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Productivity Losses and Firm Responses to Electricity Shortages: Evidence from Ghana

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Abstract

One of the commonly cited obstacles to firms' operations in developing economies is inadequate access to electricity. This paper explores the impact of electricity outages on firm productivity using arguably exogenous variation in outages, induced by an electricity rationing program, across small and medium-sized Ghanaian manufacturing firms. The results indicate that eliminating outages in this setting could lead to an increase in firm productivity. Further analyses of the strategies firms use to cope with outages show that changing the firm's product mix to favor less electricity-intensive products mitigates the negative impacts of outages on productivity. However, using a generator, a common strategy in many parts of the world, is unable to insulate firms from the negative impacts of outages on productivity.

JEL classification: D24, H54, O13, O14

Keywords: productivity, electricity, manufacturing

1. Introduction

Beginning with the seminal work of Aschauer (1989), there has been a growing literature on the impact of infrastructure on economic growth. While there is an active literature on the effects of infrastructure on various facets of growth, there has been relatively little research on how infrastructure, in particular electricity, affects the behavior of firms. Electricity has become a critical input for most production processes, especially as technological advancements in production have increased the reliance on electricity-dependent technologies.

Despite its potential to promote growth, electricity provision remains poor in most developing countries. An estimated 1.3 billion people worldwide are without electricity, over 95 percent of whom live

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in developing countries. In Africa alone, almost 600 million people lack electricity, representing approximately 60 percent of the continent's total population (International Energy Agency 2011). Even where consumers are connected to the electric grid, electricity supply tends to be unreliable and plagued with frequent outages. For instance, manufacturing firms in Africa report an average of 56 days without electric power in a year (International Monetary Fund 2008). In Ghana, the setting for this study, electricity was the most commonly cited constraint to firms' operations according to a 2007 World Bank survey. Almost 50 percent of firms surveyed ranked electricity problems as the most severe obstacle to their operations ahead of constraints such as access to finance, taxes, and crime (World Bank 2007). Since firms are an important engine of growth and electricity has increasingly become an essential input for firms, identifying the effects of outages and how firms respond to electricity constraints is crucial for understanding the micro-foundations of growth in developing economies.

While a growing strand of literature has sought to identify the impact of electricity provision on firms, there are gaps in this literature that this paper seeks to fill.[1] First, although the existing literature has investigated the potential for inadequate provision of electricity to affect firm productivity, there is little evidence on the strategies firms use to cope with electricity shortages and the extent to which these strategies effectively mitigate or exacerbate any productivity impacts.[2] This gap is partly due to lack of data. Very few firm-level datasets provide information on firms' use of generators and other strategies for coping with inadequate electricity provision. These coping strategies may influence the impacts of inadequate electricity supply on firm productivity, but the lack of data has made it difficult to analyze the existence and efficacy of these strategies. This analysis is important because, in the absence of uninterrupted electricity supply, an understanding of the efficacy of these coping mechanisms can help inform policies on positioning firms to better endure electricity shortages.

Second, most existing studies have focused on large firms perhaps by virtue of the fact that data tend to readily exist for this population.[3] However, small and medium-sized firms may differ from large firms in substantial ways, such as a lowered ability to finance generator use. In particular, since firms of this size constitute the bulk of firms and account for the majority of employment in developing countries, it is essential to understand how this particular population responds to electricity constraints. Small and medium-sized firms are estimated to account for about 90 percent of businesses and over 50 percent of employment (International Finance Corporation 2012). In Ghana, small and medium-sized firms are estimated to provide about 85 percent of manufacturing employment and contribute about 70 percent of the country's GDP (Government of Ghana 2017). To fill these gaps in the literature, this study surveyed over 800 small and medium-sized manufacturing firms in Ghana and collected data for the years 2011 through 2015. Ghana has suffered several episodes of electricity, crises with the most recent one resulting in an electricity rationing program that started in 2012 and ended in 2015. In addition to data on firms' products and inputs, the survey elicited information on firms' strategies for coping with electricity shortages. Using these data and the random variation across firms in electricity access induced by the rationing program, this paper assesses the magnitude of productivity losses resulting from the lack of electricity and the ability of firms to mitigate these productivity losses.

The results indicate that firms experienced reductions in productivity as a result of the lack of electricity. The productivity losses are of significant magnitude. The firms in the sample reported an average of 10 days with no electricity in a typical month. The estimates suggest that reducing this number to zero, which would be consistent with the situation in most developed countries, could result in about a

1 Recent papers include Reinikka and Svensson (2002), Rud (2012a,b), Zuberi (2012), Alby, Dethier, and Straub (2013), Fisher-Vanden, Mansur, and Wang (2015), Allcott, Collard-Wexler, and O'Connell (2016), Abeberese (2017) and Hardy and McCasland (2018).

2 Recent papers on firm productivity include Fisher-Vanden, Mansur, and Wang (2015) and Allcott, Collard-Wexler, and O'Connell (2016).

3 A notable exception is Hardy and McCasland (2018), who analyze the effects of outages on small firms.

10 percent increase in both labor productivity and total factor productivity. This paper goes beyond the existing literature to analyze how firms cope with the electricity outages. This analysis shows that the most common strategies used by firms included using a generator, switching to less electricity-intensive products, and changing production times. Further analysis investigates the ability of these strategies to alleviate the adverse impacts of electricity outages on productivity. The results indicate that changing their product mix to favor less electricity-intensive products allows firms to reduce the productivity losses from outages. On the other hand, using a generator, commonly considered a coping strategy for outages, is unable to mitigate losses from outages.

This paper is most closely related to Fisher-Vanden, Mansur, and Wang (2015); Allcott, Collard-Wexler, and O'Connell (2016); and Hardy and McCasland (2018), who analyze the effects of electricity outages on firms. Fisher-Vanden, Mansur, and Wang (2015) find that, in response to shortages, manufacturing firms in China shifted from producing intermediate goods in house to buying them and experienced no substantial productivity losses. Allcott, Collard-Wexler, and O'Connell (2016) similarly find no significant impact of outages on the productivity of manufacturing firms in India. Their results are in contrast to those in this paper, which indicate that firms experience significant productivity losses. This difference stems from the fact that while these papers focus on large firms, this paper focuses on small and medium-sized firms. These smaller firms, in contrast to large firms, are unlikely to be involved in the in-house production of intermediate goods. They may also have a limited ability to efficiently use generators to insure against outages due to the substantial economies of scale in generator use given its relatively high fixed costs. For instance, the average firm in the sample has 6 workers, and only 26 percent of firms use generators. In contrast, the average firm in the sample studied in Allcott, Collard-Wexler, and O'Connell (2016) has 79 workers, and 44 percent of firms use generators.

Allcott, Collard-Wexler, and O'Connell (2016) do find that firms without generators are more severely affected by outages. In the sample in this paper, however, the use of generators is unable to shield firms from the negative impacts of outages, potentially suggesting inefficient use of generators by smaller firms. As discussed above, in addition to understanding the impacts of electricity shortages on large firms, it is essential to understand the impacts on smaller firms since these firms tend to constitute the bulk of producers in developing economies and may differ in their ability to weather electricity outages.

A notable exception that focuses on small firms is Hardy and McCasland (2018), who study the effect of electricity outages on small garment makers. They focus on very small firms with, on average, two workers and find that some firms increase labor, which acts a substitute for electrical equipment, during outages and avoid output losses. This paper, which focuses on small and medium-sized firms, is therefore nestled between the work on small firms in Hardy and McCasland (2018) and the work on large firms in Fisher-Vanden, Mansur, and Wang (2015) and Allcott, Collard-Wexler, and O'Connell (2016). By bringing into play medium-sized firms, this paper, more broadly, sheds light on a population of firms that has hitherto been largely understudied in the development literature on firm barriers. These firms appear to be too small to use generators efficiently to mitigate outage losses as in Allcott, Collard-Wexler, and O'Connell (2016).

The rest of the paper is organized as follows. Section 2 describes the electricity rationing program in Ghana that is exploited in the analysis. Section 3 describes the survey data used for the analysis. Section 4 discusses the empirical strategy and results. Section 5 concludes.

2. Electricity Rationing in Ghana

Electricity generation in Ghana is primarily conducted by the Volta River Authority (VRA), a government-owned entity. VRA is responsible for 2,434 MW of installed generation capacity, which represents about 70 percent of total installed generation capacity in the country. Another government-owned entity, Bui Power Authority, accounts for about 10 percent of total installed generation capacity, while privately

Figure 1. An Example of an Electricity Rationing Schedule

LOAD-SHEDDING GUIDE

The Electricity Company of Ghana wishes to inform its cherished customers that due to generation shortfall it has become necessary to publish this load shedding guide.

All Communities in the bracket are on loadshedding, but all or some may not go off depending on the quantum of power to be shed.

	FRIDAY 06/02/2015	SATURDAY 07/02/2015	SUNDAY 08/02/2015	MONDAY 09/02/2015	TUESDAY 10/02/2015	WEDNESDAY 11/01/2015	THURSDAY 12/02/2015
DAY 6AM TO 7PM	B; (A)	C; (B)	A; (C)	B; (A)	C; (B)	A; (C)	B; (A)
NIGHT 6PM TO 6AM	A; (C)	B; (A)	C; (B)	A; (C)	B; (A)	C; (B)	A; (C)
	FRIDAY 13/02/2015	SATURDAY 14/02/2015	SUNDAY 15/02/2015	MONDAY 16/02/2015	TUESDAY 17/02/2015	WEDNESDAY 18/01/2015	THURSDAY 19/02/2015
DAY 6AM TO 7PM	C; (B)	A; (C)	B; (A)	C; (B)	A; (C)	B; (A)	C; (B)
NIGHT 6PM TO 6AM	B; (A)	C; (B)	A; (C)	B; (A)	C; (B)	A; (C)	B; (A)
	FRIDAY 20/02/2015	SATURDAY 21/02/2015	SUNDAY 22/02/2015	MONDAY 23/02/2015	TUESDAY 24/02/2015	WEDNESDAY 25/01/2015	THURSDAY 26/02/2015
DAY 6AM TO 7PM	A; (C)	B; (A)	C; (B)	A; (C)	B; (A)	C; (B)	A; (C)
NIGHT 6PM TO 6AM	C; (B)	A; (C)	B; (A)	C; (B)	A; (C)	B; (A)	C; (B)
	FRIDAY 27/02/2015	SATURDAY 28/02/2015	SUNDAY 01/03/2015	MONDAY 02/03/2015	TUESDAY 03/03/2015	WEDNESDAY 04/03/2015	THURSDAY 05/03/2015
DAY 6AM TO 7PM	B; (A)	C; (B)	A; (C)	B; (A)	C; (B)	A; (C)	B; (A)
NIGHT 6PM TO 6AM	A; (C)	B; (A)	C; (B)	A; (C)	B; (A)	C; (B)	A; (C)
	FRIDAY 06/03/2015						
DAY 6AM TO 7PM	C; (B)						
NIGHT 6PM TO 6AM	B; (A)						

Source: *Daily Graphic* (2015).
Note: The figure shows the electricity rationing schedule for February 6 to March 6, 2015, for service areas in groups A, B, and C.

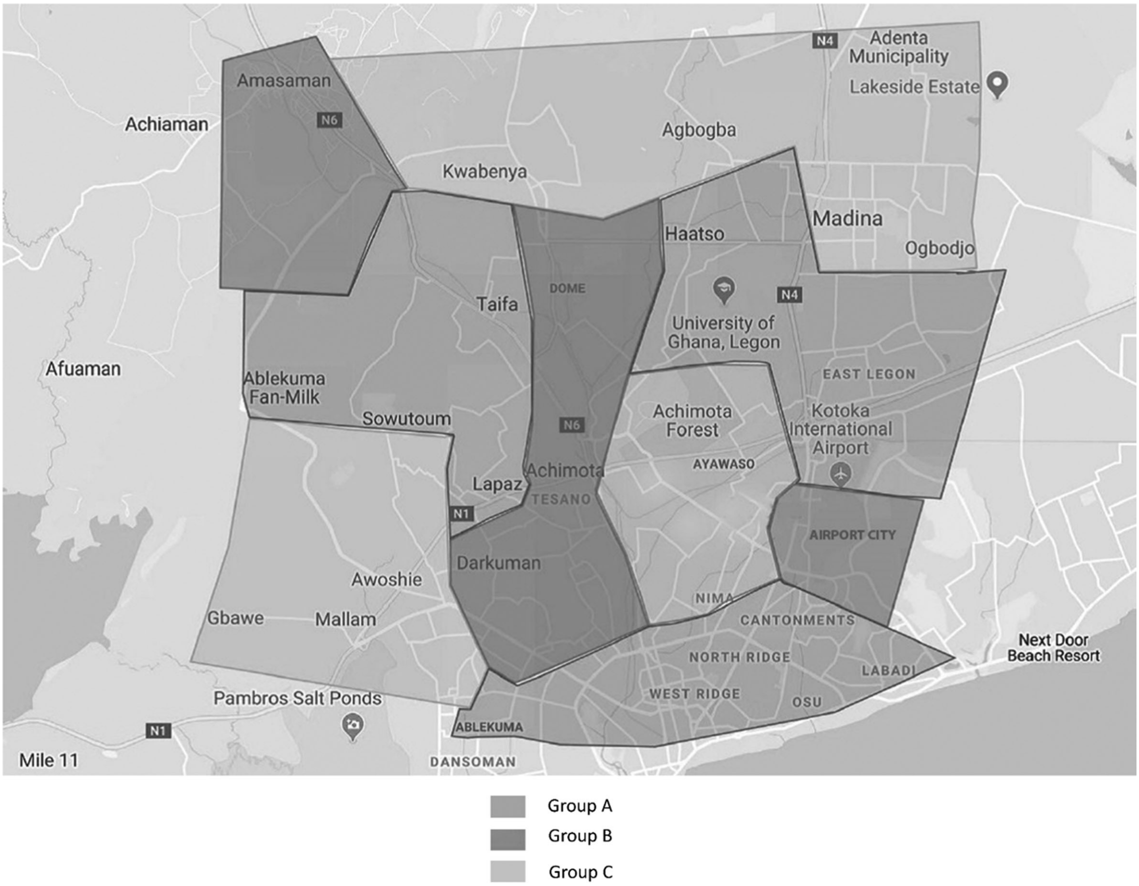
owned independent power producers account for the remaining 20 percent. Thermal and hydro generation, mainly from the Akosombo Dam, account for about 55 and 45 percent, respectively, of the electricity generated in the country (Volta River Authority 2017).

Electricity transmission is carried out by GRIDCo, while the Electricity Company of Ghana (ECG), Northern Electricity Distribution Company (NEDCo), and Enclave Power Company (EPC) are responsible for the distribution of electricity. ECG, which is government owned, is the main distributor, with a market share of over 70 percent. NEDCo, also government owned, is responsible for the northern part of the country, and EPC, which is privately owned, is responsible for a free zone enclave in the city of Tema (Electricity Company of Ghana 2017a). The cities in the sample are all located in regions served by ECG.

Ghana's electricity shortage crises date back to 1983 when a drought resulted in low levels of water that hampered the generation of hydroelectric power from the Akosombo Dam. In response, power supply to consumers was curtailed. This crisis reoccurred in 1997–1998 and in 2007–2008, all driven by droughts. The latest electricity crisis started in 2012 and lasted until 2015. The primary drivers of this crisis included poor rainfall impeding the operation of the hydroelectric power plants, disruptions in the supply of gas from Nigeria to the thermal power plants due to infrastructure damage, and gas being diverted to the domestic Nigerian market, and deteriorating electrical infrastructure (Oxford Business Group 2017).

The resulting electricity shortage led ECG to put in place an electricity rationing program. Figure 1 shows the electricity rationing schedule for February 6 to March 6, 2015, which provides an example of the design of the rationing program (Daily Graphic 2015). Areas of the country served by ECG are divided into over 500 service areas. Each neighborhood mostly corresponds to one service area, but there can be multiple service areas within larger neighborhoods. Within each city, these service areas were put into three groups, A, B, and C. In a given 36-hour period, each group would experience one 12- or 13-hour block (typically 6 p.m. to 6 a.m. or 6 a.m. to 7 p.m.) with no power and one 12- or 13-hour block

Figure 2. An Example of Service Areas



Source: Constructed by authors using Google Maps and data from *Daily Graphic* (2015).
Note: The figure shows the service areas in groups A, B, and C for part of the city of Accra.

in standby mode. In areas in standby mode, the power could go off if it was determined that the available electricity supply at the time was inadequate to meet electricity demand at that time. This implied that in any given 36-hour period, there was only one 12- or 13-hour block of time in which consumers in a given area were guaranteed power. The listed group (not in parentheses) would have no power in the indicated time block, while the group in parentheses would be in standby mode.

The three groups (A, B, and C) were not clustered in an effort to prevent large contiguous areas of the country from having no power at the same time. The map in fig. 2 illustrates this. The map shows part of the city of Accra with service areas in groups A, B, and C.

In addition to the rationing schedule, a service area could experience unexpected outages as a result of electrical equipment being damaged due to a wide array of causes, including adverse weather such as lightning, wind and rain, overheating, animals coming into contact with electrical equipment, fallen trees, and so on (Electricity Company of Ghana 2017b).

The rationing schedule, with its guaranteed and standby modes, combined with sporadic outages due to damaged equipment led to a patchwork of outages that can be considered as good as random. The resulting random variation in outages across firms is exploited in the empirical analysis below. Graphical illustrations of this variation are also presented in the next section.

Table 1. Summary Statistics

	Mean (1)	Standard deviation (2)	Number of observations (3)
No. of workers	6.32	9.45	4,261
Output (GHS)	85,760	259,443	4,195
Machinery (GHS)	5,682	24,207	4,221
Raw materials (GHS)	19,522	68,917	4,234
Outage days	10.65	5.34	4,124
Use a generator	0.26	0.44	4,224
Generated share of electricity	0.16	0.28	4,024

Source: Authors' analysis based on data from authors' 2016 survey of small and medium-sized manufacturing firms in Ghana.
Note: All monetary values are in 2006 Ghanaian cedis (GHS).

3. Data

The main source of data for the analysis in this paper is a survey of small and medium-sized manufacturing firms in Ghana that the study conducted from August to September 2016. The survey collected firm-level data for the years 2011 through 2015.

The sample for the survey was derived from the first phase of the Ghana Integrated Business Establishment Survey (IBES). The IBES is an economic census of all business establishments across all sectors of the Ghanaian economy conducted by the Ghana Statistical Service (GSS) in 2014–2015. From the IBES, the study selected all small and medium-sized manufacturing firms located in the cities of Accra, Tema, Kumasi, and Sekondi-Takoradi, the main industrial clusters in the country, for the survey. The IBES defines small firms as those with up to 30 workers and medium-sized firms as those with 31 to 100 workers. The universe of small and medium-sized manufacturing firms obtained from the IBES was 1,244 firms. The survey attempted to cover all of these firms. Of these, 73 firms refused to participate in the survey, 55 had folded up, and 231 could not be located using the contact information obtained from GSS. Therefore, 885 firms ended up being surveyed. These firms operated in 20 distinct ISIC Rev. 4 two-digit industries in the following sectors: food and beverage products, textiles and wearing apparel, chemicals, metal, machinery and equipment, wood and wood products, and other manufacturing.

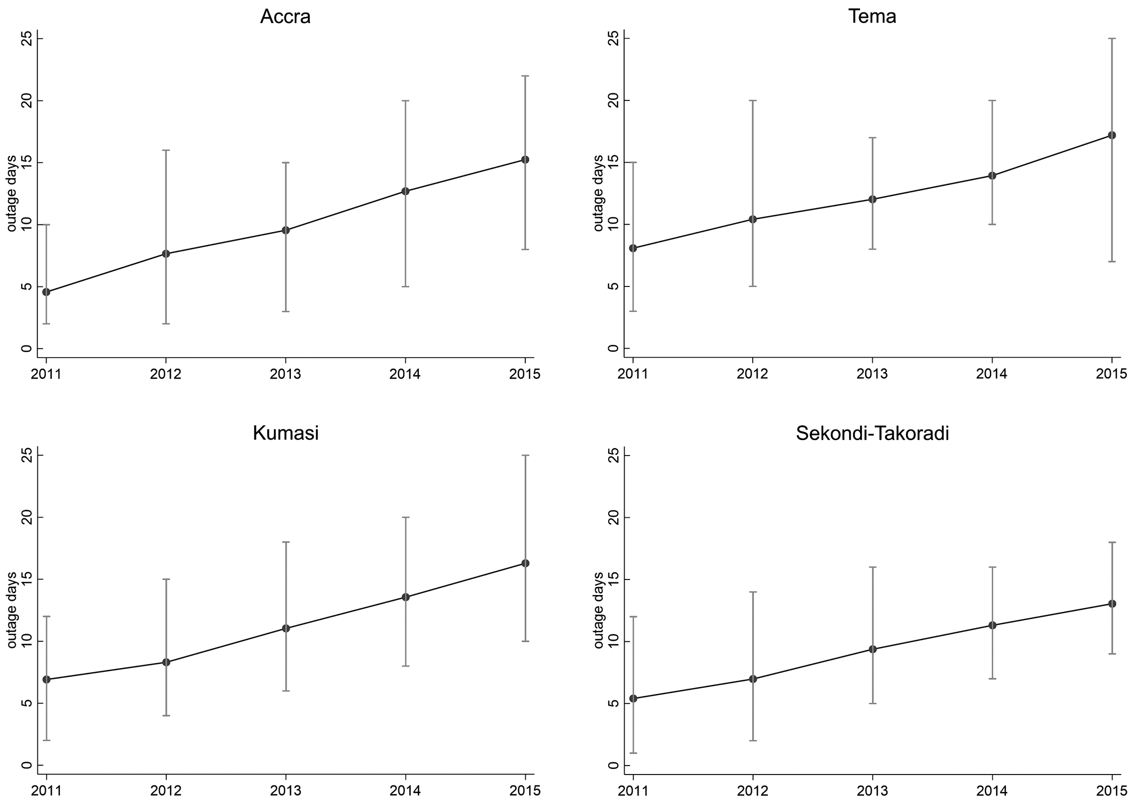
Data collected from the firms included information on output; inputs including electricity, capital, investment, labor, and electricity outages; and strategies for coping with outages as well as their location (neighborhood and city). The survey enumerators were instructed to directly record the information from the firm's written records. They were instructed to elicit the information from the respondents in the absence of records. For about 60 percent of the firms, the owner was the respondent. For another 30 percent of the firms, a manager was the respondent, and for the remaining firms an employee (not identified as the owner or a manager) was the respondent.

All monetary values are deflated to 2006 Ghanaian cedis using producer price indices from the Ghana Statistical Service. Firm output is deflated with industry-specific producer price indices. Machinery is deflated with the producer price index for machinery. All other variables are deflated with the overall producer price index. To reduce the influence of outliers, firm-level variables within each year are "winsorized" by setting values below the 1st percentile to the value at the 1st percentile and values above the 99th percentile to the value at the 99th percentile.

Table 1 provides summary statistics for the sample. The average firm in the sample is relatively small, with only about six workers. On average, firms experience about 10 days of outages in a month. About a quarter of firms use a generator, and about 16 percent of electricity consumed comes from generators.

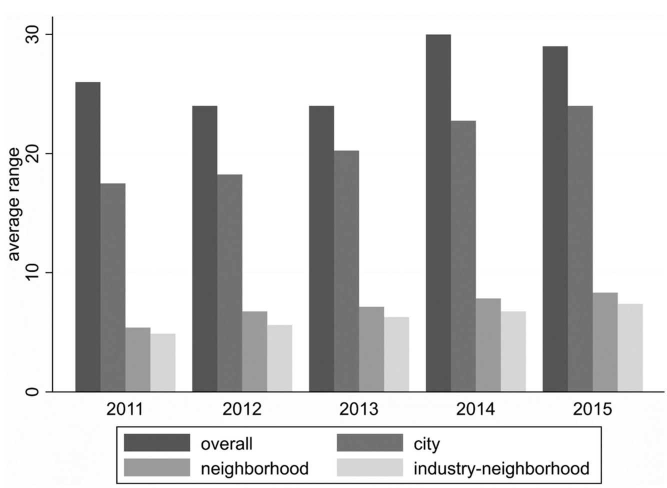
Figures 3 and 4 explore the variation in outage days present in the data. Figure 3 shows the average number of outage days reported by firms in each of the four cities in each year. As seen in the graph,

Figure 3. Outages over Time



Source: Constructed by authors using data from authors' 2016 survey of small and medium-sized manufacturing firms in Ghana.
Note: The figure shows the average number of outage days reported by firms in each of the four cities in each year. The vertical spikes show the 5th and 95th percentiles of outage days within each city in each year.

Figure 4. Variation in Outages



Source: Constructed by authors using data from authors' 2016 survey of small and medium-sized manufacturing firms in Ghana.
Note: The figure shows the average range of outage days reported by firms.

the intensity of the crisis increased over time. There was also variation within and across cities in the number of outage days, with firms in Accra and Sekondi-Takoradi reporting a lower number of outage days relative to firms in Kumasi and Tema.

In fig. 4, the height of the first bar for each year shows the value of the range of outage days for the entire data set. The second bar shows the average value of the range of outage days within each city. The third bar shows the average value of the range within each neighborhood, while the fourth bar shows the average value of the range within each industry in a given neighborhood. While there is less variation in outage days within a city compared to the overall variation, there is still substantial variation, as each city is comprised of multiple service areas in different rationing groups and, hence, on different rationing schedules. This variation is substantially reduced when one looks within a neighborhood in a city as shown in the third bar. This is consistent with what one would expect, since all firms within a given service area should be exposed to the same number of outages, and neighborhoods roughly correspond to service areas. However, there is still some variation as shown in the figure because neighborhoods do not perfectly correspond to service areas. Larger neighborhoods can have multiple service areas. While there are data on a firm's neighborhood, there are no data on a firm's specific service area.

In line with all firms in a service area being exposed to the same number of outages, there should be little variation in outages across industries within the same neighborhood. The fourth bar in fig. 4 confirms this. The range in outages within an industry in a neighborhood is similar to that within a neighborhood. In sum, the variation in outages reported by firms in the dataset matches what would be expected, given the design of the rationing program.

Could certain firms have been given preferential treatment, rendering the outages endogenous? The following argument suggests that this was unlikely. The electricity distribution system is such that each service area is served by a feeder power line that delivers power from a substation. ECG cuts power to a service area by switching off the feeder for that area. Therefore, all customers in that area would have no power. A customer can be excluded from the outage only if it has a dedicated feeder line, which is the case for large public entities including the airports and public hospitals. Because of this technical setup, it would not have been feasible for ECG to give preferential treatment to a given firm in a given service area in the sample, especially since the sample includes only small, private entities. Nonetheless, the analysis below checks whether the number of outage days reported is correlated with available firm characteristics.

The characteristics include whether the firm is female-owned, foreign-owned, a sole proprietorship, or in an electricity-intensive industry. An electricity-intensive industry is defined as one whose average ratio of electricity expenditure to value added exceeds the overall average. Data from the initial year are used to minimize endogeneity. Because ECG is government owned, a concern is that politically connected firms may have received preferential treatment. While this is likely to be a concern for larger firms, the firms in the sample are very small. As shown above, the average firm had six workers. The survey includes data on firm ownership (which are used to determine female and foreign ownership), but none of the firms have any government ownership.

Table 2 reports the results from the regressions of outages on each firm characteristic. None of the characteristics appear to be correlated with outages. Nonetheless, in the event that some unobserved time-invariant firm characteristics are correlated with the outages reported by firms, the regressions include firm fixed effects.

4. Econometric Analysis

This section presents the study's empirical strategy and results.

Table 2. Firm Characteristics and Outages

	Outage days
	(1)
Female-owned	−0.245
	(0.216)
Foreign-owned	0.124
	(1.089)
Sole proprietorship	−0.0868
	(0.400)
Electricity-intensive	−0.0306
	(0.292)
No. of observations	4,124
No. of firms	842

Source: Authors' analysis based on data from authors' 2016 survey of small and medium-sized manufacturing firms in Ghana.
Note: Each cell represents a separate regression of the number of days with outages on a firm characteristic. *** Indicates statistical significance at the 1 percent level, ** at the 5 percent level, and * at the 10 percent level. Robust standard errors, in parentheses, are clustered at the firm level.

Empirical Strategy

The impact of electricity shortages on firm outcomes is analyzed using the following estimating equation

$$y_{ijct} = \beta_0 + \beta_1 outage\ days_{ijct} + \lambda_i + \eta_{jt} + \delta_{ct} + \varepsilon_{ijct} \tag{1}$$

y_{ijct} is an outcome for firm i in industry j in city c in year t and $outage\ days_{ijct}$ is the average number of days on which the firm experienced power outages in a month.

Despite the arguably random nature of outages, several precautions are taken to address any potential endogeneity. First, firm fixed effects are included in all regressions to account for any time-invariant firm characteristics that could potentially simultaneously affect a firm's reported outage frequency and its other outcomes. Second, industry-year fixed effects are included to control for shocks that affect all firms in a particular industry. City-year fixed effects are also included to control for shocks that affect all firms in a particular city. Thus, β_1 is an estimate of the effect of an increase in the outages experienced by a firm on its outcomes, controlling for any other shocks in the firm's industry and city. Standard errors are clustered at the firm level to account for serial correlation within firms.

Effect of Outages on Productivity

Tables 3 and 4 report the results from estimating equation (1) with labor productivity and total factor productivity as the outcomes of interest. Labor productivity is calculated as the ratio of the firm's value-added to its number of workers. Total factor productivity is calculated following the method in Levinsohn and Petrin (2003). Details on the construction of the total factor productivity measure are provided in supplementary online appendix S1 available with this article at *The World Bank Economic Review* website.

Estimates are first presented without any fixed effects in column (1) of tables 3 and 4. The estimates suggest negative and statistically significant effects on productivity. In the event that there are any unobserved time-invariant firm characteristics that may affect the outages reported by firms, firm fixed effects are included in column (2). The magnitudes of the coefficients change slightly, but they remain negative and statistically significant. In column (3), industry-year fixed effects are included to control for shocks that may have affected all firms in an industry that are correlated with both outages and firm outcomes. For instance, shocks such as adverse weather could cause unexpected outages outside the rationing schedule, and could also potentially directly reduce firm productivity for certain industries. Not accounting for such shocks could bias the coefficients and result in overestimating the magnitude of the impact of

Table 3. Effect on Labor Productivity

	Log(labor productivity) (1)	Log(labor productivity) (2)	Log(labor productivity) (3)	Log(labor productivity) (4)
Outage days	−0.0421***	−0.0349***	−0.0123***	−0.0116***
	(0.00934)	(0.00259)	(0.00344)	(0.00350)
No. of observations	3,907	3,907	3,907	3,907
No. of firms	812	812	812	812
Firm effects		×	×	×
Industry-year effects			×	×
City-year effects				×

Source: Authors' analysis based on data from authors' 2016 survey of small and medium-sized manufacturing firms in Ghana.
Note: *** Indicates statistical significance at the 1 percent level, ** at the 5 percent level, and * at the 10 percent level. Robust standard errors, in parentheses, are clustered at the firm level.

Table 4. Effect on Total Factor Productivity

	Log(tfp) (1)	Log(tfp) (2)	Log(tfp) (3)	Log(tfp) (4)
Outage days	−0.0235*	−0.0235***	−0.0161***	−0.0160***
	(0.0122)	(0.00237)	(0.00343)	(0.00349)
No. of observations	3,637	3,637	3,637	3,637
No. of firms	751	751	751	751
Firm effects		×	×	×
Industry-year effects			×	×
City-year effects				×

Source: Authors' analysis based on data from authors' 2016 survey of small and medium-sized manufacturing firms in Ghana.
Note: *** Indicates statistical significance at the 1 percent level, ** at the 5 percent level, and * at the 10 percent level. Robust standard errors, in parentheses, are clustered at the firm level.

outages. Controlling for industry-year fixed effects in column (3) reduces the magnitudes of the estimates, but they remain negative and statistically significant. Further, controlling for city-year fixed effects in column (4) slightly changes the magnitudes. Given the impacts of these controls on the magnitudes of the estimates, firm, industry-year and city-year fixed effects are included in the following regressions.

Because of the retrospective nature of the survey, a potential cause for concern is recall error. In particular, in attempting to recall outages, firms may have engaged in ex post rationalization whereby a firm, believing that outages negatively affect productivity, may have reported higher outages for years in which it had low productivity. However, this seems less likely, since, as shown in section 3, the variation in reported outages lines up with what would be expected based on the design of the rationing program. Nonetheless, because the magnitude of recall error tends to increase over time, the robustness of the results to recall error is tested by successively dropping earlier years from the sample in estimating equation (1) in table S2.1 in the supplementary online appendix.[4] The estimates still indicate statistically significant negative impacts of outages on productivity, with the magnitudes of the effects similar to those from the full sample in tables 3 and 4.

To further address the concern of ex post rationalization, regressions where the number of outage days reported by a firm is replaced with the average of the outage days reported by all firms in the firm's neighborhood excluding the firm's own reported outages are run. Table S2.2 in the supplementary

4 Note that, with the fixed effects estimation, at least two years of data are needed, so data from 2014 cannot be dropped since the last year of data is 2015.

online appendix reports the estimates from these regressions.[5] The estimates still suggest negative impacts of outages on productivity, with higher magnitudes. These results suggest that the negative relationship between outages and productivity is unlikely to be driven by ex post rationalization by firms.

To further assess whether the findings are driven by recall error, administrative data on a metric for outages from ECG are used in place of the firm-reported outages. The metric, System Average Interruption Duration Index (SAIDI), captures the average number of outage hours per customer in a month. This metric is available at the following aggregate location levels: the city of Accra, the city of Tema, the Ashanti region where the city of Kumasi is located, and the Western region where the city of Sekondi-Takoradi is located. Using this metric for outage hours in place of firm-reported outage days, there is still a negative relationship between outages and productivity. Table S2.3 in the supplementary online appendix reports the results of this analysis. In the World Bank's enterprise survey in Ghana in 2013, firms reported that, on average, an outage lasted for 7.8 hours. Multiplying this number by the estimates of the effect of an additional hour of outages in table S2.3 produces magnitudes of the same order as the estimates of the effect of an extra day with outages in tables 3 and 4.[6]

In summary, the estimates indicate that power outages result in a reduction in labor productivity and total factor productivity. The magnitudes of the estimates suggest economically meaningful impacts. From the estimates in column (4) of tables 3 and 4, one extra day of outages each month results in about a 1 percent reduction in labor productivity and total factor productivity. The average number of days with outages in a month in the sample is 10.[7] Thus, the estimates suggest that reducing this number to zero, which is a common scenario in most developed countries, could increase productivity by about a nontrivial 10 percent. A caveat worth noting is that this prediction depends on the assumption that each additional day of outages has the same effect on productivity regardless of the history of outages. The aggregate annual nature of the data, unfortunately, does not make it possible to tease out whether the history of outages matters for the effects of an additional day of outages.

It is also worth noting that the variation in outages in the strategy, generated by variation over time and across service areas, could be driven by variation in both scheduled and unscheduled outages. Recall that during the rationing program, if a service area was in stand-by mode it could be subject to unscheduled power outages if the electricity demand during that period exceeded supply. In addition, unscheduled power outages could occur due to unexpected damage to electrical equipment. While it would be useful to understand the effects of scheduled versus unscheduled outages, unfortunately there is no information on whether an outage experienced by a firm was a scheduled or unscheduled one. The estimates should, therefore, be interpreted as the effects of both scheduled and unscheduled outages.

Effect of Outages on Output and Inputs

The analysis in table 5 unpacks the negative impact of outages on productivity by looking at the impacts on output and production inputs. The results indicate that while output falls due to outages (column 1), there is no statistically significant impact of outages on the number of workers used by the firm (column 2).[8]

5 Note that there are fewer firms compared to tables 3 and 4 because some firms were the only ones in their neighborhood.

6 Please note that although the inclusion of city-year fixed effects in tables 3 and 4 slightly reduces the magnitudes of the estimates, particularly in the case of labor productivity, table S2.3 excludes city-year fixed effects because the measure of outages in this table is at the city-year level.

7 This number is consistent with the data from the World Bank's enterprise surveys in Ghana, which show that the number of outages in a typical month reported by Ghanaian firms was 9.5 and 8.4 in 2007 and 2013, respectively (World Bank 2007, 2013).

8 Note that, as is a common constraint for many firm-level datasets, the labor data are available only on an annual basis and only for the extensive margin of labor, that is, the number of workers. Single-worker firms, which constitute a third of the sample, would have less flexibility to respond on this extensive margin; in table 6, when the sample is split into single-worker and multiple-worker firms, it can be seen that labor, as measured by the number of workers, is more

Table 5. Effect on Output and Inputs

	Log(output) (1)	Log(labor) (2)	Log(machinery) (3)	Log(raw materials) (4)
Outage days	−0.0104***	−0.00307	−0.00648*	−0.0136***
	(0.00334)	(0.00196)	(0.00359)	(0.00333)
No. of observations	4,063	4,120	4,011	3,974
No. of firms	830	838	818	809

Source: Authors' analysis based on data from authors' 2016 survey of small and medium-sized manufacturing firms in Ghana.
Note: *** Indicates statistical significance at the 1 percent level, ** at the 5 percent level, and * at the 10 percent level. Robust standard errors, in parentheses, are clustered at the firm level. All regressions include firm fixed effects, industry-year effects and city-year effects.

The estimates in columns (3) and (4) indicate that outages result in a reduction in raw materials and some reduction in the firm's stock of machinery. These results suggest that, while firms may flexibly alter inputs such as machinery and raw materials in response to electricity shortages, some inputs such as the number of workers tend to be less flexible potentially owing to rigidities in the labor market. In particular, the reduction in labor productivity may stem from the reduction in the amount of capital available to workers or electricity-reliant capital becoming idle.

How do these results for small and medium-sized firms compare to those found for large firms in Allcott, Collard-Wexler, and O'Connell (2016)? The results on output, materials, and labor in this paper are in line with the empirical results in their paper. Their theoretical model predicts that electricity shortages reduce the marginal productivity of materials and labor, and hence firms reduce these inputs. They argue that while their model assumes that firms set labor with knowledge of the current year's shortages, if workers are hired before shortages are known, there may be less flexibility in adjusting labor. Empirically, they find large, significant reductions in output and materials, but insignificant reductions in labor and productivity.

While the results for output, materials, and labor are similar to those in Allcott, Collard-Wexler, and O'Connell (2016), this paper finds significant reductions in productivity in contrast to their paper. They carry out simulations that show that the lack of productivity losses in their sample are driven by large firms who are able to prevent the fall in productivity by using generators. The next section provides an analysis of firms' strategies in response to outages, including whether generator use mitigates the productivity losses from outages, and provides a discussion of the difference between this paper's results on productivity and those of Allcott, Collard-Wexler, and O'Connell (2016).

In contrast to the results in this paper and those of Allcott, Collard-Wexler, and O'Connell (2016), Hardy and McCasland (2018) study microenterprises and find that firms with multiple workers increase their labor (both number of hours and number of workers staffed) in response to outages, while single-worker firms decrease the number of hours worked. They argue that their results imply that, in response to outages, demand increases for low-skilled workers, who act as substitutes for electrical equipment, in contrast to high-skilled workers who act as complements.

Following Hardy and McCasland (2018), table 6 takes a closer look at the effect on labor by splitting the sample into single-worker and multiple-worker firms.[9] The results for these two subsamples are reported in columns (1) and (2) of table 6. As expected, there is no reduction in the number of workers in single-worker firms since this would imply an exit of the firm and the survey includes only surviving firms. There is a negative impact on labor for firms with workers. Columns (3) and (4) of table 6 estimate

responsive in multiple-worker firms. More generally, due to this data constraint, the analysis is unable to capture labor responses that may be in the form of short-term fluctuations or changes in the intensive margin of labor, that is, hours worked, which may be an option for single-worker firms.

9 Single-worker and multiple-worker firms are defined based on the number of workers from the firm's first year of data.

Table 6. Effect on Labor (Single versus Multiple-Worker Firms)

	Log(labor)					
Sample	Single-worker firms (1)	Multiple-worker firms (2)	Single-worker firms (incl. apprentices) (3)	Multiple-worker firms (incl. apprentices) (4)	Multiple-worker firms (at most 5 workers) (5)	Multiple-worker firms (in wearing apparel industry with at most 5 workers) (6)
Outage days	0.00411	−0.00758***	0.00774	−0.00575***	−0.00779**	−0.0138***
	(0.00331)	(0.00220)	(0.0198)	(0.00215)	(0.00349)	(0.00513)
No. of observations	1,327	2,793	151	3,969	1,342	851
No. of firms	271	567	33	805	273	173

Source: Authors' analysis based on data from authors' 2016 survey of small and medium-sized manufacturing firms in Ghana.
Note: *** Indicates statistical significance at the 1 percent level, ** at the 5 percent level, and * at the 10 percent level. Robust standard errors, in parentheses, are clustered at the firm level. All regressions include firm fixed effects, industry-year effects, and city-year effects.

the effects using a measure of labor that includes apprentices. Column (5) of table 6 restricts the sample to firms with at most five workers, leading to an average firm size of two workers, to more closely match the sample in Hardy and McCasland (2018). Finally, column (6) of table 6, further restricts the sample to firms in the wearing apparel industry to match the industry used in Hardy and McCasland (2018). Overall, the results suggest there is no increase in labor.

A key feature of the dataset used in Hardy and McCasland (2018) is the availability of high-frequency data on labor. In both this paper and Allcott, Collard-Wexler, and O'Connell (2016), data on labor are at the annual level and only on the extensive margin: that is, the number of workers. In contrast, Hardy and McCasland (2018) observe daily data on both the number of workers and hours worked at the firm level. Because small, informal firms tend to use informal hiring contracts where workers' hours are decided on a daily basis by the firm owner, the high-frequency nature of the data in Hardy and McCasland (2018) allows that study to capture short-term fluctuations in labor as a means of adapting to electricity outages. Because of the annual nature of the data on labor, this study is limited to measuring annual long-term changes and is unable to measure short-term labor responses to outages.

Firms' Strategies in Response to Outages

This section analyzes the strategies firms use to mitigate the impacts of electricity shortages and the effectiveness of these strategies in curtailing negative productivity impacts. The survey asked firms if they had used any of 11 strategies to cope with power outages. The 11 strategies are as follows:

1. Used a generator
2. Changed time of day during which production took place
3. Changed production process to a less electricity-reliant one
4. Stopped producing electricity-intensive products
5. Started producing less electricity-intensive products
6. Laid off workers
7. Changed location of enterprise
8. Took insurance policy
9. Reduced shifts
10. Operated fewer hours
11. Temporarily suspended production

Table 7 presents the means for these strategies. The most common response was operating fewer hours. Other common strategies included changing production times, changing production processes, suspending

Table 7. Strategies for Coping with Outages

	Mean (1)	Number of observations (2)
Operated fewer hours	0.56	4,185
Changed production time	0.48	4,194
Switched to less electricity-reliant process	0.40	4,193
Temporarily suspended production	0.28	4,168
Used generator	0.27	4,149
Started less electricity-intensive products	0.26	4,184
Stopped electricity-intensive products	0.17	4,183
Laid off workers	0.04	4,171
Reduced shifts	0.04	4,168
Took out insurance policy	0.03	4,167
Changed location	0.02	4,181

Source: Authors' analysis based on data from authors' 2016 survey of small and medium-sized manufacturing firms in Ghana.
Note: Each row reports the mean and number of observations for the dummy variable for a strategy.

production, using generators, stopping the production of electricity-intensive products, and starting the production of less electricity-intensive products.

To assess the accuracy of firms' reports of the strategies used, the following analysis checks if there are changes in variables that would be consistent with the strategies reported. In table 8, various firm outcomes are regressed on the number of outage days and dummy variables for each of the strategies listed above. The estimates in column (1) show that the generated share of electricity went up for firms that reported using generators as a coping strategy as indicated by the statistically significant and positive coefficient on the dummy variable for generator use. The estimates in column (2) show that the number of workers used fell for those firms that reported laying off workers and temporarily suspending production in response to power outages.

Finally, in column (3), the amount of machinery is positively related to using a generator. Because the survey asks for the total value of machinery, and not the value of machinery excluding generators, this likely reflects the mechanical increase in a firm's machinery as a result of acquiring a generator. In summary, firm outcomes change in ways that are consistent with the strategies reported by firms, validating firms' reports of how they coped with electricity shortages.

Are these strategies effective in mitigating the negative impacts of power outages? Table 9 addresses this question. Each row in the table reports the estimates from a separate regression of the log of labor productivity on the number of days with outages, a dummy variable for a strategy, and an interaction between this dummy variable and the number of days with outages. In the interest of space, only the coefficients on the outage days and the interaction term are reported. Column (1) reports the coefficient for outage days, and column (2) reports the coefficient for the interaction term. The results suggest that stopping the production of electricity-intensive products and starting the production of less electricity-intensive products were effective in mitigating the negative effects of outages on labor productivity.

Note that when the dummy variables for both of these strategies and their interactions with outages are included in the same regression, the coefficient on the interaction with the dummy for starting the production of less electricity-intensive products remains statistically significant while the coefficient on the interaction with the dummy for stopping the production of electricity-intensive products becomes much smaller and is no longer significant. This result suggests that losses are mitigated by firms stopping the production of electricity-intensive goods to start the production of less electricity-intensive goods. The regressions in table 9 are repeated for the log of total factor productivity and the log of output in tables S2.4 and S2.5, respectively, in the supplementary online appendix and similarly show that starting the

Table 8. Checking Validity of Reported Strategies

	Generated share of electricity (1)	Log(labor) (2)	Log(machinery) (3)
Outage days	0.00413***	−0.00245	−0.00846**
	(0.000735)	(0.00202)	(0.00351)
Used generator	0.493***	0.00517	0.147**
	(0.0293)	(0.0418)	(0.0661)
Changed production time	−0.0120	0.00676	−0.0186
	(0.0182)	(0.0568)	(0.0569)
Switched to less electricity-reliant process	−0.0110	−0.0185	0.138*
	(0.0203)	(0.0814)	(0.0823)
Stopped electricity-intensive products	−0.0446	0.0112	0.0264
	(0.0308)	(0.0559)	(0.109)
Started less electricity-intensive products	−0.0122	0.00399	−0.0959
	(0.0225)	(0.0457)	(0.0827)
Laid off workers	−0.0120	−0.141**	−0.200***
	(0.0203)	(0.0597)	(0.0472)
Changed location	−0.0340	−0.0537	−0.150
	(0.0624)	(0.114)	(0.104)
Took out insurance policy	−0.0369	0.255	−0.0196
	(0.0369)	(0.182)	(0.233)
Reduced shifts	−0.0391	0.111*	−0.00195
	(0.0250)	(0.0632)	(0.0648)
Operated fewer hours	0.00838	0.0201	0.00785
	(0.0129)	(0.0323)	(0.0525)
Temporarily suspended production	0.0206*	−0.0816**	−0.118
	(0.0120)	(0.0405)	(0.0738)
No. of observations	3,800	3,948	3,846
No. of firms	780	805	787

Source: Authors' analysis based on data from authors' 2016 survey of small and medium-sized manufacturing firms in Ghana.
Note: *** Indicates statistical significance at the 1 percent level, ** at the 5 percent level, and * at the 10 percent level. Robust standard errors, in parentheses, are clustered at the firm level. All regressions include firm fixed effects, industry-year effects, and city-year effects.

production of less electricity-intensive products was effective in mitigating the negative effects of outages on output and total factor productivity.

Because the strategies are likely to be simultaneously determined with the outcomes, and hence endogenous, an instrumental variables (IV) approach is used in analyzing the effectiveness of the strategies. Given the difficulty in finding valid external instruments for each strategy, the lag of the strategy is used as an instrument. The reasoning behind this approach is that a firm would be more likely to use a strategy in the current period if it had used it in the past. With the exception of the strategies of taking an insurance policy and changing location, the *F*-statistics for the first-stage regressions are large, ranging from 9.5 to 196.4, confirming the strength of the instruments.[10] The identification further relies on the assumption that the lag of the strategy affects the current period's outcome only through its impact on the current period's strategy. The results from this IV approach are reported in tables S2.6 through S2.8 in the supplementary online appendix. The results corroborate the earlier finding that changing the firm's product mix to favor less electricity-intensive products mitigated the negative effects of outages on output and productivity.

10 The *F*-statistics for the strategies of taking an insurance policy and changing location are less than one. The results for these two strategies should, therefore, be interpreted with caution.

Table 9. Effectiveness of Strategies in Reducing Labor Productivity Losses

Dependent variable	Log(labor productivity)	
	Outage days (1)	Outage days × strategy (2)
Strategy		
Operated fewer hours	−0.0102**	−0.00582
	(0.00474)	(0.00521)
Changed production time	−0.0121***	−0.00245
	(0.00451)	(0.00543)
Switched to less electricity-reliant process	−0.0145***	0.00280
	(0.00436)	(0.00525)
Temporarily suspended production	−0.0132***	0.000176
	(0.00401)	(0.00624)
Used generator	−0.0142***	0.00333
	(0.00360)	(0.00596)
Started less electricity-intensive products	−0.0168***	0.0168***
	(0.00389)	(0.00553)
Stopped electricity-intensive products	−0.0145***	0.0134**
	(0.00436)	(0.00605)
Laid off workers	−0.0136***	0.00724
	(0.00357)	(0.0131)
Reduced shifts	−0.0129***	−0.0109
	(0.00362)	(0.00957)
Took out insurance policy	−0.0133***	−0.000461
	(0.00357)	(0.0151)
Changed location	−0.0140***	0.0276***
	(0.00356)	(0.0104)
No. of observations	3,744	
No. of firms	780	

Source: Authors' analysis based on data from authors' 2016 survey of small and medium-sized manufacturing firms in Ghana.
Note: Each row represents a separate regression of the log of labor productivity on the number of days with outages, a dummy variable for a strategy, and the interaction of these two variables. Column (1) reports the coefficient for outage days, and column (2) reports the coefficient for the interaction between outage days and the dummy variable for the strategy. *** Indicates statistical significance at the 1 percent level, ** at the 5 percent level, and * at the 10 percent level. Robust standard errors, in parentheses, are clustered at the firm level. All regressions include firm fixed effects, industry-year effects and city-year effects.

Interestingly, the use of generators, commonly thought of as a coping strategy for outages, is unable to mitigate the negative impacts of outages. This is in contrast to the results in Allcott, Collard-Wexler, and O'Connell (2016), where larger firms, because of generator ownership, are able to avoid productivity losses from outages. Keeping in mind that the average firm in their paper has 79 workers, compared to 6 in this paper, and that the lack of a negative productivity impact was found for the largest firms in their sample, a potential explanation for this difference in results is that the firms in the sample are not large enough to efficiently use generators. This is plausible, given the presence of large economies of scale in generator use resulting from its relatively high fixed costs. This lack of an apparent net benefit of generator use has also been noted in Steinbuks and Foster (2010). They show that in a sample of 25 African countries, on average the benefits of generator ownership, as measured by reductions in lost sales, do not exceed its costs. This raises the question of why these firms adopt generators. Steinbuks and Foster (2010) argue that firms may be adopting generators because of other benefits that are not captured by sales, such as reduced damage to equipment and higher quality of production. While the data do not make it possible to further explore the question of generator adoption, the results suggest that, at least for small and medium-sized firms, generators are unable to mitigate productivity and output losses from outages.

Exit of Firms

Firms may respond to the adverse impacts of outages by exiting the market. However, because the survey is retrospective in nature, this paper is able to analyze the impacts of outages only on surviving firms. Therefore, the estimates may not be representative of the initial population of small and medium-sized firms.

To assess the extent to which the sample is representative of the population, the sample is compared to the population of firms from the IBES. The IBES provided limited information on the firms. The available variables provided by the IBES include the city in which the firm is located and its specific address, the broad manufacturing sector in which it operates and whether it is a small or medium-sized firm according to the IBES definition. The firm characteristics in the sample are compared to those in the IBES population in table S2.9 in the supplementary online appendix. The largest differences are with respect to the firms' sectors. Compared to the population of firms, the firms in the survey were more likely to be in the textiles and wearing apparel sector and less likely to be in the food and beverage products sector.

The sectors in order of electricity intensity, from most intensive to least intensive, are machinery and equipment, food and beverage products, other manufacturing, textiles and wearing apparel, and wood and wood products.[11] To the extent that firms in electricity-intensive sectors are more likely to be adversely affected by outages and, hence, exit, the inability to fully represent firms in the more electricity-intensive sectors relative to those in the less-intensive ones suggests that the results may underestimate the magnitudes of the adverse impacts of outages on firms. Additionally, since the IBES census was started in 2014, two years after the onset of the crisis, the population of firms in the census itself may not be representative of the firms that existed prior to the crisis. This may further result in an underestimation of the magnitudes of the effects of outages.

5. Conclusion

Despite the potential for the pervasiveness of power outages in many developing economies to hamper growth, there has been relatively little work on understanding the implications of power outages for firms. Using random variation in power outages among small and medium-sized manufacturing firms in Ghana induced by a rationing program, this paper attempts to examine the impact of power outages on the productivity of firms and the effectiveness of firms' coping mechanisms. Two main conclusions are drawn from the analysis in this paper.

First, power outages have a significant negative impact on productivity. The estimates suggest that, for instance, reducing the number of days in a month with outages from the average of about 10 in Ghana to none, as is the typical case in most developed countries, has the potential to increase productivity by about 10 percent.

Second, firms are able to reduce the negative productivity impacts of outages by altering their product mix in favor of less electricity-intensive products. This coping strategy can have broader implications for the variety of products available to consumers. Further, the results suggest that one of the most common strategies employed worldwide, the use of a generator, is unable to alleviate the negative productivity impact potentially due to the inability of small firms to efficiently use generators, given the substantial economies of scale in electricity generation.

11 The sectors included in the broad IBES category "other manufacturing" include chemicals, metal, and all other manufacturing.

Finally, while entry and exit are dimensions along which firms may respond to electricity constraints, this paper is unable to analyze these since it uses a retrospective panel. Entry and exit are important responses that future research could explore.

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