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Impact of Electricity Shortages on Productivity: Evidence from Manufacturing Industries

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ABSTRACT

Electricity shortages present a significant constraint on manufacturers, who rely on electricity as an important input into production. In China, electricity supply has been growing rapidly. However, the rapid industrialization sometimes makes the power supply still unable to meet the demand. Using a survey of 1673 Chinese manufacturing firms, this paper explores how firms response to electricity shortages and its impact on productivity. We find that self-generation of electricity and investment in Research and Development (R&D) have significant positive relationships with electricity shortages. Further investigations reveal that self-generation is the most common way to deal with electricity shortages. However, it aggravates productivity loss. Though investment in Research and Development can promote productivity, it cannot offset the negative impact of electricity shortages on productivity. Analyses on subsamples show heterogeneity in the impacts of electricity shortages across firms. In particular, large firms are more inclined to invest in R&D than small and medium-sized firms are. They are also the one who suffer significant productivity loss due to self-generation of electricity. Though it is possible for medium-sized firms to reduce productivity loss through R&D, they are not likely to invest in R&D as a response to electricity shortages. This study illustrates that firms can hardly have effective solutions to electricity shortages, and policy makers should take great efforts to increase electricity supply.

KEYWORDS

Electricity shortages; research and development; productivity; electricity efficiency

1 Introduction

Infrastructure is widely perceived to be basic and important for economic growth. For some resources, like electricity, reliable and economic storage is hardly possible. Unreliable supply of electricity requires firms to respond in other ways to ensure their performance.

In the past decades, China has spent greatly on power sector. However, electricity supply remains as an important issue for China's economic and social development [1–3]. According to the prediction by China Electricity Council (CEC), in the second half of 2020, there are still power shortages in Hunan, Jiangxi, Guangdong, and Western Inner Mongolia during the peak period. Production and operation are suspended when electivity is cut off. Though the cutoff is supposed to be orderly arranged, and enterprises can adjust their production plan accordingly, losses are unavoidable. Responses, such as self-supply of electricity with generators, are taken to reduce the losses as much as possible. However, these responses can be costly by themselves.

In this paper, we study how firms respond to electricity shortages and the impact on productivity. First, we try to find out whether there are effective measures to deal with power failure. To this end, we examine firms' investment in technology, labor and generator. Although the impact of energy prices on productivity and output has been recognized by the existing research, little discussion has been done about the impact of electricity shortages on the investment in technologies. As most innovations in production processes are reliant on electricity, we can expect that the electricity intensity of an industry is positively associated with its technology intensity. In this case, electricity shortages would result in less use of new technologies. An alternative is to invest in more electricity-efficient technologies, which may offset the impact of electricity shortages on productivity. In this paper, we will explore how firms respond to electricity shortages from the perspective of investment in technology.

Second, we also identify other possible partial solutions: Use of temporary workers and generating electricity as site, namely "self-generation". Although policymakers are well aware that electricity shortages can be obstacles for economic growth, it is difficult to increase electricity supply in a short period, because the construction of power infrastructure normally will take several years. The fluctuation of electricity demand and the delay of electric power investment will inevitably result in an unbalance between electricity demand and supply. Quantifying the distortions of firms' activities due to electricity shortages will motivate policymakers to advance the plan for electric power investment.

Third, we examine whether firms' responses can reduce the productivity loss caused by electricity shortages. If the productivity loss due to electricity shortages cannot be reduced at firm level, increasing electricity supply at the country level will be the best solution. For the policymakers, it is important to increase power supply, and to do it in environmental-friendly way. This study will underline the important role government plays in developing clean energy and promoting economic growth.

The remainder of the paper is organized as following. Section 2 is literature review; Section 3 represents our empirical strategy, including the descriptions of data, the empirical model, and the variables we will use. In Section 4, we will represent our results and discussion and Section 5 will be the conclusions.

2 Literature Review

This paper is part of the extensive literature that evaluates the economic effects of investment in infrastructure. Based on a panel of 18 OECD countries during 1870–2009, Farhadi [4] found that the growth of infrastructure could positively influence the growth of labor productivity and total factor productivity. Similarly, Banerjee et al. [5] found that access to transportation networks had a positive causal effect on *per capita* GDP. Yu et al. [6] found positive spatial spillover effects of transport infrastructure in Chinese regions during 1978–2009. Dimitriou et al. [7] studied the economic effects of mega infrastructure project. Applying the input-output (IO) method, Dimitriou et al. [8] analyzed the economic footprint of air transport in Greece, and found that the air transport sector contributed 10.8% of the national GDP. When assessing the macroeconomic impact of Niger's Kandaji Dam project, Beguy et al. [9] found that construction of the project spurred domestic production and increased GDP by 0.25. The econometric estimations based on panel surveys of the households in rural Vietnam suggested that grid electrification benefited not only the households in income, expenditure, and educational outcomes, but also the rural economy as a whole [10]. Some studies have focused on the disproportionate impact of public infrastructure deficiencies. For example, Hallward-Driemeier et al. [11] and Dollar et al. [12] revealed that in developing countries enterprises' access to infrastructure services varied by type of service and firm size, with smaller firms shouldering disproportionate burdens.

Our paper is also part of the subset studies concerning about the impact of energy, especially electricity supply, on economic growth and performance. Chakravorty et al. [13] examined the effects of connecting a household to the grid and daily electricity supply on non-agricultural incomes. Using a panel of more than 10,000 households during the period between 1994 and 2005, they found that a grid connection could increase non-agricultural incomes of rural households by about 9 percent. Lipscomb et al. [14] examined the long-term effects of electrification on local income and population density in Brazil. They found large positive effects of improved electricity supply on in-migration of people and firms. Based on an econometric analysis with data from 1953 to 2010, Cheng [15] revealed that China's electricity generation growth way-one Granger caused her GDP growth. Ou et al. [16] used a CGE model to simulate the impacts of electricity shortages on China's Economy. They found that electricity shortages affected the macro-economy negatively, and the light industry, the coal production industry, and the heavy industry were most affected. Study of Pakistan's agriculture sector, industrial sector, and service sector also revealed that electricity shortages deteriorated output [17]. Moreover, power shortages led to the closure of factories and the losses of jobs [18].

Some studies focused on the effects of electricity shortages on firms' activities. To offset the negative impacts of electricity shortages on operation, industrial firms often opt for self-generation of electricity. A review of 25 sub-Saharan countries by Foster et al. [19] showed that in-house generation accounted for more than 25 percent of the installed generating capacity, though self-generation is over 300 percent more expensive than electricity supplied from the grid. Similarly, the study on developing countries by Alby et al. [20] revealed that unreliable electricity supply induced firms to invest in costly generators or to settle for second-best technologies in sectors whose first-best technology depended heavily on electricity. In these sectors, small firms were squeezed out of the financial market by a high prevalence of power outages and unable to borrow to expand production. Hallward-Driemeier et al. [11] and Dollar et al. [12] also documented patterns of access to infrastructures in developing countries and show that electricity were often the largest barrier, especially for small firms.

Besides the more adverse impact on small firms, unreliable electricity supply also has negative effects on industry choices and performance. Abeberese [21] found that Indian firms switched to less electricity-intensive production processes when there was an increase in electricity price, which led to lower output and productivity growth rates. On the contrary, electricity network expansion could lead to an increase in manufacturing output [22]. Allcott et al. [23] found that electricity shortages reduced the average Indian firm's revenues and producer surplus. Fisher-Vanden et al. [1] estimated the impacts of electricity shortages in the early 2000s on Chinese manufacturing firms. They found that firms purchased more electricity-intensive inputs in response to electricity shortages. This shift from "make" to "buy", namely "outsourcing", could be costly, but helped firms to avoid substantial productivity losses. A recent study by Elliott et al. [24] revealed that as a result of rising electricity costs, Chinese manufacturing firms were more likely to switch to a less energy intensive industry.

3 Methodologies

3.1 Data and Information on Chinese Firms

The material we use for empirical study is the World Bank Enterprise Survey (WBES) of Chinese manufacturing firms. The WBES conducted in 2012 provides the information on a random sample of 1,673 manufacturing firms over the fiscal year 2011 in 25 Chinese cities[1]. Most of these cities are in eastern China and are either capital cities or main cities. The experience of these typical cities in 2011 could well represent the effects of energy supply on Chinese economic development in the past decades of years.

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[1] The samples are from the following 25 cities: Hefei, Beijing, Guangzhou, Shenzhen, Foshan, Dongguan, Shijiazhuang, Tangshan, Zhengzhou, Luoyang, Wuhan, Nanjing, Wuxi, Suzhou, Nantong, Shenyang, Dalian, Jinan, Qingdao, Yantai, Shanghai, Chengdu, Hangzhou, Ningbo, Wenzhou.

Firms' locations and sizes can change their access to electricity. Capital cities or main cities, especially those in eastern provinces, have priorities in electricity consumption, as they are the economic centers. Important economic position makes it possible that these cities experience less power outages. Therefore, it is plausible to believe that firms in these cities are less affected by electricity shortages. This may be a disadvantage, because the impact of electricity shortages would be underestimated. Another important factor is firms' sizes. Large firms play an important role in local economic development. Though enjoying more bargaining power over resources access, they are also vulnerable as they may use more machines in production process. In fact, about 12% of the large firms in our investigation reported that they experienced at least one power outage in a typical month in 2011.

Our work provides firm-level distribution of energy shortages. Based on the firm-level data on power outages in a typical month over the fiscal year 2011, we build up two indicators of electricity shortages. The measure is to divide firms into three groups. The first group consists of firms who reported experiencing no power outage. The second group includes firms who reported experiencing one power outage in a typical month. The third group consists of firms who experienced two or more outages a month. Among the 232 firms who experienced power outages 51 firms reported that they experienced more than two times of outages a month, and 181 firms reported only one outage a month. Fig. 1 shows the distribution of power outages.

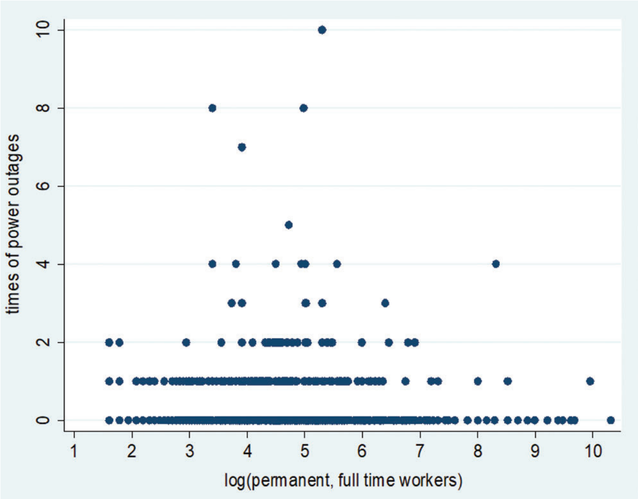

Figure 1: Distribution of power outages in a typical month and firms' permanent, full-time workers

The WBES dataset also provides information on sales, employees, investment in Research and Development and so on over the fiscal year 2011. Tab. 1 is a summary of the information including the number of firms, power outages, the average number of permanent and temporary employees, and the number of firms who used licensed technology, invested in research and development (R&D), and owned or shared a generator. According to the number of permanent, full-time employees at the end of 2011, there are 228 firms with employees less than 20, and 724 firms with more than 100 employees. Firms with employees between 20 and 100 are most likely to suffer from power outages. There are totally 210 firms owning or sharing a generator, and almost half of them are large firms. The large firms also have the largest average number of temporary, full-time workers, the highest ratio of investing in R&D and using licensed technology from a foreign company.

Table 1: Descriptions of electricity shortages and other factors

Firm size	Number of firms	Power outages		Generator	Employees	Temporary workers	Licensed technology	R&D
		One	Two or more					
small	228	24 (10.6%)	3 (1.3%)	19 (8.3%)	13	3	21 (9.2%)	46 (20.2%)
medium	721	94 (13.2%)	19 (2.7%)	90 (12.5%)	55	8	148 (20.5%)	294 (40.8%)
large	724	63 (8.8%)	29 (4.0%)	101 (14.0%)	609	18	231 (31.9%)	379 (52.3%)
all firms	1673	181 (10.9%)	51 (3.1%)	210 (12.6%)	289	12	400 (23.9%)	719 (43.0%)

Note: Firms with employees less than 20 are small; firms with 20 to 100 employees are medium; firms with over 100 employees are large.

There seems to be positive relationships between electricity shortages and self-generation, use of temporary workers, and investment in new technology including using licensed technology from foreign companies and investing in R&D. When production is significantly affected by electricity shortages, firms will respond in a number of ways to offset the effect. For example, a firm may choose to invest in more electricity-efficient technologies either by investing in R&D or by buying technology from other companies, which will increase output when electricity is available. Owning or sharing a generator will provide self-generating electricity during blackout. If power outages are seasonal or scheduled, using temporary workers to produce more when there are no blackouts are plausible.

In the following empirical analysis, we first explore the ways Chinese manufacturing firms respond to electricity shortages. Their responses have important policy implications. If there is a significant positive relationship between electricity shortages and investing in R&D, it implies that the investment in R&D might be able to improve electricity efficiency. Such technology will improve productivity, and at the same is environmental friendly. Using licensed technology from foreign companies may have the same implication. If a significant positive relationship is found between electricity shortages and owning or sharing a generator, it indicates that Chinese manufacturing firms turn to self-generation and might suffer productivity loss, becasue the price of self-generation is higher than that of grid. If the production is electricity-intensive, it is less likely to offset the effect of electricity shortages by using more labors as most of the production processes depend on machines. A significant positive relationship between electricity shortages and temporary, full-time workers might imply that the production is less dependent on electricity and more labor-intensive.

The second issue we are interested in is whether the above possible responses are able to relieve or offset the impact of electricity shortages on firms' productivity. Take R&D investment for example. Technology innovation is closely related to productivity improvement. If productivity-enhancing technologies are those that are electricity-intensive, technology development will make production more relied on electricity. In this case, only more electricity-efficient technology will bring higher productivity when there are electricity shortages.

According to the discussion above, we develop three testable hypotheses:

1. Investment in technology: Firms may invest in R&D or licensed technology from foreign-owned companies when facing electricity shortages, implying a potential productivity improvement.
2. Self-Generation: Firms may turn to self-generation during power outages, resulting in high production cost and low productivity.
3. Temporary workers: Firms may substitute away from machines toward labors to ensure production, implying switching to less electricity-intensive industries.

3.2 Empirical Model

To test the three hypotheses presented in Section 3.1, we start with examining the relationship between electricity shortages and the possible responses: Investment in technology, self-generation and using temporary, full-time workers. To this end, we use the following empirical Model 1:

$$response_i = \alpha_0 + \alpha_1 outage_i + \alpha_2 outages_i + \Gamma cont_{firm_i} + \Omega cont\_region_r + \eta_r + \eta_j + \varepsilon_i \tag{1}$$

where i denotes firm, r denotes region, and j denotes industry. $response_i$ denotes firm's responses to electricity shortages, including investing in R&D, using licensed technology from foreign companies, owning or sharing a generator, and using temporary, full-time employees. $outage_i$ and $outages_i$ are indicators of power outages the firms experienced in a typical month. $cont\_firm_i$ is a set of firm-level control variables, including labor-productivity, human capital, size, ownership and exporting experience. $cont\_region_r$ consists of two region-level control variables, GDP and population of the cities where the firms locate. η_r and η_j are fixed effects for city and industry, respectively, to control bias due to unobserved factors. ε_i is the error term that includes all the unobservable factors.

Another important issue is whether these responses can offset the impact of electricity shortages on productivity. As most of the production processes are reliant on electricity, we might expect it to be the case that these responses are to relieve the impact of electricity shortages on productivity. The identification of the effects is achieved through the presence of interaction terms between the indicators of power outages and the indicators of the responses. A positive and significant coefficient indicates that a certain response can reduce productivity loss due to electricity shortages. To this end, we use the following empirical Model 2:

$$\begin{aligned} laborprod_i = {} & \alpha_0 + \alpha_1 outage_i + \alpha_2 outages_i + \alpha_3 outage_i \cdot response_i + \alpha_4 outages_i \cdot reponse_i \\ & + \Gamma' cont\_firm_i + \Omega cont\_region_i + \eta_r + \eta_j + \varepsilon_i \end{aligned} \tag{2}$$

where i, j and r denote firm, industry and region, respectively. $laborprod_i$ represents labor productivity. All the other symbols have the same meaning as in Model 1.

3.3 Measurements

1. Electricity shortages: $outage_i$ and $outages_i$. In WBES dataset, the firms reported how many power outages they experienced in a typical month. For firms who reported one power outage in a typical month, variable $outage_i$ will be assigned value of one. Otherwise, it will be assigned zero. $outages_i$ is one for firms who reported two or more outages. Otherwise, it is zero.
2. Investment in technology: $R\&D_i$ and $licensed\_tech_i$. We use two dummies to indicate whether the firms had invested in new technology. Dummy $R\&D_i$ is equal to one for firms who had spent on R&D. A second variable to measure investment in new technology, $licensed\_tech_i$, is based on the report on whether using technology licensed by a foreign-owned company, excluding office software. For the firms who reported "Yes", $licensed\_tech_i$ is equal to one.
3. Self-generation: $self\_g_i$. $self\_g_i$ is equal to one if a firm owned or shared a generator.
4. Temporary worker: $temp\_w_i$. It is the number of full-time seasonal or temporary workers.
5. Control variables: $cont\_firm_i$ (firm-level control variables) and $cont\_region_r$ (region-level control variables). $laborprod_i$ denotes firms' productivity. As there is no information on total output for the calculation of total factor productivity, we use sales *per capita* as a proxy, where sales are total annual sales for all products and services. $worker\_edu_i$, denoting human capital, is the ratio of employees who completed second school to the total of full-time permanent workers. $exporter_i$, a dummy, is equal to 1 if more than 10% of the products is exported directly. According to the definition of foreign direct investment in Chinese Statistical Yearbook, we define $foreign_i$ as a

dummy, equal to 1 if private foreign individuals, companies or organizations own over 10% share of the firms. $laborprod_i$, $worker\_edu_i$, $exporter_i$, and $foreign_i$ are all firm-level control variables. The region-level control variables include $city\_GDP_j$ and $city\_pop_j$, denoting GDP and resident population of the cities where the firms are located.

The definitions and sources of the variables are summarized in Tab. 2. The descriptive statistics are presented in Tab. 3.

Table 2: Variables, their definitions and sources

Variable type	Variable	Definition	Data sources
Electricity shortages	*outage*	Dummy, One power outage in a typical month	World Bank Enterprise Survey
	outages	Dummy, two or more power outages in a typical month	
Possible responses	*R&D*	Dummy, investing in R&D	World Bank Enterprise Survey
	licensed_tech	Dummy, use licensed technology from a foreign-owned company, excluding office software	
	self_g	Dummy, own or share a generator	
	temp_w	Number of full-time seasonal or temporary workers	
cont_firm:	*laborprod*	labor productive: Logarithm of sales *per capita*	World Bank Enterprise Survey
	worker_edu	Human capital: Ratio of full-time permanent workers who completed second school	
	exporter	Dummy, more than 10% of the products is exported directly	
	foreign	Dummy, over 10% share of the firms are owned by private foreign individuals, companies or organizations	
cont_region:	*city_GDP*	Logarithm of city GDP	Statistical yearbooks of each city
	city_pop	Logarithm of resident population of the cities	

Table 3: Descriptive statistics

Variable	Mean	SD	Min	Max
outage	0.109	0.311	0	1
outages	0.030	0.172	0	1
R&D	0.433	0.495	0	1
licensed_tech	0.241	0.428	0	1
self_g	0.125	0.331	0	1
temp_w	11.979	38.400	0	600
laborprod	12.458	1.034	8.911	17.770
worker_edu	50.285	28.205	0	100
exporter	0.198	0.398	0	1
foreign	0.075	0.264	0	1
city_GDP	8.646	0.451	7.701	9.862
city_pop	6.735	0.261	6.377	7.761

4 Results and Discussion

4.1 Response of Chinese Manufacturing Firms as a Whole to Electricity Shortages

Our first step is to investigate firms' responses to electricity shortages by estimating the Model 1. Tab. 4 reports the results. We omit the firm-level and region-level control variables in odd-numbered columns (1), (3), (5) and (7). Our results remain qualitatively unchanged when these variables are controlled for in the even-numbered columns, indicating that our results are robust to a certain extent.

Table 4: Estimations for firms' response and electricity shortages

	Dependent Variable: *response*							
Independent Variables	*response = R&D*		*response = licensed_tech*		response = *temp_w*		*response = self-g*	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
outage	0.196*	0.373***	−0.069	0.075	2.972	3.932	1.187***	1.153***
	(0.101)	(0.106)	(0.110)	(0.119)	(4.008)	(4.299)	(0.106)	(0.110)
outages	0.478***	0.471**	0.024	−0.122	14.518	13.862	1.337***	1.175***
	(0.183)	(0.190)	(0.197)	(0.201)	(10.278)	(10.293)	(0.183)	(0.185)
city_pop		0.386**		0.460***		12.623***		−0.366
		(0.171)		(0.175)		(4.304)		(0.228)
city_GDP		−0.477***		0.193*		−6.633**		0.256**
		(0.094)		(0.102)		(2.820)		(0.122)
laborprod		0.198***		0.076**		1.893*		0.100**
		(0.032)		(0.035)		(1.047)		(0.041)
worker_edu		0.007***		0.006***		0.015		−0.005***
		(0.001)		(0.001)		(0.031)		(0.001)
foreign		0.203		0.719***		1.251		0.212
		(1.127)		(0.125)		(4.554)		(0.162)
exporter		0.427***		0.437***		6.017**		0.360***
		(0.084)		(0.089)		(2.995)		(0.106)
constant	−0.088	−1.393	−0.364***	−6.614***	18.858***	−34.702	−1.505***	−2.370*
	(0.088)	(1.013)	(0.097)	(1.057)	(2.856)	(27.646)	(0.125)	(1.362)
City fixed effects & Industry fixed effects are controlled								
observations	1647	1621	1645	1617	1631	1609	1658	1631
R^2	0.01	0.07	0.03	0.12	0.01	0.02	0.13	0.16

Notes: (1) *, **, ***: Coefficients are statistically significant at the levels of 10%, 5% and 1%, respectively. (2) In the parentheses are robust standard error.

In column (1) and column (2), the coefficients on *outage* and *outages* are all positive and significant when the dependent variable is R&D. In column (2), the coefficients on *outage* and *outages* are 0.373 and 0.471, respectively. Electricity shortages increase the probability of investing in R&D. One power outage a month increases the probability of investing in R&D by approximately 13.6%. The probability would be even higher, namely 17.2%, if there are two power outages in a typical month. The coefficients on control variables, except *foreign* and *city_GDP*, are positive and significant. The significant positive relationship between electricity shortages and investment in R&D suggests that when facing electricity shortages, firms are likely to adopt new and advantage technologies or machines. We will investigate in Sector 4.4 whether R&D investment aims at relieving the impact of electricity shortages on productivity.

Though R&D is an important source for technology development, the failure of R&D will result in nothing of any new or advanced technologies. Besides, self-reported R&D investment could be noisy and subjective because it is based on the firms' self-assessment about their product or process innovations. Therefore, following Montalbano et al. [25], we use variable *licensed_tech* as an indicator of investment in advanced technology. The results are presented in column (3) and column (4). To our surprise, the coefficients on *outage* are not significant. Neither are the coefficients on *outages*. In column (5) and column (6) are the estimations for using temporary, full-time workers. The coefficients on *outage* and *outages* are positive, but not significant. This means using more temporary labors is not a popular way to deal with electricity shortages.

Column (7) and column (8) report the results for owning or sharing a generator. The coefficients on the two indicators of electricity shortages are positive and significant at the 1% level. In particular, for firms who reported one outage a month, the probability of owning or sharing a generator is 19.6 percent higher. For firms who experienced two or more outages, the probability is almost 20 percent higher. It is highly possible that firms use self-generated electricity to relieve the impact of electricity shortages on their production.

4.2 Robustness Tests

As can be seen from Tab. 1, the small firms have the smallest sample size and the lowest ratio in spending on R&D and generator. Spending on R&D and generator have a higher request for financing ability. However, small firms are in an inferior positon. Missing of the control for firms' abilities to obtaining finance may result in misleading conclusions. In Tab. 4, the insignificant coefficients on power outages may catch not only the effect of power outages, but also the effect of financial abilities. The firms reported to what degree "*access to finance*" is an obstacle to their operation in the WBES. Thus, we add a finance-specific variable, *finaccess*, to Model 1. *finaccess* is equal to zero when access to finance is reported as "no obstacle" or "minor obstacle", and equal to one when access to finance is regarded as "moderate obstacle", "major obstacle", or "very severe obstacle". The results are presented in column (1) and column (4) of Panel A and Panel B in Tab. 5. After controlling for the financial abilities, there remain significant positive relationships between electricity shortages and two types of responses, namely, investment in R&D and self-generation. Our results remain qualitatively unchanged from those in Tab. 4.

Table 5: Robustness tests

Dependent variable: *response*						
Panel A	(1)	(2)	(3)	(4)	(5)	(6)
	response = R&D			*response = licensed_tech*		
outage	0.321*** (0.107)	0.368*** (0.107)	0.383*** (0.114)	0.081 (0.119)	3.932 (4.299)	0.072 (0.125)
outages	0.505*** (0.194)	0.522** (0.193)	0.457** (0.197)	−0.114 (0.201)	13.862 (10.293)	−0.115 (0.205)
constant	−1.993* (1.066)	−1.332 (1.033)	−0.822 (1.093)	−6.797*** (1.072)	−34.702 (27.646)	−6.859*** (1.151)
observations	1611	1611	1410	1607	1609	1405
R^2	0.09	0.08	0.07	0.12	0.02	0.11
Panel B	*response = temp_w*			*response = self-g*		
outage	3.190 (4.363)	3.588 (4.245)	3.912 (4.855)	1.147*** (0.111)	1.174*** (0.111)	1.209*** (0.119)
outages	14.329 (10.390)	14.378 (10.477)	14.188 (10.923)	1.195*** (0.189)	1.219*** (0.188)	1.241*** (0.192)
constant	−30.775 (28.273)	−25.658 (27.732)	−24.331 (31.737)	−2.344* (1.396)	−2.355* (1.407)	−2.542* (1.457)
observations	1598	1598	1397	1620	1620	1418
R^2	0.02	0.02	0.02	0.17	0.18	0.18

Notes: (1) *, **, ***: Coefficients are statistically significant at the levels of 10%, 5% and 1%, respectively. (2) In the parentheses are robust standard error. (3) Control variables and fixed effects are also included in estimating, but not reported here in order to save space.

To investigate whether the above results hold, we use another measure of *finaccess*. When access to finance is taken as "major obstacle" or "very severe obstacle", *finaccess* is equal to one. Otherwise, it is equal to zero. The results are reported in column (2) and column (5) of Panel A and Panel B. We get consistent results, too.

Another source of bias is the sample size of the small firms. The small firms take only 13.6% of the whole sample. The WBES sample for China is selected using stratified random sampling at three levels: Industry, establishment size, and region. To some degree, the small sample size of the small firms is due to their small part in the industry or in the region. For the sake of robustness, Model 1 is estimated without the small firms. The results are presented in column (3) and column (6) of Panel A and Panel B in Tab. 5. Again the results are very similar to the previous ones.

4.3 Heterogeneity in Responses to Electricity Shortages

In sector 4.1, we investigate the ways firms respond to electricity shortages using all the firms as a sample, and the results are proved robust in Sector 4.2. However, how to respond to electricity shortages is also related to some characteristics of the firms. For example, investment in R&D and licensed technology incur high costs. Small firms usually have less financial resource to cover the costs. On the other hand, small firms are more flexible in management and production plan so that it is more possible for them to offset the impact through coordinating production plans with electricity supply. The WBES classifies firms into three groups: Small, medium, large according to their number of employees. The small firms are those with less than 20 employees (excluding 20). The medium-sized firms are those with 20 to 100 employees (excluding 100). The firms with more than 100 employees are large. Tab. 6 reports the results of the heterogeneous responses to electricity shortages across firms of different sizes.

Table 6: Heterogeneous responses to electricity shortages

Dependent variable: *response*						
Independent variables	(1) small firms	(2) medium-sized firms	(3) large firms	(4) small firms	(5) medium-sized firms	(6) large firms
	Panel A					
	response = R&D			*response = liecensed_tech*		
outage	0.233 (0.309)	0.203 (1.151)	0.729*** (0.193)	−0.029 (0.417)	0.037 (0.187)	0.127 (0.178)
outages	0.449 (0.802)	0.263 (0.307)	0.606** (0.263)	——	0.017 (0.343)	−0.212 (0.259)
constant	−4.987* (2.812)	−0.340 (1.561)	−0.965 (1.601)	−4.706 (3.313)	−6.736*** (1.760)	−7.203*** (1.587)
observations	225	695	701	223	691	700
R^2	0.04	0.04	0.12	0.25	0.14	0.09
Independent variables	Panel B					
	response = temp_w			*response = self_g*		
outage	2.516 (1.525)	0.813 (1.723)	10.907 (11.746)	0.792** (0.322)	1.273*** (0.164)	1.266*** (0.183)
outages	2.114 (2.293)	1.287 (3.740)	21.613 (17.514)	——	1.460*** (0.305)	1.129*** (0.246)
constant	−17.355 (10.806)	−74.277** (32.626)	−2.623 (56.730)	−0.795 (3.556)	−2.146 (2.280)	−2.416 (1.932)
observations	225	694	690	216	698	707
R^2	0.05	0.04	0.03	0.07	0.17	0.21

Notes: (1) *, **, ***: Coefficients are statistically significant at the levels of 10%, 5% and 1% respectively. (2) In the parentheses are robust standard error. (3) Other control variables and fixed effects are also included in estimating, but not reported here in order to save space. (4) "—" means perfect collinearity.

As can be seen in Tab. 6, the heterogeneous responses exist mainly in the relationship between electricity shortages and investment in R&D. In particular, column (1) and column (2) in Panel A represent the results for the small firms and the medium-sized firms, respectively. The coefficients on *outage* and *outages* are positive, but not significant. It is probably because R&D is a too costly for them. Contrary to the small and the medium-sized firms, we find a significant positive relationship between electricity shortages and R&D investment in the large firms as shown in column (3) Panel A.

From column (4) to column (6) in Panel A and from column (1) to column (3) in Panel B are results for using licensed technology and temporary workers, respectively. No coefficients on the indicators of electricity shortages are significant. In contrast, all the coefficients on the indicators of electricity shortages in columns (4), (5), and (6) in Panel B are positive and significant, implying that all firms, regardless of their sizes, are likely to turn to self-generation. Our finding differs from Fisher-Vanden et al. [1] in respective of large firms. Their sample focused on the largest electricity users and they found that large firms did not self-generate electricity often.

So far, we have consistently found that when the firms are faced with electricity shortages, they are likely to invest in R&D, or to generate electricity themselves. However, we do not find any evidence for adopting licensed technology or hiring temporary workers as solutions to electricity shortages.

4.4 Effects on Labor Productivity

In Sections 4.1, 4.2, and 4.3, our empirical analyses reveal that investment in R&D and self-generation are positively related to electricity shortages. We want to find out whether these responses can relieve the negative impact of electricity shortages on productivity. To this end, we estimate Model 2. Our interest is on the interaction terms involving the responses and the indicators of electricity shortages. We expect that the coefficients on the interaction terms will be positive, if a certain response can offset the impact of electricity shortages on productivity.

Tab. 7 reports the results. From column (1) to column (4) are the results for R&D investment. The result for all firms in column (1) shows that no interaction terms are significant, while the coefficients on *R&D* is positive and significant at the 1% level. Investing in R&D can promote labor productivity, but cannot offset the impact of electricity shortages. The results from column (2) to column (4) reveal that in medium-sized firms it is not the case. In particular, the coefficient on the interaction term of *outages* and *R&D* in column (3) is positive and significant at the 5% level, implying that R&D investment in medium-sized firms can improve labor productivity by offsetting the impact of electricity shortages. We do not find the same effects in the large firms or in the small firms. Instead, we find that in the large firms the coefficient on *R&D* is significant and positive, while the coefficients on the interaction terms are not significant. Therefore, the positive effect of R&D investment on productivity exists mainly in the large firms, while the effect of offsetting the negative impact of electricity shortages exists mainly in the medium-sized firms.

From column (5) to column (8) in Tab. 7 are the results for self-generation. To our surprise, the coefficients on the interaction terms are all negative. Particularly, the coefficients on the interaction terms of self-generation and the indicator of *outages* are negative and significant in the full sample and the sub-sample of large firms. Generating electricity on site not only requires additional capital and diesel purchases, but also crowds out other investment opportunities and reduces productivity. When power outages happen occasionally, self-generation will ensure firms from output reduction. However, self-generation is costly. Frequent self-generation will make it less advisable because it will increase production cost disproportionally, especially when the production is highly electricity dependent, such as in large firms who use more machines or more electricity-intensive technologies. Therefore, we reach the conclusion that firms do not self-generate electricity to reduce the loss of labor productivity due to electricity shortages.

Table 7: Estimations for the effects on labor productivity

Dependent variable: *laborprod*								
Independent Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	all firms	small	medium	large	all firms	small	medium	large
	response = *R&D*				*response* = *self_g*			
outage• response	−0.089	0.206	−0.111	0.049	−0.158	−0.841	0.001	−0.014
	(0.146)	(0.573)	(0.173)	(0.236)	(0.176)	(0.524)	(0.221)	(0.315)
outages• response	0.101	−1.913	0.743**	−0.162	−0.607**	——	−0.303	−0.737***
	(0.333)	(2.153)	(0.364)	(0.279)	(0.293)		(0.426)	(0.283)
response	0.325***	0.243	0.118	0.554***	0.259**	0.241	0.130	0.348**
	(0.055)	(0.154)	(0.078)	(0.087)	(0.101)	(0.205)	(0.155)	(0.160)
constant	11.361***	11.646***	11.966***	10.444***	11.625***	11.690***	12.047***	11.116***
	(0.758)	(1.844)	(1.013)	(1.262)	(0.761)	(1.787)	(1.027)	(1.281)
observations	1622	225	696	701	1631	226	698	707
R^2	0.05	0.07	0.07	0.11	0.04	0.06	0.06	0.06

Notes: (1) *, **, ***: Coefficients are statistically significant at the levels of 10%, 5% and 1%, respectively. (2) In the parentheses are robust standard error. (3) Independent variables *outage* and *outages*, other control variables, and fixed effects are also included in estimating, but not reported here in order to save space. (4) "——" means perfect collinearity.

5 Conclusions

In this study, we explore the responses of manufacturing firms to electricity shortages and their effects on labor productivity using the WBES dataset. We find that when facing electricity shortages, firms of all sizes switch to self-generation. However, self-generation causes productivity loss, which is most obvious in the large firms to whom generators are most accessible. We also find that firms, especially large firms, are more probable to spend on R&D. Nevertheless, the medium-sized firms benefit from R&D from the perspective of reducing productivity loss due to electricity shortages. The large firms can improve their productivity through R&D, but cannot offset the negative impact of electricity shortages. Besides, we do not find that using more labors or licensed technologies can play important roles in coping with electricity shortages. To sum up, our study reveals that self-generation is the most adopted, but also costly solution to electricity blackouts. Technology developments from R&D can promote productivity, but cannot offset the negative impact of blackouts on productivity.

The results of this paper underline the importance of infrastructure supply in developing countries. Faced with infrastructure constrains—in this case, unreliable electricity supply—firms may use costly self-generation in an attempt to rely less on that infrastructure. However, this damages productivity. Though new technology is usually supposed to promote productivity, our findings remind us that electricity shortages cannot be offset by technology innovations in manufacturing sectors, because technology development makes machines more widely used, and thus production becomes more electricity-intensive. Although this paper addresses electricity shortages specifically, one can imagine that firms may react in undesirable ways to cope with other infrastructure constraints. The findings in this study also imply the important role the government should play in infrastructure supply, as it can hardly be economically self-sufficient at firm level. Although our study seem to suggest that more power plants be built, this conclusion could not be made at the expenses of environment. Actually, it is more advisable for policy makers to consider other mechanisms to trade off the social cost of investing in energy supply with the benefits.

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