generator in the first stage but not the level of outage loss in the second stage. Following Abdisa (2020), we use managerial experience as one instrumental variable and additionally include the firm's age as a second instrumental variable.[2]

Since we are interested in investigating the relationship between self-generation, i.e., investment in a generator, and outage loss, we use the results of the endogenous switching regression model to calculate the average treatment effect of the treated (ATT) and the average treatment effect of the untreated (ATU).

Following Lokshin and Sajaia (2004), the conditional expectations for outage losses are given as:

$$E[Y_{Gi}|G_i = 1] = \gamma_G X_i + \sigma_{G\mu}\lambda_{Gi}, \tag{4a}$$

$$E[Y_{Ni}|G_i = 0] = \gamma_N X_i + \sigma_{N\mu}\lambda_{Ni}, \tag{4b}$$

$$E[Y_{Ni}|G_i = 1] = \gamma_N X_i + \sigma_{N\mu}\lambda_{Gi}, \tag{4c}$$

$$E[Y_{Gi}|G_i = 0] = \gamma_G X_i + \sigma_{G\mu}\lambda_{Ni}. \tag{4d}$$

While Eq. (4a) and Eq. (4b) refer to the expected outage losses for firms with and without self-generation actually observed in the sample, Eq. (4c) and Eq. (4d) refer to the unobserved counterfactuals. That is, Eq. (4c) gives the expected outage loss for firms with self-generation if they had not chosen to self-generate and Eq. (4d) gives the expected outage loss for firms without self-generation if they had chosen to self-generate.

The ATT can then be calculated as the average of the difference between Eqs. (4c) and (4a):

$$\text{ATT} = E[Y_{Ni}|G_i = 1] - E[Y_{Gi}|G_i = 1] = (\gamma_N - \gamma_G)X_i + (\sigma_{N\mu} - \sigma_{G\mu})\lambda_{Gi}. \tag{5}$$

Similarly, the ATU can be calculated as the average of the difference between Eqs. (4d) and (4b):

$$\text{ATU} = E[Y_{Gi}|G_i = 0] - E[Y_{Ni}|G_i = 0] = (\gamma_G - \gamma_N)X_i + (\sigma_{G\mu} - \sigma_{N\mu})\lambda_{Ni}. \tag{6}$$

To further illustrate our methodological approach, a flowchart of our empirical analysis is shown in Fig. 1. In particular, the figure shows that the estimated results of the endogenous switching regression model from the first step of our analysis are used to derive the average treatment effects in the second step. The average treatment effects are calculated as the difference between the average expected outage loss in the counterfactual state of self-generation and the respective actual state. For firms with self-generation, this difference is referred to as the average treatment effect of the treated (ATT) and for firms without self-generation as the average treatment effect of the untreated (ATU).

[2] To test the validity of the selected instruments, we conduct a simple falsification test by estimating a probit model for the decision of firms to invest in a generator and an ordinary least squares regression model for the outage loss of the firms without self-generation (see, DiFalco et al. 2011). The results presented in Table A.3 in the Appendix show that managerial experience and firm age are statistically significantly related to the decision to invest in a generator, but not to the level of outage loss, so they can be considered valid instruments.

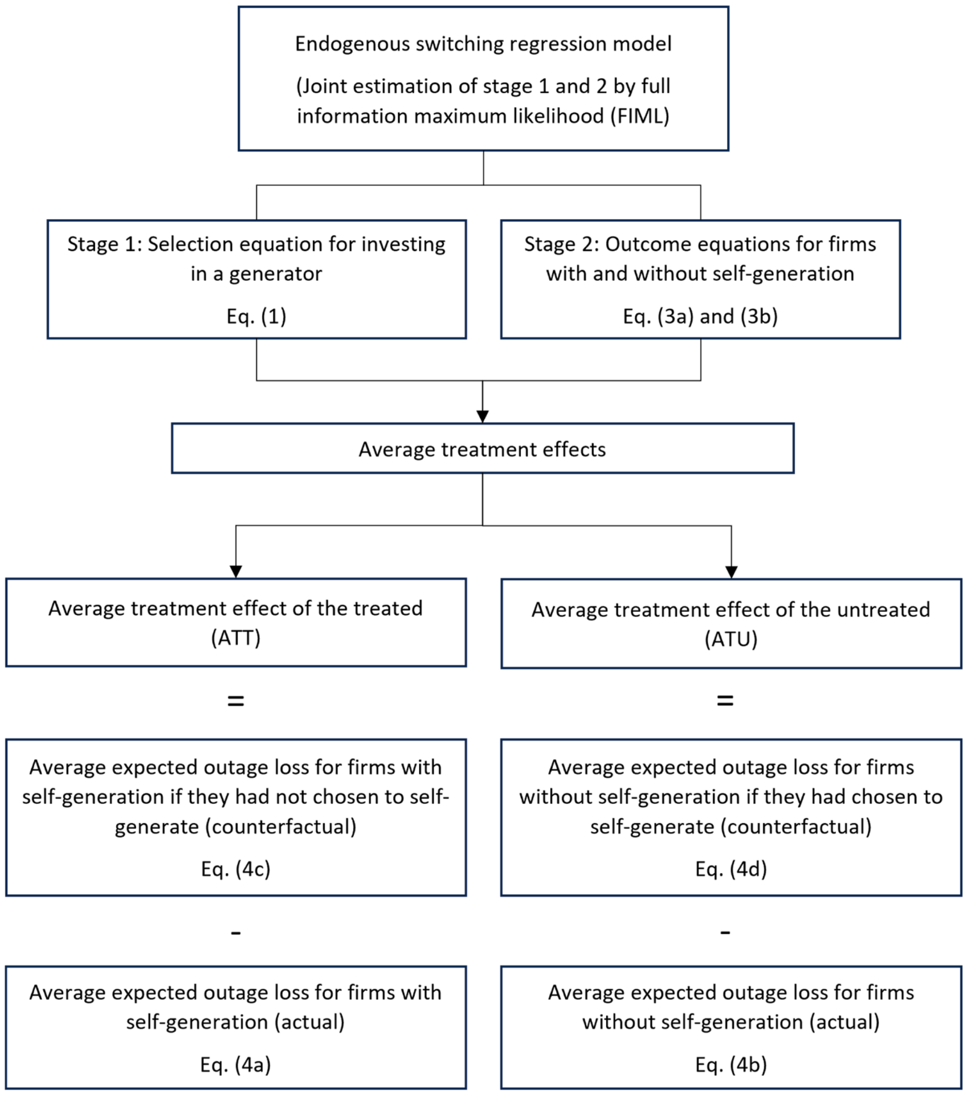

Fig. 1. Flowchart of the empirical analysis.

5. Results

The estimation results for the endogenous switching regression model defined in Eqs. (1) and (3a) and (3b) are presented in Table 3. In addition to the variables described in Section 3 we included sector and country controls to account for corresponding sector- and country-specific heterogeneities in the model.

The second column shows the estimated coefficients for the selection equation, which represents factors that may determine the firms' decision to invest in a generator for self-generation. As expected, the coefficients for the variables *Outages* and *Electricity costs* are positive and statistically significant, indicating that firms facing a higher number of outages and higher electricity costs are more likely to invest in a generator. The same is found for larger, older, and exporting firms, as shown by the positive and statistically significant coefficients for the variables *Employees, Age,* and *Exporter*. These results are consistent with previous studies by Steinbuks and Foster (2010), Oseni and Pollitt (2015), Abdisa (2018), and Abdisa (2020).

In line with Abdisa (2020), the negative and statistically significant coefficient for the variable *Manager experience* suggests that firms with more experienced management are less likely to invest in a generator. Abdisa (2020) argues that this could be due to improved management practices by experienced managers in adapting to electricity problems, for example, by adapting their production process to the availability of electricity rather than investing in a generator.

Turning to the results on the outcome equations reported in columns 3 and 4 for firms with and without self-generation, the estimated coefficients for all variables point in the same direction and mostly have a similar level of statistical significance. The coefficient on the variable *Outages* is positive and statistically significant for both groups, indicating that the annual outage loss positively correlates with the annual number of outages. For firms with self-generation, the magnitude of the estimated coefficient suggests that a 10 percent increase in the number of outages leads to a 2.5 percent increase in annual outage loss. For firms without self-generation, the corresponding coefficient is more than twice as large, suggesting that a 10 percent increase in the number of outages leads to a 5.4 percent increase in annual outage loss.

A similar result is observed for the variable *Employees*, with a positive and statistically significant coefficient of 0.495 and 1.109 for firms with and without self-generation, respectively. For both groups, the positive and statistically significant coefficients for the variable *Electricity costs* indicate an increase in annual outage losses of about 4 percent, resulting from a 10 percent increase in electricity costs. Finally, for firms without self-generation, the positive and statistically significant coefficient for *Exporter* indicates a higher annual outage loss for exporting firms than for non-exporting firms.

Overall, the differences in the magnitude of the estimated coefficients in the outcome equations between firms with and without self-

Table 3
Estimation results.

Dependent variable	Generator 1/0	Generator = 1 (firms with self-generation) Outage loss (in logs)	Generator = 0 (firms without self-generation) Outage loss (in logs)
Outages (in logs)	0.118***	0.251***	0.535***
	(0.022)	(0.028)	(0.073)
Employees (in logs)	0.340***	0.495***	1.109***
	(0.029)	(0.028)	(0.201)
Electricity costs (in logs)	0.071***	0.420***	0.449***
	(0.016)	(0.020)	(0.050)
Exporter	0.257***	0.048	0.797***
	(0.094)	(0.096)	(0.294)
Foreign ownership	-0.424***	-0.234	-0.540
	(0.142)	(0.204)	(0.422)
Age (in logs)	0.059*		
	(0.031)		
Manager experience (in logs)	-0.046*		
	(0.027)		
Constant	-0.896***	0.013	0.176
	(0.150)	(0.154)	(0.300)
Sector controls	Yes	Yes	Yes
Country controls	Yes	Yes	Yes
ρ_j		-0.024	1.374**
		(0.073)	(0.581)
Wald test of indep. equations	5.65**		
	(0.018)		
No. of observations	5639	4154	1485

Notes: Robust standard errors in parentheses. ***, ** and *: Significant at the 1%-, 5%- and 10%-level. ρ_j denotes the correlation coefficients between the error term in Eq. (1) and the error terms in Eqs. (3a) and (3b). To conserve space, the estimated coefficients of the country and sector controls are reported in Table A.4 in the appendix.

generation point to heterogeneities in the two groups. Furthermore, the statistically significant correlation coefficient ρ_2 and the Wald test of independence indicates that the selection and outcome equations are dependent, supporting the estimation of an endogenous switching model.

The estimated average expected outage losses and average treatment effects by country are presented in Table 4. First of all, it can be seen that in all countries, firms with self-generation have a higher expected outage loss on average than firms without self-generation. The average expected outage loss for all countries is 4.37 (in log US-dollars) for firms with self-generation compared to 2.84 (in log US-dollars) for firms without self-generation. In both groups, the highest average expected outage loss is estimated for firms in India. However, as there may be unobserved heterogeneities between the two groups that affect the level of outage losses this simple comparison can be misleading. For a meaningful comparison, one should look at the estimated average expected outage loss of firms with self-generation in the actual state (column 2) and the estimated average expected outage loss of firms without self-generation in the counterfactual state (column 7), that is, the expected outage loss of firms without self-generation if they had invested in self-generation. Making this comparison, the values in Table 4 indicate that, on average, firms with self-generation suffer more from outage losses than firms without self-generation, even if the latter had invested in self-generation in all countries. These results suggest that firms with self-generation are more vulnerable to outage losses from power interruptions than firms without self-generation.

In particular, the estimates for the ATT indicate for all countries that firms with self-generation would have suffered from significantly higher outage losses if they had not invested in self-generation. For example, for firms in Bangladesh the estimation results indicate an increase in outage losses of about 113 percent on average if they had not invested in self-generation. The highest ATT is observed for Myanmar (134 percent) and the lowest for China (74 percent).

On the other hand, the estimated ATU for firms without self-generation indicates that firms in China, India, and Indonesia could have reduced their average outage losses by 16 percent, 5 percent, and 25 percent, respectively, if they had invested in self-generation. Interestingly, the estimated ATU for Myanmar, the Philippines, and Sri Lanka is positive, suggesting that the expected average annual outage losses for firms without self-generation are lower in the actual state than in the counterfactual state with self-generation. However, the difference is only statistically significant at the 10 percent level for Myanmar.

6. Conclusion

Access to reliable and affordable electricity is essential for economic development in emerging and developing countries. However, many firms in these regions struggle to obtain a stable supply of electricity from the grid, leading them to invest in self-generation technologies. This decision involves significant upfront costs but can be cost effective

Table 4
Average expected outage loss by country (in logs) and average treatment effects.

	Firms with self-generation				Firms without self-generation			
Country	Actual	Counter- factual	Difference	ATT (in %)	Actual	Counter-factual	Difference	ATU (in %)
Bangladesh	3.2	6.82	3.61***	113%	2.02	2.01	-0.01	0%
			(0.13)				(0.08)	
China	4.24	7.37	3.12***	74%	3.6	3.03	-0.57***	-16%
			(0.22)				(0.21)	
India	4.59	8.42	3.84***	83%	3.72	3.55	-0.18***	-5%
			(0.04)				(0.06)	
Indonesia	4.04	7.48	3.43***	85%	2.01	1.5	-0.51**	-25%
			(0.23)				(0.21)	
Myanmar	3.60	8.44	4.84***	134%	2.79	3.3	0.51*	18%
			(0.18)				(0.23)	
Philippines	4.45	8.38	3.94***	88%	3.14	3.45	0.31	10%
			(0.35)				(0.24)	
Sri Lanka	3.33	7.15	3.82***	115%	1.42	1.44	0.02	1%
			(0.24)				(0.14)	
All	4.37	8.23	3.86***	88%	2.84	2.71	-0.13**	- 5%
			(0.04)				(0.05)	

Notes: Standard errors in parentheses. ***, ** and *: Significant at the 1%-, 5%- and 10%-level.

in the face of unreliable or expensive electricity from the grid. The reliability of electricity supply also affects firm performance during outages, impacting production, equipment, and revenue.

Against this backdrop, this paper focuses on manufacturing firms in emerging and developing countries in Asia to examine the factors driving the decision to self-generate and the impact of self-generation on mitigating economic losses during power outages. Using survey data from the World Bank Enterprise Survey (WBES) of 5639 manufacturing firms in seven Asian countries and an endogenous switching regression model, we analyzed the interplay between self-generation decisions, outage losses, and firm characteristics.

Our results show that firms experiencing more power outages and higher electricity costs are more likely to invest in self-generation. Larger, older, and exporting firms also show a higher propensity to self-generate. Interestingly, firms with more experienced management are less likely to invest in self-generation, possibly due to the ability of experienced managers to adapt production processes to mitigate the impact of electricity-related challenges.

Furthermore, when examining the impact of self-generation on outage losses, our results indicate that both self-generating and non-self-generating firms experience higher outage losses as outages increase. However, the magnitude of this effect is greater for non-self-generating firms, suggesting that self-generation helps mitigate outage losses. Factors such as firm size and electricity costs also influence outage losses, with larger firms and those with higher electricity costs experiencing greater losses. Overall, these findings are consistent with previous research in other countries and regions (Steinbuks and Foster, 2010; Oseni and Pollitt, 2015; Abdisa, 2018; Abdisa, 2020).

In addition, an analysis of the estimated expected outage losses and average treatment effects by country indicates that firms that invested in self-generation would have experienced, on average, outage losses that were 88 percent higher than their actual losses if they had not invested. Conversely, firms without self-generation could have reduced their actual outage losses by on average 5 percent by implementing self-generation strategies. Moreover, comparing to Abdisa's (2020) results for Sub-Saharan African firms, our analysis shows significantly higher estimated losses for firms with self-generation in case they would not have invested. While Abdisa (2020) reports an increase in outage losses of 36–100 percent, our results indicate an increase of 74–134 percent. These results suggest that self-generating firms in Asian emerging and developing countries are particularly vulnerable to losses from power outages.

In conclusion, our findings underline the importance of reliable electricity supply for firms in emerging and developing Asian countries. The decision to self-generate electricity emerges as a strategic choice influenced by factors such as outage frequency, electricity cost, firm size, and managerial experience. Self-generation helps mitigate economic losses during power outages. These findings underscore the economic importance of addressing electricity supply reliability and encouraging investment in self-generation technologies.

Policymakers should prioritize improving electricity infrastructure and minimizing outages to support economic continuity and growth. Incentives for firms to invest in self-generation could further improve resilience to power disruptions. Firms, especially those that rely on a stable supply of electricity, should carefully consider the potential benefits of self-generation technologies despite the upfront costs.

In addition, our results point to avenues for further research, such as investigating the costs and benefits of different self-generation technologies in different seasons (e.g. summer and winter) and for different times of the day or week (e.g. peak and off-peak). Load forecasting studies can be helpful in this regard. While the data used in this study did not allow for such an analysis, more detailed analysis in this direction is a promising avenue for an even deeper understanding of the role of self-generation in mitigating economic losses due to power outages. Considering the Sustainable Development Goal of ensuring access to affordable, reliable, sustainable, and modern energy for all (SDG-7), further research should also assess the long-term sustainability of self-generation solutions. For example, companies with self-generation based on renewable energy sources could, on the one hand, limit their economic losses due to grid-related power outages and, on the other hand, contribute to a more sustainable energy supply system as a whole.

Author statement

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CRediT authorship contribution statement

Anam Shehzadi: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing. **Heike Wetzel:** Conceptualization, Data curation, Formal analysis, Methodology, Supervision, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Appendix

Table A.1
Detailed descriptive statistics of firms with self-generation (N = 4154)

Variable	Mean	Median	Std. dev.	Minimum	Maximum
Annual outage loss in % of annual sales	4.55	2.00	5.59	0.00	20
Annual outage loss in thousand US-dollars	369.65	81.32	638.44	0.00	2323
Annual outage time in days	23.04	15.00	21.28	0.21	76.
No. of employees	136.18	40.00	357.88	3	8000
Electricity costs in thousand US-dollars	658.35	68.71	13,447.13	0.14	857,174
Exports (yes = 1)	0.09	-	0.29	0	1
Foreign ownership (yes = 1)	0.02	-	0.14	0	1
Age in years	20.04	17.00	14.21	1	150
Manager experience in years	14.76	12.00	9.33	1	64

Note: To avoid measurement errors and extreme values in the self-reported information on annual outage loss and annual outage time, the obtained values for all outage variables are winsorized at the 95th percentile (cf. Oseni and Pollitt, 2015).

Table A.2
Detailed descriptive statistics of firms without self-generation (N = 1485)

Variable	Mean	Median	Std. dev.	Minimum	Maximum
Annual outage loss in % of annual sales	5.21	2.65	5.83	0.00	20
Annual outage loss in thousand US-dollars	116.26	15.42	340.61	0.00	2323
Annual outage time in days	23.06	15.00	23.29	0.50	76
No. of employees	51.84	17.00	197.38	2	5000
Electricity costs in thousand US-dollars	153.90	12.66	892.12	0.04	22,343
Exports (yes = 1)	0.04	-	0.19	0	1
Foreign ownership (yes = 1)	0.03	-	0.17	0	1
Age in years	18.73	15.00	13.40	1	99
Manager experience in years	16.25	15.00	10.09	1	64

Note: To avoid measurement errors and extreme values in the self-reported information on annual outage loss and annual outage time, the obtained values for all outage variables are winsorized at the 95th percentile (cf. Oseni and Pollitt, 2015).

Table A.3
Validity test of instruments

Dependent variable	Model 1 Generator 1/0	Model 2 Outage loss of firms without self-generation (in logs)
Outages (in logs)	0.113***	0.411***
	(0.021)	(0.056)
Employees (in logs)	0.354***	0.597***
	(0.026)	(0.063)
Electricity costs (in logs)	0.078***	0.349***
	(0.017)	(0.033)
Exporter	0.245***	0.449*
	(0.097)	(0.237)
Foreign ownership	-0.469***	0.177
	(0.150)	(0.291)
Age of firm (in logs)	0.092***	-0.002
	(0.030)	(0.060)
Manager experience (in logs)	-0.070**	-0.070
	(0.032)	(0.071)
Constant	-0.848***	-0.227
	(0.137)	(0.265)
Sector controls	Yes	Yes
Country controls	Yes	Yes
Wald test on joint significance of instruments	χ^2 = 10.35***	F-statistic = 0.58
No. of observations	5639	1485

Notes: Model 1: Probit model; Model 2: Ordinary least squares. Robust standard errors in parentheses. ***, ** and *: Significant at the 1%-, 5%- and 10%-level.

Table A.4
Estimation results for country and sector controls

Dependent variable	Generator 1/0	Generator = 1 (firms with self-generation) Outage loss (in logs)	Generator = 0 (firms without self-generation) Outage loss (in logs)
Country Controls			
Bangladesh	-1.057***	-1.210***	-2.830***
	(0.089)	(0.111)	(0.602)
China	-1.043***	-0.680***	-2.380***
	(0.116)	(0.142)	(0.701)
Indonesia	-1.132***	-0.521	-2.010***
	(0.115)	(0.323)	(0.526)
Sri Lanka	-0.637***	-0.631***	-1.060**
	(0.115)	(0.202)	(0.458)
Myanmar	0.446***	-0.099	1.300**
	(0.125)	(0.118)	(0.595)
Philippines	-0.844***	-0.162	-0.580
	(0.137)	(0.237)	(0.516)
Sector Controls			
Textile	-0.154**	-0.024	-0.825***
	(0.090)	(0.113)	(0.254)
Garments	0.029	0.136	-0.529**
	(0.098)	(0.130)	(0.251)
Food	0.133**	0.164	0.108
	(0.077)	(0.102)	(0.191)
Plastic & Rubber	0.130	0.229**	-0.118
	(0.085)	(0.098)	(0.226)
Fabricated Metallic Mineral	0.190**	0.061	0.063
	(0.088)	(0.104)	(0.222)
Machinery and Equipment	0.301***	0.120	0.284
	(0.097)	(0.106)	(0.316)
Chemicals	0.073	0.307***	0.155
	(0.091)	(0.107)	(0.236)
Non-Metallic Mineral Products	-0.328***	-0.034	-0.743**
	(0.084)	(0.123)	(0.295)

(continued on next page)

Table A.4 (*continued*)

Dependent variable	Generator 1/0	Generator = 1 (firms with self-generation) Outage loss (in logs)	Generator = 0 (firms without self-generation) Outage loss (in logs)
Basic Metals	-0.002	0.296***	0.195
	(0.976)	(0.109)	(0.243)
Electronics	0.277***	0.166	0.228
	(0.105)	(0.108)	(0.294)
Transport Machines	0.454***	0.261**	0.496
	(0.108)	(0.103)	(0.331)

Notes: Robust standard errors in parentheses. ***, ** and *: Significant at the 1%-, 5%- and 10%-level.

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